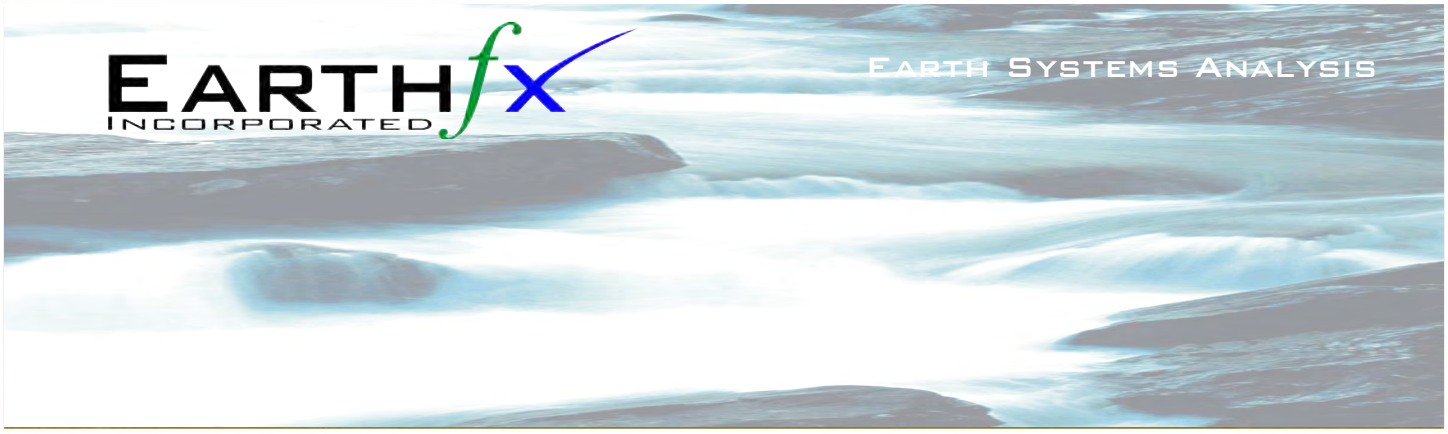
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Strada Pit/Quarry

LEVEL 1 AND 2 HYDROGEOLOGICAL ASSESSMENT

Strada Aggregates

File 123016 | June 26, 2025

Document Control

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1 Introduction

Strada Aggregates Inc. (Strada) owns and operates the Shelburne Pit, located at 437159 4th Line, Melancthon, Ontario, in the County of Dufferin, which is an above water pit that consists of three licenses (License #626199, #625155 and #129167) under the Aggregate Resources Act (ARA).

Strada is proposing to combine the three existing licenses into one license to allow the pit operations to continue and permit below water quarry extraction within the northern two-thirds of the site (i.e. existing license #626199 and #129167). The existing pit, wash plant and product stockpiles will be located in the southern third of the site (i.e. existing license #625155). Earthfx and Tatham were retained to conduct a Level 1 and Level 2 hydrogeological assessment of the site and determine (1) potential impact to aquifers, water courses and surface water bodies, springs, and discharge areas in the vicinity and (2) evaluate potential mitigation measures. Work included field investigations, development of a conceptual hydrogeologic model, and the construction and calibration of an integrated surface water/groundwater model. The integrated model was applied to determine potential impacts to groundwater levels, streamflow, wetland stage, and the water balance at different phases of the operation of the proposed Strada Pit/Quarry.

1.1 SITE DESCRIPTION

The site is bound by County Rd. 17 on the south, 4th Line on the west, the Bonnefield agricultural property and Sideroad 15 to the north, and the CBM property and 13th Line to the east. The Town of Shelburne and the brow of the Niagara Escarpment are located approximately 7 kilometres (km) to the south, and 3.3 km to the east, respectively (Figure 1).

1.2 STUDY AREA DESCRIPTION

The lands surrounding the site comprise primarily agricultural lands, rural residential properties, other aggregate operations, undeveloped forests, and wetlands. Additional land use and surface cover details are provided in Appendix C.

As part of the preliminary field investigations, properties within 1 km of the Strada property were included to establish baseline groundwater conditions in the vicinity of the Strada property. A preliminary door-to-door water well survey was completed and as part of the survey five domestic water well owners agreed to participate in a long-term groundwater monitoring program.

The study area was then expanded as part of this Level 1 and 2 Hydrogeological Assessment to further establish baseline groundwater conditions and to support an early warning system which would identify any adverse interference resulting from the proposed quarry operations that may compromise the integrity of domestic water supplies and surface water and natural heritage features. The Study Area now extends south of County Road 17, and is bound to the east by Mulmur/Melancthon Townline, extends north of Sideroad 15 to the north, and extends west of County Road 124 to the west.

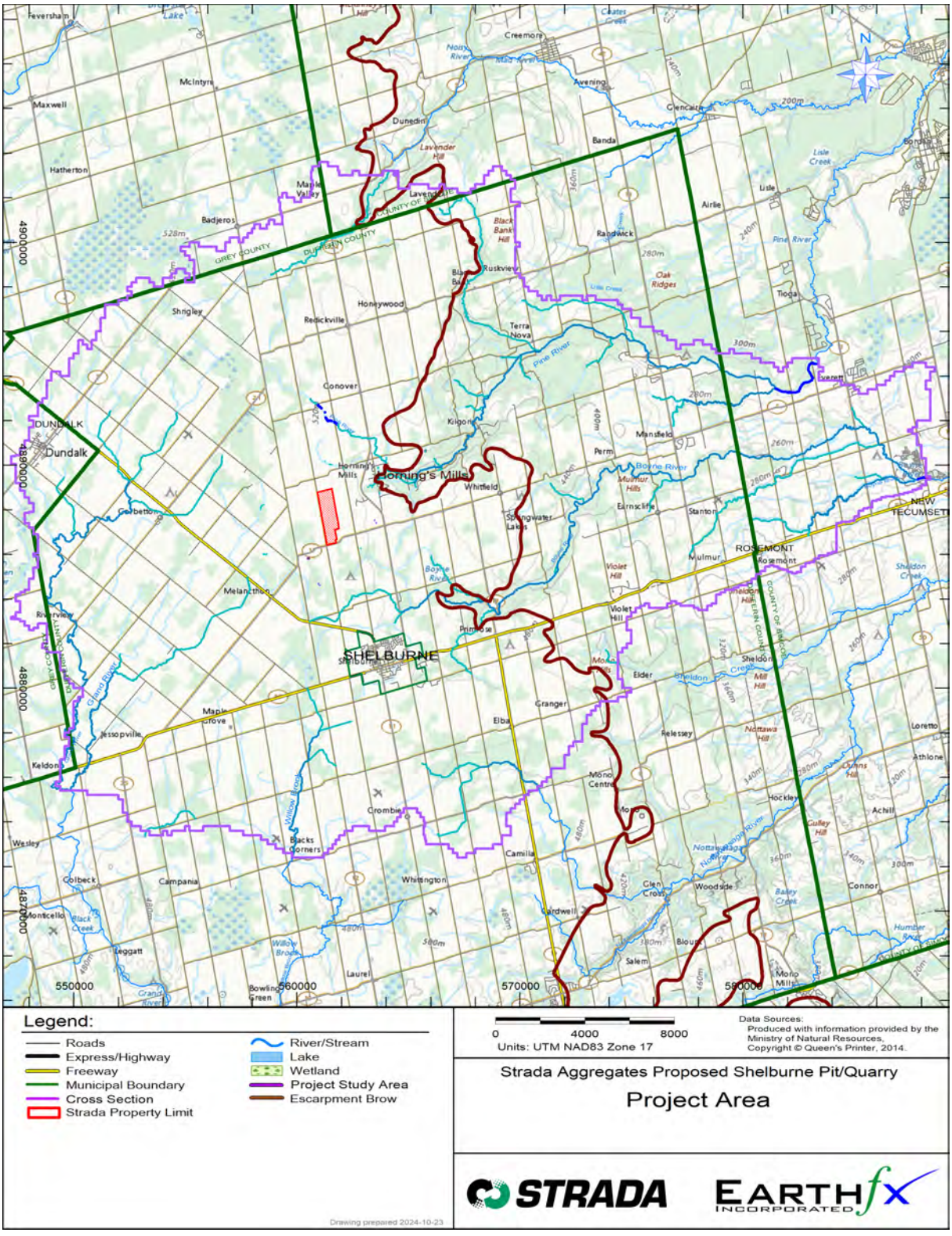


Figure 1: Location of the Proposed Strada Pit/Quarry

1.3 STUDY OBJECTIVES

This investigation was conducted to fulfill the requirements of a Level 1 and 2 Hydrogeological and Hydrological Assessment for the licensing of a Class 'A' Pit/Quarry Below the Groundwater Table, under the Aggregate Resources Act (ARA), and to support a Planning Act Application.

Level 1 and Level 2 assessment reports were completed concurrently. The purpose of the Level 1 assessment report is to determine the potential impacts which may result from the proposed below water quarry activities on:

- Water wells including private water wells, municipal/communal/industrial, geothermal and agricultural wells. Where a proposed quarry site is within a Well Head Protection Area (WHPA) for Quantity (Q1 or Q2) as outlined in the applicable Source Water Protection Plan, the applicable Source Water Protection Policies and mitigation measures are to be incorporated and implemented as part of the proposed site plans;
- Groundwater aquifers;
- Water courses and surface water bodies;
- Springs;
- Discharge areas;
- Where the Level 1 assessment report identifies a potential impact to one of the above receptors, a Level 2 assessment report is then completed to quantify the potential impact and ultimately assess the significance and potential mitigation measures.

The Level 2 report and impact assessment must include:

- A description of the local geology, hydrogeology and surface water systems supported by field and technical data;
- A description of the proposed water diversion, discharge, storage and/or drainage facilities;
- A water budget outlining how water will be managed on-site;
- A detailed description of the potential impacts to receptors within the zone of influence of the proposed quarry, both negative and positive, and the proposed mitigation measures to reduce or eliminate the potential impacts.

Table 1 summarizes the requirements for a Level 1 and Level 2 assessment, with an overview of the issues particular to this application. Given the local presence of water wells, springs and wetlands, a Level 2 evaluation, as described by the MNR, is needed. This report has been prepared to meet the Level 1 and 2 assessment report requirements as outlined in Aggregate Resources of Ontario: Technical Reports and Information Standards document.

The study approach included field investigations of the bedrock and overburden geology, monitoring of groundwater levels, and sampling of water quality. A Conceptual Model was developed to synthesize regional information and the interpretation of the field data.

To assess the potential impacts of the proposed quarry operation on the nearby water regime an integrated surface water/groundwater model was developed. The integrated model represents all components of the hydrologic cycle and was

used to estimate groundwater recharge, baseflow and overland runoff to streams, and groundwater discharge to local streams, ponds, and wetlands. The model was calibrated to match available groundwater level and flow data and then applied to quantitatively assess changes to groundwater and surface water flows and wetland water budgets under baseline conditions and at different stages of site development including site rehabilitation.

An important aspect of this approach is that it included the evaluation of both long-term average conditions and seasonal transient variability. Seasonal processes, such as spring snowmelt or summer drought, are fully evaluated and the model can assess future changes to these processes as a result of site operations. The model was also used to aid in the optimization of mitigation measures, including low-permeability barriers and infiltration features, designed to manage water on site.

Table 1: Evaluation of need for Level 2 Hydrogeological Assessment

POTENTIAL GROUNDWATER AND SURFACE WATER FEATURES	LEVEL 1 ASSESSMENT	LEVEL 2 ASSESSMENT
Water Wells	Water wells located within 120 metres of the Site obtain water from sand and gravel aquifer.	Level 2 Assessment for water wells required.
Springs	Springs located downgradient of Site in the Pine River Valley, and headwater streams located in and around the escarpment area.	Level 2 assessment needed to assess potential impact on springs.
Groundwater Aquifers	Extraction will occur in the local Bedrock aquifer.	Level 2 assessment required to assess the potential reduction in water levels in the wells. Limited potential for water quality effects as groundwater dewatering will maintain flow directions into the quarry.
Discharge to Surface Water	The Site will be operating in geological materials that are contiguous with off-site surface water features. Field investigations indicate a portion of Wetland NAT-19 is located on the Strada property.	Level 2 assessment required to evaluate the impact of changes to wetland water budget. Wetland NAT-19 is located adjacent to the proposed central infiltration gallery, ensuring the wetland will be protected.
Water Diversion, Storage and Drainage Facilities On-Site	Water diverted into excavations.	A Level 2 assessment is required to address alterations to water diversion, storage and drainage facilities. A detailed assessment of site water management is included in this report.
Water Balance	There will be an increase in evaporation from the Site.	Level 2 assessment is needed to evaluate changes in the water balance. Assessment of site water balance is included in each evaluation scenario in this report.
Source Water Protection	The Shelburne municipal wellfield, located more than 5 km to the south of the Strada property, includes the only wells in the area that fall under the provincial SWP assessment program. The wellfield capture zone and threats assessment was updated in 2022 and that analysis indicates that the wells capture groundwater from the west. This confirms the proposed Strada development is lateral to, or downgradient of, the	Level 2 assessment is not needed because of the detailed SWP analysis completed in 2022 (The Strada pit was not identified as a water quantity or quality threat). Water Quality: The proposed Strada quarry is lateral/ downgradient of the Shelburne wellfield so any possible water quality changes during rock extraction cannot impact the municipal wellfield.

POTENTIAL GROUNDWATER AND SURFACE WATER FEATURES	LEVEL 1 ASSESSMENT	LEVEL 2 ASSESSMENT
	wellfield, and therefore will not be a water quality or quantity threat to the wellfield.	Water Quantity: The operational design of the proposed quarry, including the proposed southern infiltration system, ensures that drawdowns will not propagate towards the wellfield. Water Quantity: The operational design of the proposed quarry, including the proposed southern infiltration system, ensures that drawdowns will not propagate towards the wellfield.

2 Level 1 and 2 Study Components

Overall, the technical content for this ARA application is compiled in five Appendices (A through E), which includes:

- Field characterization of the current hydrogeologic conditions at the proposed pit/quarry site; (See Appendix A and B, Tatham and Earthfx, 2024)
- Evaluation of the current hydrogeologic and hydrologic conditions through data interpretation, conceptual interpretation and the development of a groundwater/surface water model of the site; See:
  - Appendix C: Conceptual Model Report (Earthfx, 2024a);
  - Appendix D: Model Development and Calibration Report (Earthfx, 2024b); and
  - Appendix E: Impact Assessment Report (Earthfx, 2024c).
- Curriculum Vitae's (CVs) of the technical team are provided in Appendix F.

The following is an overview of the studies and companion documents to this report that together meet this requirement.

2.1 FIELD INVESTIGATIONS

The field program supporting the quarry application built on an extensive borehole and monitoring network including over 21 active groundwater well nest locations that monitor 41 discrete aquifer/aquitard intervals within the overburden and bedrock aquifers developed at the site over the last 16 years of aggregate extraction. This includes long-term water-level monitoring and historic records of pumping for wash water operations. The field program included drilling of new wells, aquifer testing, and long-term water level monitoring programs. This information has been compiled into a comprehensive database and is fully documented in Appendix A and B (Tatham and Earthfx, 2024).

2.2 CONCEPTUAL SITE CHARACTERIZATION

The site and regional field data were evaluated and presented as a comprehensive Conceptual Model. The Conceptual Model presents a description of the physical setting, including local geology, hydrogeology, and surface water features in and around the site, as per MNR guidelines. The Conceptual Model represents a synthesis of available data and is fully documented in Appendix C (Earthfx, 2024a). A three-dimensional hydrostratigraphic model, mapping the tops and bottoms of each aquifer and aquitard, was developed as part of the Conceptual Model investigation.

2.3 MODEL DEVELOPMENT AND CALIBRATION

Building on the conceptual model, an integrated surface water/ groundwater model was developed as part of the comprehensive evaluation of site conditions, and for use in the impact assessment. A detailed discussion of the development and calibration of the model is provided in Appendix D (Earthfx, 2024b).

2.4 IMPACT ASSESSMENT

The impact Assessment documents the application of the integrated model to predict the effects of quarry development and closure on groundwater levels, agricultural properties, adjacent aggregate operations, local septic beds, residential/agricultural wells, surface water streamflow, and wetland resources. A detailed discussion of the impact assessment is provided in Appendix E (Earthfx, 2024c).

Section 2 of Appendix E presents a numerical simulation of the "Baseline" conditions at the site. Both steady state (average) and transient (time-varying) conditions were assessed, illustrating how the surface water and groundwater systems behave on a seasonal and inter-annual basis.

The baseline assessment provides:

- Groundwater flow and levels under a range of climate conditions;
- Surface water flows under a range of climate conditions; and
- Comprehensive wetland water budgets.

Model results are aggregated over time to assess monthly and long-term average response.

The Level 2 impact assessment is included in Section 3 of Appendix E. Each of the major development phases of pit/quarry and rehabilitation is simulated and compared to the baseline flows and levels on both an average and monthly basis. In this way, the results of future development scenarios were directly compared to baseline conditions, thereby providing insight into the effects of the proposed site on a monthly, seasonal, and inter-annual basis.

An extensive program of monitoring and private well protection and management has been undertaken in conjunction with local agencies. This program is described in Sections 4 and 5 of Appendix E.

The numerical model was also used to identify the available drawdown in the aquifer under baseline and future conditions. Results indicated that groundwater resources would remain sustainable under these conditions, as discussed further on in this report.

3 Site Development

At the time quarry operations commence, it is expected the available sand and gravel resource will have been extracted from all portions of the site except for the northern portion of existing License #626199. The proposed phasing sequence is shown on Figure 2 through Figure 8.

Quarry operations will commence in Phase 1A which is located in the southern portion of existing License #129167 and will operate concurrently with pit operations in Phase 2C which is located in the northern portion of existing License #626199.

The quarry floor elevation is expected to vary between 438 m asl and 442 m asl based upon the geological formations. The quarry is anticipated to be extracted in three lifts with lifts varying in height as each follows the geological formations across the site. Lift 1 is approximately 11 to 24 m deep, lift 2 is approximately 11 to 17 m deep, and lift 3 is approximately 14 to 23 m deep.

Quarry extraction will occur in a phased manner divided between four phases with each phase containing multiple sub-phases. Quarry operations will occur sequentially. Phases 1A, 1B, 2A, 2B, and 2C will extract lift 1 and 2. Phase 3A includes extraction of lift 3. Phase 3B, 4A and 4B include extraction of lifts 1, 2 and 3.

All material will be processed by portable plants within close proximity to the active pit and quarry working faces. A portion of the material will also be transported to the wash plant within existing License 626155 where it will be washed.

The new license is proposed to ship a maximum of 2 million tonnes per annum and will utilize both of the existing pit entrance/exits until Phase 3B is extracted. After which only the south entrance/exit will be used.

3.1 WATER CONTROL FEATURES

3.1.1 Benches

Three benches will be used to reach the full extraction depth of the proposed quarry extraction area. The first bench coincides with the Guelph formation; the second bench with the Ancaster/Niagara Falls formation, and the third bench with the Gasport formation. Gravel extraction in the remaining northern pit area will be extracted in conjunction with Phase 1 quarry development, along with simultaneous extraction of Bench 1 and 2.

3.1.2 Water Control Barriers

Groundwater inflow control barriers will be constructed along the overburden and bedrock benches as pit/quarry development progresses, thus restricting groundwater inflow to a limited active extraction face. Barriers will be constructed on Bench 1 (Guelph) and Bench 3 (Gasport), while no barriers are needed in the Ancaster/Niagara Falls bench because permeability and pump testing indicate it is a significant aquitard.

The design of the barriers will meet all standards for site closure, grading and rehabilitation. Geotechnical analysis indicates that the on-site Tavistock till may be suitable for water control barriers if confirmed to be sufficiently impermeable by a geotechnical consultant prior to construction of the barriers. (See Section 10: Geotechnical Assessment report included in

Appendix E). If the on-site Tavistock Till is not considered to be sufficiently impermeable, off-site soil may need to be imported for the construction of the barriers.

A limited portion of the final deep Gasport bench face will be left open to allow long-term drainage of the quarry lake into the Gasport aquifer. The Closure scenario, presented below, demonstrates that this will ensure that the lake elevation never rises high enough to result in off-site overland discharge.

3.1.3 Injection Wells

Four injection wells will be constructed along the eastern property boundary prior to Phase 1. Two of the injection wells will be installed in the Guelph Formation and the remaining two will be installed in the Gasport unit. The combined capacity of the injection wells is assumed to be at least 12 L/s. Water captured from the buried tile drain constructed along the western property limit will be diverted directly to the injection wells ensuring water being infiltrated via the injection wells is non-contact water collected upgradient of the on-going aggregate activities. Section 6 contains additional details.

3.1.4 On-Site Infiltration System

Groundwater and surface water (including stormwater and precipitation) will be captured and infiltrated on-site. Three on-site infiltration systems will be constructed, including two infiltration ponds in the south portion of the site and a two-part infiltration trench along the northeast portion of the site. The infiltration systems will be constructed in peripheral areas of sand and gravel materials, thus locally recharging the overburden aquifers with no off-site overland surface water flow.

A buried tile drain will be constructed along the western property boundary to collect groundwater and reduce groundwater mounding to the west of the property. The clean water from the drains will be injected directly into two Guelph and two Gasport injection wells along the eastern property boundary.

The combination of bench barriers (to restrict inflow), and on-site re-infiltration ensures that no off-site surface water discharge will occur, and that groundwater drawdowns will be minimal.

The proposed infiltration systems are shown on Figure 9. See Section 6 for additional details.

3.2 PHASE ONE

Phase 1 represents the final extraction of sand and gravel from the north portion of the pit, (in the area labeled Phase 2C/Phase 3A in Figure 2, which refers to later phases of bedrock removal); and extraction of bedrock from Bench 1 and 2 in the central portion of the site, labeled as Phase 1A and Phase 1B. The open extraction faces are shown as dotted lines in Figure 2. A cross section showing the extraction conditions is shown in Figure 3.

The start of bedrock extraction will be a sinking cut located in the Phase 1A area. Groundwater levels in the Phase 1A area are near the lowest recorded on site, and extraction from this initial location will have the minimal impact on the overburden water table.

Overburden water control barriers have been constructed on three sides of the overburden (green line). Progressive barriers have been constructed along the south and east face of Bench 1 (dark blue line), and an open face exists in Bench 1 and 2 along the west and northern faces (dashed red lines).

Quarry floor drains have been constructed to distribute inflow to both the infiltration trenches in the northeast portion of the site and the southern infiltration galleries.

3.3 PHASE TWO

Phase 2 represents the complete extraction of aggregate from Bench 1 and 2 under Phases 1 and 2 and the ongoing extraction of Phase 2C. The open extraction face is shown as dotted lines in Figure 4. A cross section showing the extraction conditions is shown in Figure 5.

Overburden water control barriers have been constructed on four sides of the overburden (green line). Progressive barriers have been constructed along three sides of Bench 1 (dark blue line), and an open face exists in Bench 1 and 2 along the northern face (dashed red line).

Quarry floor drains are constructed to distribute inflow to both the infiltration trenches in the northeast portion of the site and the southern infiltration galleries.

During this phase a buried tile drain constructed along the north western property boundary will collect groundwater so as to reduce groundwater mounding to the west of the property. This water is collected and directly injected into the Guelph and Gasport injection wells along the eastern property boundary. Any excess is added to the eastern infiltration system trenches. The combined injection capacity of these wells is 12 L/s, and a minimum length of 570 m of drain is estimated to generate this flow.

3.4 PHASE THREE

Phase 3 represents the continued extraction of Bench 2 and initial extraction of Bench 3. Phase 3 only includes a partial removal of Bench 3 with the remaining portion of Bench 3 to be removed in Phase 4. The analysis and presentation of potential impacts were limited to Phase 4 (discussed below) which is considered to be a “worst case scenario” when comparing Phase 3 and Phase 4 conditions.

3.5 PHASE FOUR

Phase 4A represents extraction of bedrock from the second to final Phase 4A cell (Figure 6). In this scenario Benches 1, 2 and 3 are all open along the active face in the south east portion of the excavation. The location of the open extraction faces is shown as a dotted red line in Figure 6. A cross section showing the extraction conditions is shown in Figure 7.

Overburden water control barriers have been constructed on four sides of the overburden (green line). Barriers have been constructed along the majority of Bench 1, with the exception of the south face (dark blue line). As noted, an open face exists in Bench 1, 2 and 3 in the Phase 4A cell (dashed red line). Quarry floor drains are constructed to distribute inflow to both the infiltration trenches at the northeast portion of the site and the southern infiltration ponds.

During this phase a buried tile drain constructed along the north western property boundary will collect groundwater so as to reduce groundwater mounding to the west of the property. This water is collected and conveyed to the Guelph and Gasport injection wells along the eastern property boundary and any excess is added to the eastern infiltration trenches. The combined injection rate is 12 L/s. The drain is subdivided into three segments to provide flexibility in diverting and controlling

flow, as needed. In the model representation, the north and central segment divert 12 L/s directly to the injection wells (with any seasonal excess going to the northern infiltration trench), and the southern segment discharges into the central infiltration site.

3.6 REHABILITATION

The Rehabilitation scenario represents conditions after final rehabilitation and closure of the pit and quarry.

At this time, all on-site water control and infiltration systems will be modified and/or removed so as to allow groundwater and surface water conditions to return to near baseline conditions without any active long-term water management.

Water control barriers that were constructed on all four sides of the pit/quarry in the overburden and Bench 1 will remain in place for the purpose of slope rehabilitation (Figure 8). The exception to this is that a 365-m portion of the eastern overburden barrier will be opened to allow lateral seepage into the shallow groundwater system east of the property. The area of barrier opening is shown as a thick orange line in Figure 8. Seepage from this opening will eliminate drawdowns and support streamflow in the tributary that flows into NAT-18.

The barriers constructed on Bench 3 will remain in place; however, a small portion of the Gasport formation along the western face of Phase 4 will remain open to the quarry lake to ensure that the lake does not overtop and discharge as surface water.

Water from the western tile drain will no longer be infiltrated into the bedrock injection wells. The wells will be sealed and decommissioned. The northern segment of the tile drain will be opened so as to freely drain into the quarry lake. This will prevent long-term groundwater mounding west of the quarry.

All of the infiltration ponds and trenches will be re-graded and converted into appropriate future land uses, as outlined on the closure site plans. The southern portion of the site, west of the constructed wetland and Wetland NAT-19, will be re-graded so that runoff and interflow can enter and support the constructed wetland. Any excess water in the constructed wetlands will be allowed to overflow into Wetland NAT-18.

In summary, the site will be returned to a condition that restores local and regional surface and groundwater conditions, with no need for any form of active water management.

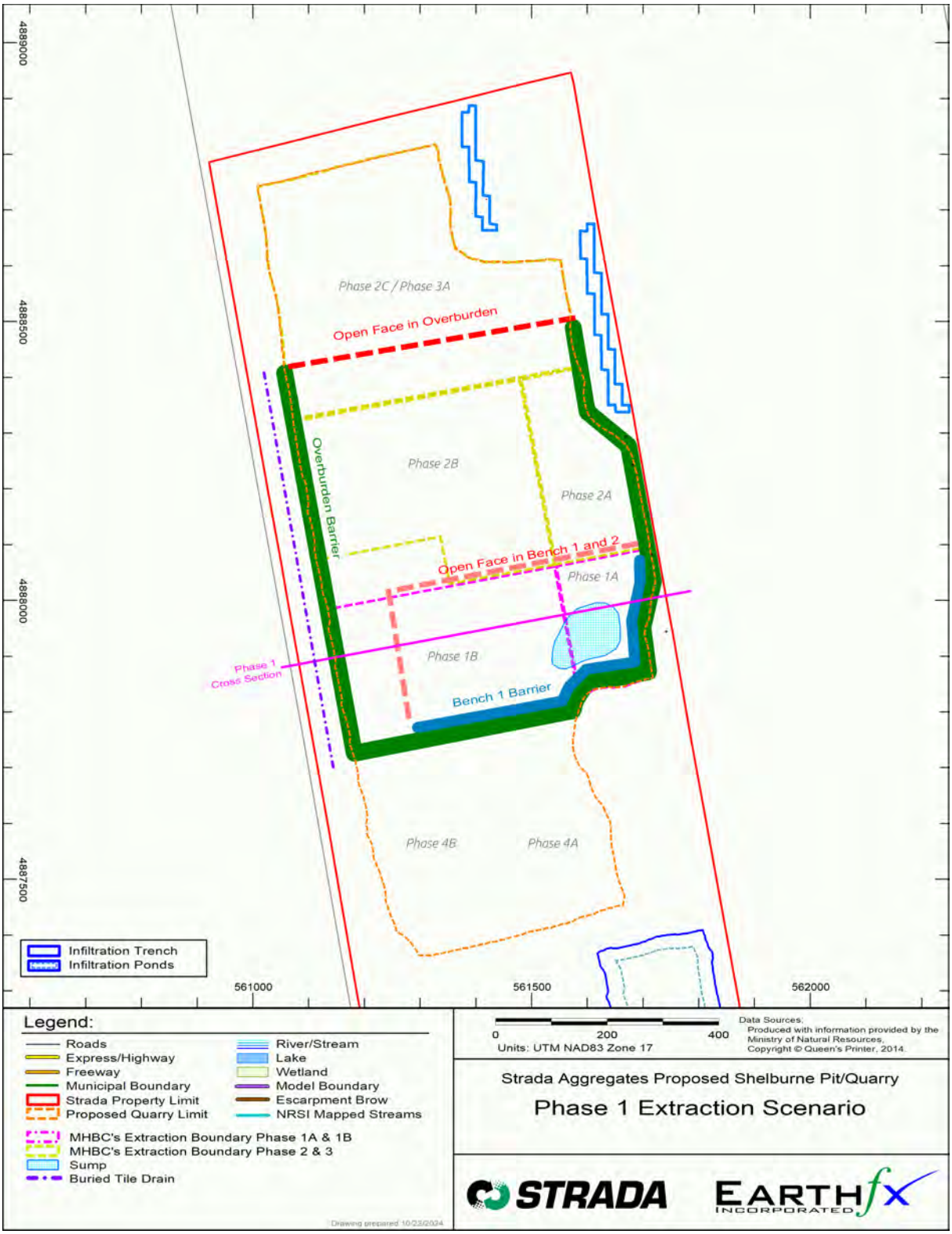


Figure 2: Proposed Strada Pit/Quarry Phase 1 Extraction Scenario

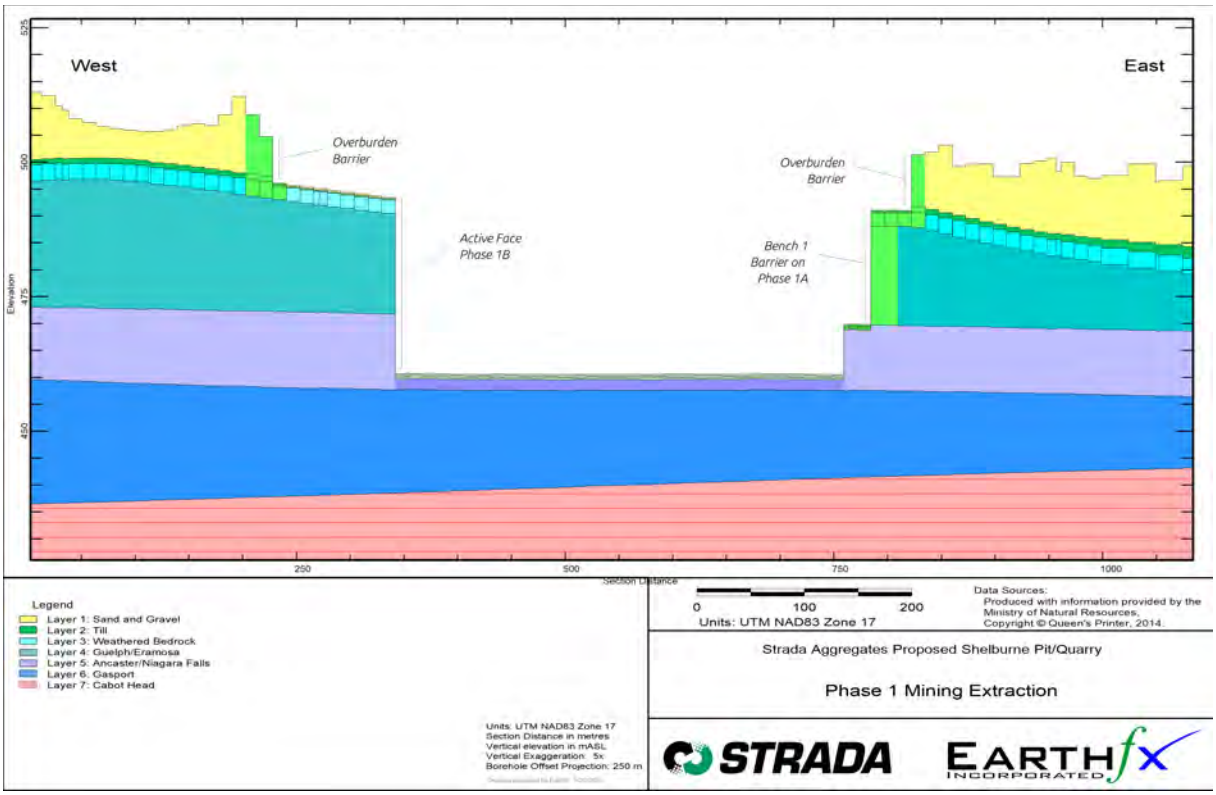


Figure 3: Proposed Strada Pit/Quarry Phase 1 Extraction Scenario E-W Section

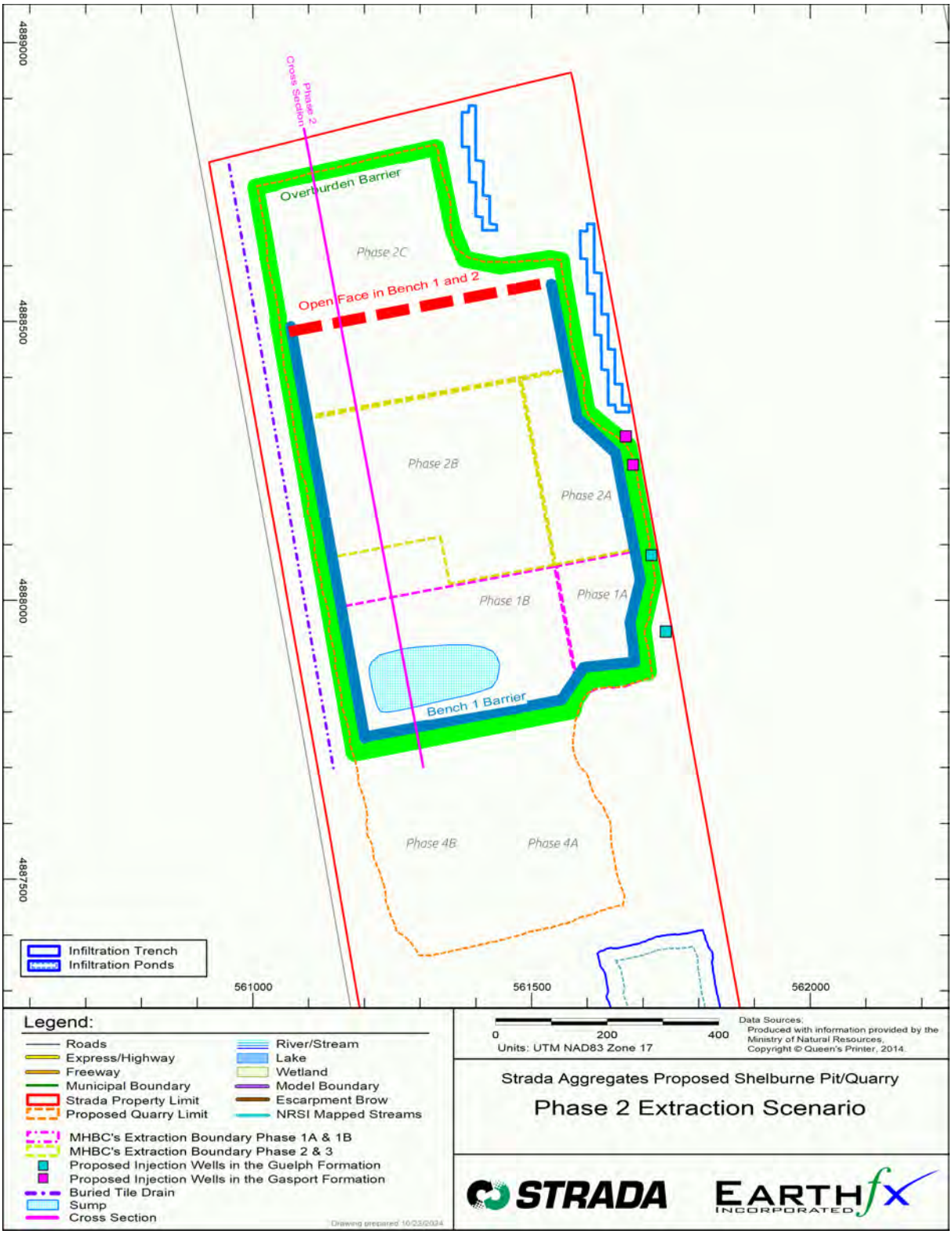


Figure 4: Proposed Strada Pit/Quarry Phase 2C Extraction Scenario

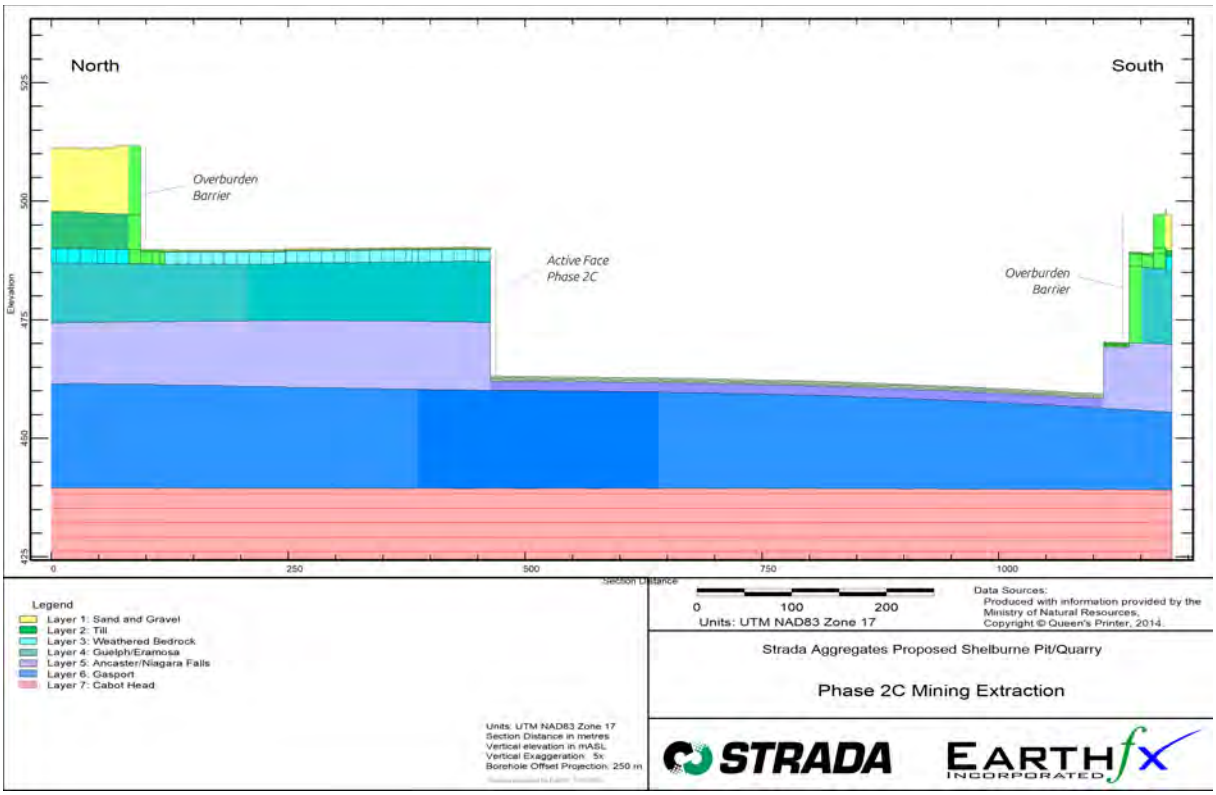


Figure 5: Proposed Strada Pit/Quarry Phase 2C Extraction Scenario N-S Section

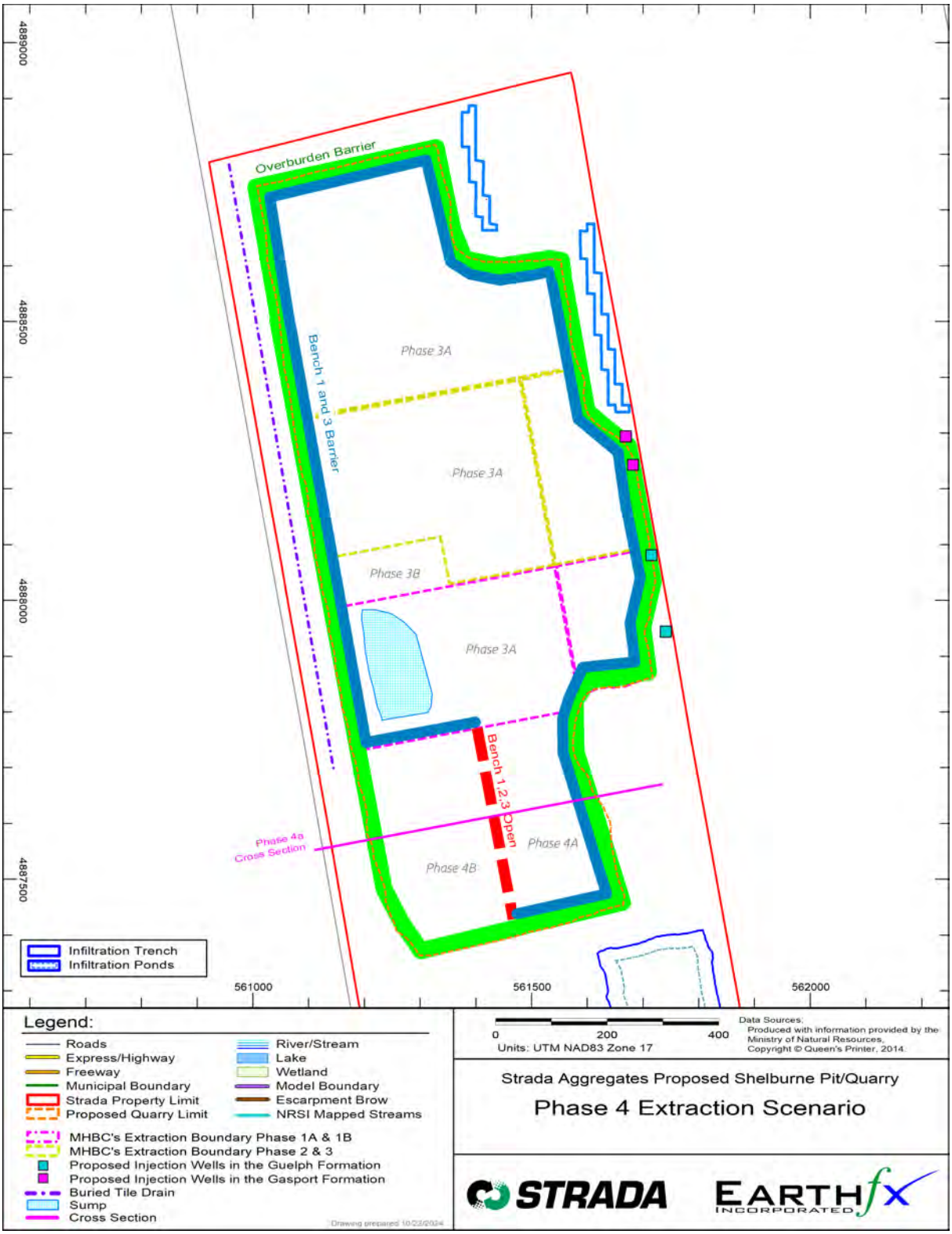


Figure 6: Proposed Strada Pit/Quarry Phase 4A Extraction Scenario

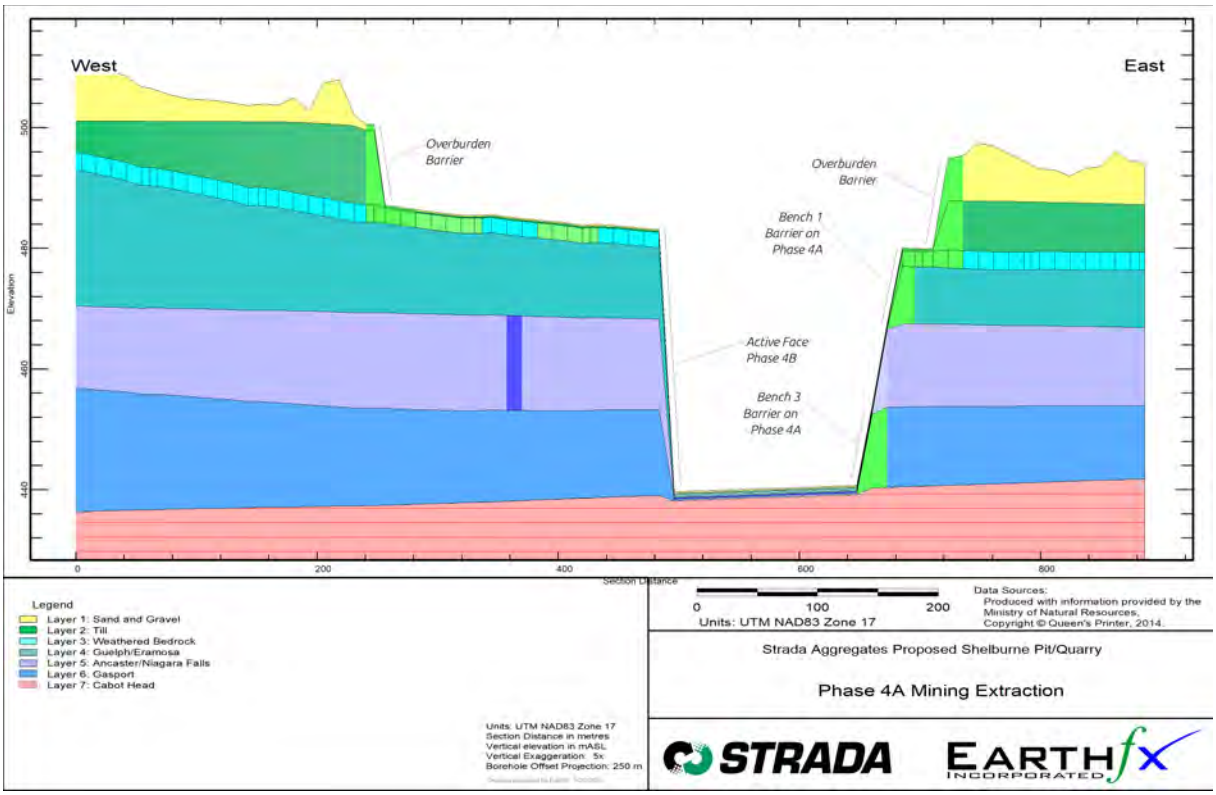


Figure 7: Proposed Strada Pit/Quarry Phase 4A Extraction Scenario N-S Section

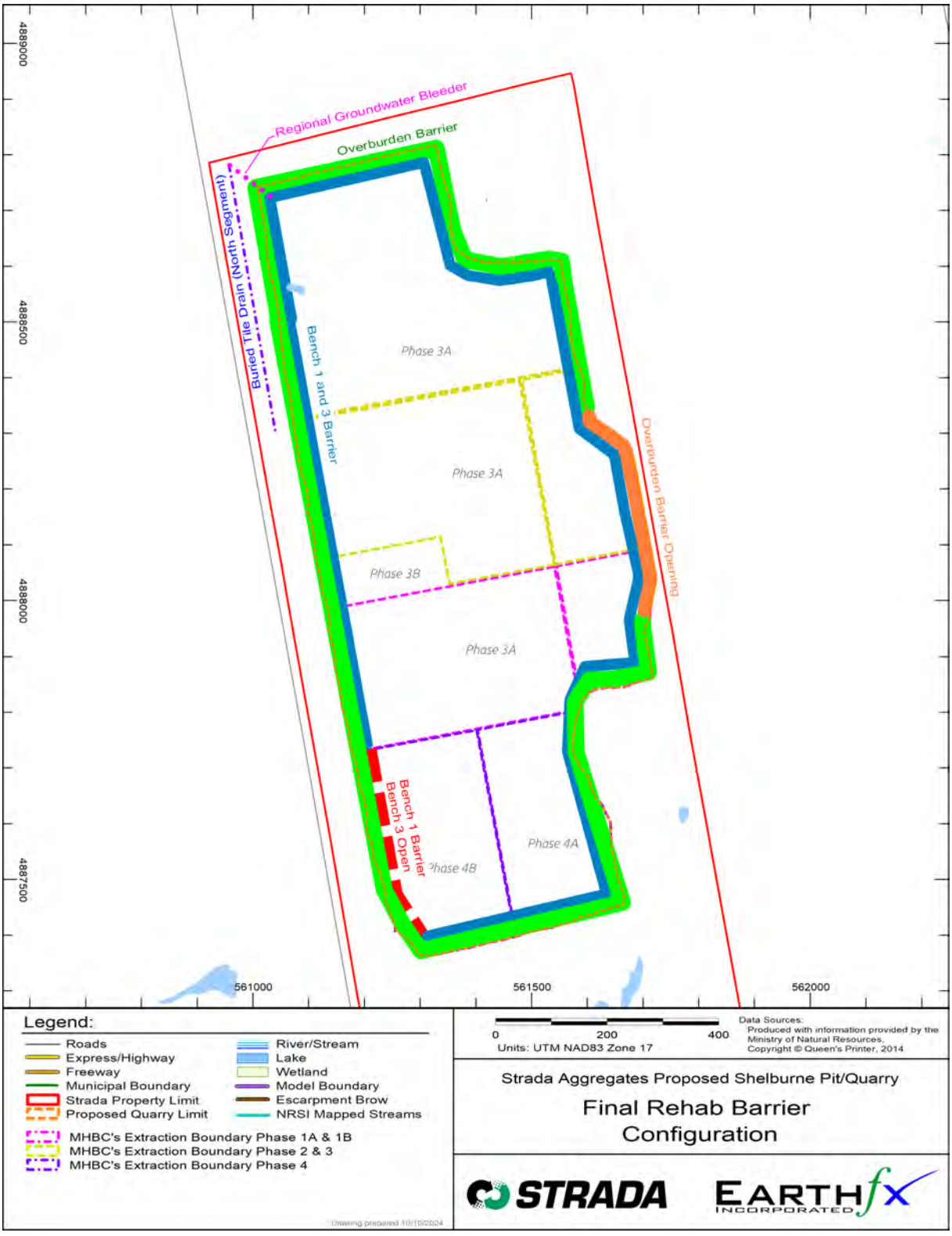


Figure 8: Proposed Strada Pit/Quarry Rehabilitation (Rehab) Scenario

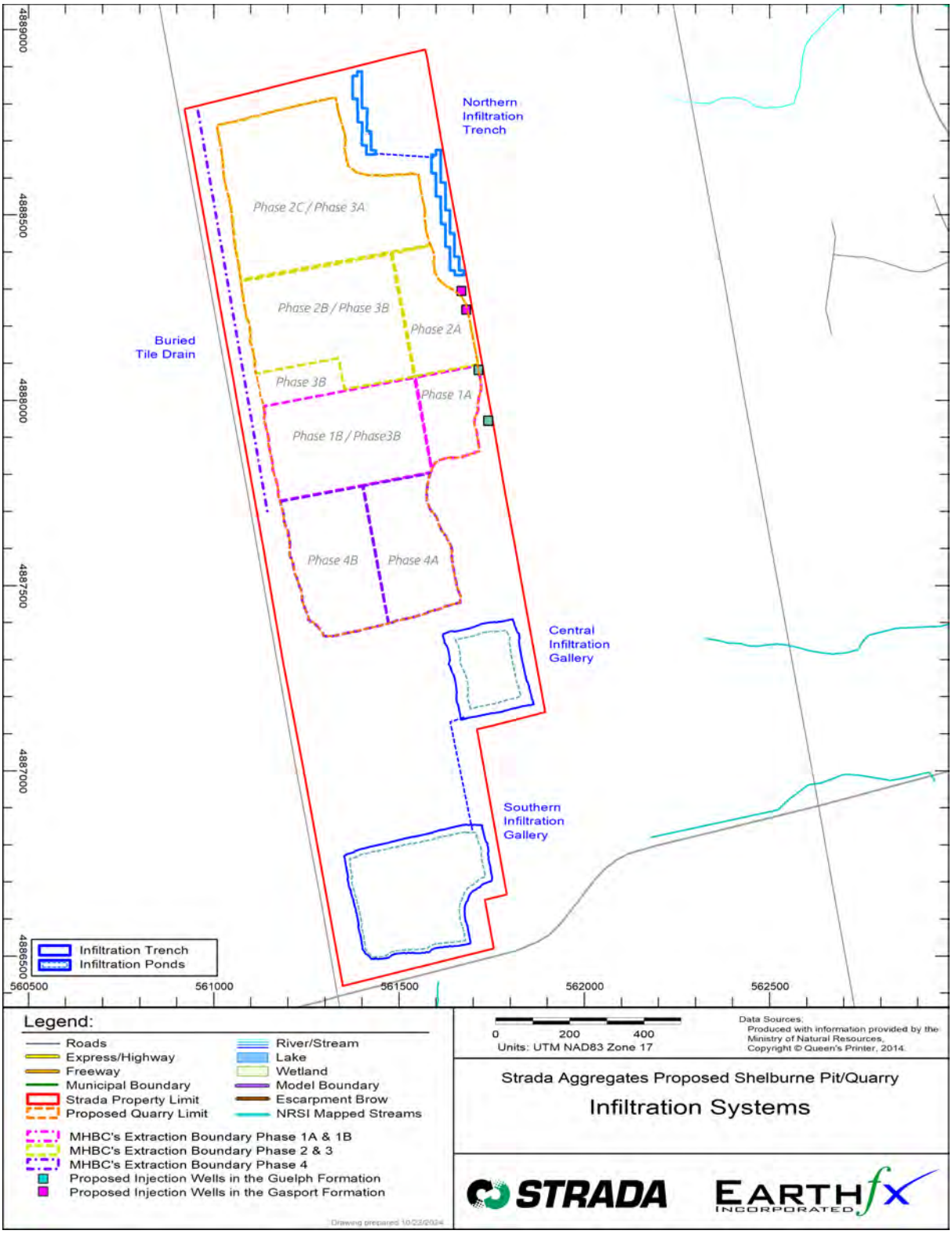


Figure 9: Proposed Strada Pit/Quarry Infiltration Features

4 Results and Conclusions

The representation and quantification of current site conditions and baseline conditions for impact assessment are two important aspects of the assessment process.

"Current Conditions" represent the observed site conditions as measured by the monitoring network. Current conditions are documented and discussed in detail in Appendix A and B through Appendix D.

"Baseline Conditions" represent conditions in and around the site once the gravel extraction operations are complete as per the current pit operating license. As defined here, Baseline Conditions represent near future, not current, conditions. It is important to note that site conditions will change as extraction progresses within the currently approved license area and permitted pumping for aggregate wash operations occurs. The on-going pit operations will result in changes in runoff and infiltration in and around the site. The numerical model discussed in Appendix E compares the modelled Baseline Conditions to the various proposed extraction phases. Changes to the land use, topography and layer geometry were made, and the Precipitation Recharge Modelling System (PRMS) model was used to estimate the changes in recharge and runoff patterns.

4.1 BASELINE CONDITIONS

The Baseline Conditions scenario provides a detailed integrated transient numerical simulation of the study area and is detailed in Appendix E Section 2. The average condition maps provide an overview, while the hydrographs from the assessment locations present insight regarding the dynamic and complex surface and groundwater processes.

The Baseline Conditions surface water analysis demonstrates that, while there are limited interactions between the surface and groundwater systems, most of the wetlands are "headwater" features with strong seasonal variability in groundwater seepage. The dammed pond west of Horning's Mills (NAT-18) is located in a groundwater discharge area and thus receives relatively high groundwater inflows.

Groundwater level and streamflow hydrographs at select locations provide insight into the natural seasonal and inter-annual variability in the system. Wetland water budgets provide a more detailed breakdown in the function and effects on the natural heritage features.

4.2 PHASE 1 EXTRACTION

Phase 1 represents the final extraction of sand and gravel from the north portion of the pit, and extraction of bedrock from Bench 1 and 2 in the central portion of the site, as discussed in Appendix E Section 3.5.

The development of Phase 1 will create groundwater drawdown in the central portion of the site, but this will be offset by groundwater mounding related to the infiltration systems. The net change is small, and the 1 m drawdown in the deepest layer extends less than 800 m from the proposed excavation.

The drawdowns are, at every location, small relative to the available drawdown in the aquifer, indicating that any shallow private wells could be readily deepened if necessary. The drawdown at location GWP-4 (near a new housing development

west of Horning's Mills) is approximately 0.5 m, while the available drawdown at that location is approximately 25 m, so there remains plenty of available well capacity during Phase 1 operations.

The drawdown reduces streamflow and surface leakage into Pond NAT-18. Hydrographs indicate that the difference between Baseline and Phase 1 streamflows at location STR8 are moderate while at STR7 they are low. Impact varies with the season at STR7, with less impact during spring time. Of note is that the measured impact on streamflows tends to affect headwater streams with low flows throughout the year and higher-order streams during the summer. At NAT-19, however, the water table is expected to rise, leading to increased groundwater ET, groundwater discharge to land surface, and decreased groundwater recharge (i.e. seepage out the bottom of the wetland).

4.3 PHASE 2 EXTRACTION

The development of Phase 2 will create groundwater drawdown in the central portion of the site, but this will be offset by groundwater mounding created by the infiltration systems. The net effect is small, and the 0.5 m drawdown in the deepest layer extending approximately 1700 m from the excavation.

The drawdowns are, at every location, small relative to the available drawdown in the aquifer, indicating that any shallow private wells could be readily deepened if necessary. The drawdown at location GWP-4 (near a new housing development west of Horning's Mills) is approximately 1.1 m, while the available drawdown at that location is approximately 25 m, so there remains plenty of available well capacity during operations.

The drawdown reduces streamflow and surface leakage into Pond NAT-18. In comparison to Phase 1, the impact on streamflow is of similar magnitude but slightly greater. Hydrographs indicate that the difference between Baseline and Phase 2 streamflow at location STR7 in Horning's Mills is expected to be between 10% and 20%. Of note is that the measured impact on streamflow affects small headwater streams with low flows throughout the year.

4.4 PHASE 4 EXTRACTION

The development of Phase 4A will create groundwater drawdown in the central portion of the site, but this will be offset by groundwater mounding related to the infiltration systems. The net effect is small, and the 1 m drawdown in the deepest layer extends approximately 2000 m from the excavation.

The drawdowns are, at every location, small relative to the available drawdown in the aquifer, indicating that any shallow private wells could be readily deepened if necessary. The drawdown at location GWP-4 (near a new housing development west of Horning's Mills) is approximately 2.5 m, while the available drawdown at that location is approximately 25 m. In general, 5 m of available drawdown is considered adequate in limestone aquifers such as those encountered in the study area, so there remains plenty of available well capacity during operations.

The drawdown reduces streamflow and surface leakage into Pond NAT-18. Hydrographs indicate that the difference between Baseline and Phase 4A streamflows at location STR7, downstream of the pond are significant during the summer and moderate during the spring. Streamflow at location STR8, a low-order stream, is expected to be significantly reduced throughout the year. Of note is that the measured impact on streamflow tends to affect headwater streams with low flows throughout the year.

4.5 REHABILITATION

Rehabilitation Conditions will return water levels and flows to near baseline conditions, with a small drawdown in the immediate vicinity of the quarry lake. These drawdowns are created (by leaving a small window to the deep Gasport aquifer) so as to ensure that the lake does not overflow to nearby properties.

The final condition drawdowns are small relative to the available drawdown in the aquifer, indicating that any shallow private wells could be readily deepened, if necessary. The drawdown at location GWP-4 (near a new housing development west of Horning's Mills) is approximately 0.6 m, while the available drawdown at that location is approximately 25 m. In general, 5 m of available drawdown is considered adequate in limestone aquifers such as those encountered in the study area, so there remains plenty of available well capacity after site rehabilitation.

Streamflows at STR locations are expected to still exhibit an impact, albeit small to moderate, depending upon the season.

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5 Source Water Protection

The site is located in the Nottawasaga Valley Source Protection Area (SPA). The Nottawasaga Valley SPA falls within the South Georgian Bay Lake Simcoe (SGBLS) Source Protection Region (SPR) comprised of Black-Severn, Lake Simcoe, Nottawasaga Valley and Severn Sound watersheds under the jurisdiction of the Lake Simcoe Region Conservation Authority, Nottawasaga Valley Conservation Authority and Severn Sound Environmental Association (Approved South Georgian Bay Lake Simcoe Source Protection Plan, 2023). The Nottawasaga Valley SPA encompasses 3,600 km^2 of plan area.

5.1 WATER QUALITY AND WATER QUANTITY RISK ASSESSMENT

The closest municipal drinking water supply is the Shelburne municipal wellfield, located approximately 5.0 km south of the site. The wellfield capture zone and threats assessment was updated in 2022 and that analysis indicates that the wells capture groundwater from the west. This confirms the proposed Strada development is lateral to, or downgradient of, the wellfield, and therefore will not be a water quality threat to the wellfield.

From a water quantity perspective, the operational design of the proposed quarry, including the proposed southern infiltration system, ensures that drawdowns will not propagate towards the municipal wellfield.

5.2 SIGNIFICANT GROUNDWATER RECHARGE AREAS AND HIGHLY VULNERABLE AQUIFERS

A significant groundwater recharge area (SGRA) is subject to the rules outlined in the Clean Water Act (2006), Technical Rules for Development of an Assessment Report and the MNRF in the form of a Technical Bulletin. In general, the determination of the SGRAs uses hydrogeological modelling and data from Tier I, II and III water budgets, which account for the geology, soils, land cover and topography of the Region. The site lies within an SGRA with a score of 6 and is identified as being a highly vulnerable aquifer (HVA).

6 Water Management Plan

A water management plan has been developed for the Strada Pit/Quarry through the integrated surface water and groundwater model to manage direct precipitation, surface water, and intercepted groundwater on-site. The objective of the water management plan is to maintain dry operating conditions within the extraction and operations areas while mitigating potential off-site impacts. The water management plan consists of water control barriers, a buried tile drain and injection wells, quarry sumps, a settling pond and clean water pond, and infiltration ponds and trenches. The water management plan for the Strada Pit/Quarry is described in detail in the following sections and illustrated on the Site Plans and Figure 9.

6.1 WATER CONTROL BARRIERS

Water control barriers will be constructed along the overburden and bedrock benches as pit/quarry extraction progresses, restricting groundwater inflow to that of the active extraction face. Water control barriers will be constructed along the overburden face and on Bench 1 (Guelph formation) and Bench 3 (Gasport formation). A water control barrier is not needed for Bench 2 (Ancaster/Niagara Falls formation) as the permeability and pump testing of this formation indicate it is a significant aquitard.

The water control barriers will be constructed out of sufficiently impermeable material (to be verified by a geotechnical engineer prior to and during construction of the water control barriers). The geotechnical feasibility study completed indicates the on-site Tavistock till may be suitable for the construction of water control barriers. However, if the on-site Tavistock till is deemed unsuitable for this use by the Geotechnical engineer, sufficiently impermeable off-site material will be sourced and imported for the water control barrier construction.

The water control barriers are to be designed in accordance with the recommendations of the Geotechnical engineer (refer to Section 10). Specifically, the water control barriers are to be constructed as a composite barrier design, with a low permeability core and predominantly granular shell at a maximum 2 horizontal: 1 vertical inclination. The water control barrier constructed along the overburden face is to be keyed into Bench 1 (Guelph formation) creating a contiguous barrier to prevent groundwater flow into the Strada Pit/Quarry.

The Bench 1 and 3 water control barriers will not be constructed through Phase 4B of extraction. As part of rehabilitation of the site, following completion of extraction, 365 m of the water control barriers (overburden, Bench 1 and Bench 3) along the east face of the extraction area is to be removed, allowing groundwater flow to continue draining west to east, mitigating potential long-term impacts to the surface and groundwater systems east of the Strada Pit/Quarry. The final (rehabilitation and closure) water control barriers are illustrated in the following Figure 8.

6.2 BURIED TILE DRAIN AND INJECTION WELLS

The water control barriers described under Section 6.2 have the potential to mound groundwater west of the Strada Pit/Quarry during Phases 2 through 4 of extraction. To eliminate the mounding, a buried tile drain will be constructed behind the water control barriers to intercept and convey the groundwater flow collected behind the west extraction face water

control barriers to the east side of the Strada Pit/Quarry and an injection well system. Along the west face of extraction, behind the water control barriers, outside the extraction and operations areas, 1105 m of perforated buried tile drain wrapped in filter sock will be installed at an elevation of 488 masl. 785 m of the perforated buried tile drain (north and central sections) is designed to drain to the injection well system while the remaining 320 m (south section) is designed to drain into the central infiltration feature (described in Section 6.5).

The north and central sections of the buried tile drain are designed to collect and convey non-contract water (water that has not entered the extraction or operations areas or been exposed to the atmosphere) through a passive system to the injection well system. In the northwest corner of the property, the buried tile drain will change from a perforated pipe to a solid pipe. The solid buried tile drain will run east along the north limit of extraction then south along the east limit of extraction behind the water control barriers to the injection well system. The buried tile drain (both perforated and solid) will be oversized to ensure sufficient non-contact water is conveyed to the injection well system and will be constructed at a sufficient slope (minimum 0.3%) to convey the required flows from the perforated buried tile drain to the injection well system. The buried tile drain will also be oversized to limit the quantity of groundwater entering the operation.

The south section of the buried tile drain will drain to a pump station. The pump station will collect and convey the intercepted groundwater to the central infiltration pond constructed during Phase 1 of extraction. The integrated surface and groundwater model predicts the south section of the buried tile drain will convey a peak flow of 12 L/s. As such, pump station will be designed to convey this peak flow with an appropriate factor of safety. The buried tile drain will be designed with operational flexibility, as described in the following section, to drain the south section of the buried tile drain to the injection wells if advantageous to do so from an operations and mitigation standpoint.

The results of the integrated surface water and groundwater model predict groundwater mounding behind the water control barriers west of the extraction area to begin in Phase 2. As such, the buried tile drain is not required until Phase 2 of extraction. However, the buried tile drain will be constructed progressively as extraction occurs in advance of the overburden and Bench 1 (Guelph formation) water control barrier construction. As part of rehabilitation of the site, the north section of the buried tile drain will be directed to drain into the quarry lake to address potential groundwater mounding west of the Strada Pit/Quarry after closure.

Inspection ports and control valves will be incorporated into the buried tile drain so groundwater levels can be monitored, the buried tile drain can be inspected and maintained, and for operational flexibility so the water management system can be optimized during operations. The inspection ports will allow the groundwater levels behind the water control barriers to be monitored to confirm any mounding upstream of the water control barriers is not adversely impacting the adjacent properties and land uses. The inspection ports and control valves will allow sections of the buried tile drain to be isolated so they can be flushed and cleaned ensuring the buried tile drain works continuously throughout operations. As a contingency, the inspection ports are also being install so a pumping station can be incorporated into the north and central sections of the buried tile drain, if necessary, either during maintenance of the buried tile drain or long-term. The control valves will also be installed so groundwater flow from the south section of the buried tile drain can be diverted to the injection well systems if additional water is required or to limit the quantity of water which enters the extraction and operations areas.

Four injection wells are proposed along the eastern limit of the extraction area to discharge non-contract water back into groundwater aquifer, into both the Guelph and Gasport formations. The injection wells proposed will be drilled wells constructed in accordance with O.Reg.903. Two injection wells are proposed into the Guelph formation with a total capacity of 5 L/s. Two injection wells are proposed into the Gasport formation with a total capacity of 7 L/s. As the buried tile drain will be oversized, additional non-contact water will drain to the injection well system. The non-contact water which exceeds the capacity of the injection wells will overflow the injection well system into a pump station which will discharge the excess water into the north and south infiltration trenches (described in Section 6.5).

The injection well system will be located beneath the acoustic barrier along the east limit of the extraction area. The injection wells will be extended above grade and capped so they can be inspected and maintained. The injection well system will be capped with low permeable material and the acoustic berm will be graded to direct surface runoff away from the injection well system, ensuring the injection wells received non-contact water only. The injection well system is required for Phase 2 of extraction. However, as the injection well system will be constructed beneath an acoustic berm, the injection well system will have to be constructed as part of the acoustic berm construction prior to Phase 1 of extraction.

6.3 QUARRY SUMPS

Direct precipitation which falls in the extraction and operations areas and the intercepted groundwater will be collected in a quarry sump constructed in the quarry floor. The quarry floor will be graded to direct the surface runoff to the quarry sump. The location of the quarry sump will vary depending on the Phase of extraction and the quarry sump will be sized to satisfy the requirements of the that Phase of extraction, specifically it will be sized to maintain dry operating conditions within the extraction and operations areas.

The water collected in the quarry sump will be pumped into the settling ponds constructed in the operations area (described in Section 6.4) for treatment. Alternatively, if the water collected in the quarry sump satisfies the water quality objectives of the Strada Pit/Quarry Environmental Compliance Approval (ECA), the water may be pumped directly into the central infiltration pond (described in Section 6.5). The water quality objectives will be established through the ECA application process following the issuance of the ARA license.

6.4 SETTLING AND CLEAN WATER PONDS

A settling pond will be constructed in the floor of the operations area to settle the sediment from the sump discharge (if any) and process water before it enters the clean water pond. The settling pond will be designed and constructed to treat the maximum combined discharge from the quarry sump and process water considering a typical quarry sediment particle size distribution. Specifically, the settling pond will be designed to satisfy the water quality objectives specified in the Strada Pit/Quarry ECA (to be resolved through the ECA application process). The settling pond will need to be cleaned out periodically to ensure the required level of sediment removal is achieved.

The treated water from the settling pond will enter a clean water pond constructed in the floor of the operations area of the Strada Pit/Quarry. From the clean water pond, water will be taken for processing of aggregate on-site or transferred to the central infiltration pond. The settling pond and clean water pond will form a closed loop system for the processing of aggregate. Only water from the clean water pond, or water from the quarry sump which satisfies the water quality objectives

of the Strada Pit/Quarry ECA, will be discharged into the central infiltration pond. This ensures the infiltration capacity of the on-site infiltration features will not be inhibited by sediment from the quarry sump or process water.

6.5 INFILTRATION PONDS AND TRENCHES

There are no watercourses in the immediate vicinity of the Strada Pit/Quarry. As such, there is no opportunity for off-site discharge of non-contact or contact water to a watercourse. Two infiltration ponds (central and south infiltration ponds) and two infiltration trenches (north and south infiltration trenches) are proposed within the license area to manage water on-site and discharge the contact water (direct precipitation falling within the extraction and operations area and intercepted groundwater) into the sand and gravel layer along the east limit of the property. The contact water will be managed on-site and allowed to infiltrate into the sand and gravel layer along the east limit of the property to maintain dry operating conditions within the extraction and operations areas while mitigating potential off-site impacts. The north and south infiltration trenches will also be used to infiltrate non-contact water exceeding the capacity of the injection wells.

The infiltration ponds and trenches have been sized through the integrated surface water and groundwater model. The infiltration pond and trench characteristics, including elevations and storage volumes, are summarized in Table 2:

Table 2: Infiltration Ponds and Trenches Characteristics Summary

INFILTRATION FEATURE	ELEVATION (m)			AREA (m^2)	VOLUME (m^3)
	Floor	Top of Bank	Max Water Level		
Central Infiltration Pond	475.35	495.00	494.00	43,594	618,410
South Infiltration Pond	480.60	495.00	494.00	104,062	947,950
North Infiltration Trench	503.00	510.00	509.00	6,554	23,730
South Infiltration Trench	503.00	507.00	506.00	4,368	10,920

The side slopes of the infiltration ponds and trenches are to be designed in accordance with the recommendations of the Geotechnical engineer (refer to Section 10). Specifically, the infiltration trench side slopes are to be constructed at a maximum 2 horizontal: 1 vertical inclination. The east and south side slopes of the central infiltration pond are to be constructed at 2:1 (max) and the north and west banks of the central infiltration pond are to be constructed with 3:1 slopes (max) with a water control barrier. The south infiltration pond side slopes are to be constructed at 2:1 (max) and the north and west banks of the south infiltration pond are to be constructed with a water control barrier. The side slopes of the infiltration ponds and trenches are to be protected from erosion with suitable erosion protection measures (e.g. topsoil, hydroseed and erosion control blanket, rip rap, etc.) approved by a geotechnical engineer at the time of trench construction.

6.6 WATER MANAGEMENT SYSTEM FLOWS

As there are no watercourses in the immediate vicinity of the Strada Pit/Quarry, there is no opportunity for off-site discharge of non-contact or contact water to a watercourse. As such, all water must be managed on-site. The water will be stored on-site and allowed to infiltrate into the sand and gravel overburden in a manner like existing conditions and consistent with current stormwater management techniques. The flow of water to the various water management plan features for the phases of extraction included in the integrated surface water and groundwater model are summarized in Table 3.

Table 3: Water Management Plan Flow Components Summary

WATER MANAGEMENT PLAN FEATURE	AVERAGE FLOW	% OF FLOW	PEAK FLOW
Phase 1			
Total Flow of Water to North Infiltration Trench	**11.6 L/s**	**39%**	**22.1 L/s**
From Central Infiltration Pond to North Infiltration Trench	0 L/s	0%	1.3 L/s
From South Infiltration to North Infiltration Trench	0 L/s	0%	0.7 L/s
From Quarry Sump to North Infiltration Trench	11.6 L/s	39%	20.1 L/s
Total Flow of Water to South Infiltration Trench	**4.3 L/s**	**15%**	**5.1 L/s**
Between South and North Trench	0 L/s	0%	0 L/s
From Quarry Sump to South Infiltration Trench	4.3 L/s	15%	5.1 L/s
Total Flow of Water to Central Infiltration Feature	**13.1 L/s**	**44%**	**25.1 L/s**
Total Flow or Water to South Infiltration Feature	**0.5 L/s**	**2%**	**12.0 L/s**
Total Flow of Water in Quarry	**29.5 L/s**	**100%**	**64.3 L/s**
Phase 2C			
Total Flow of Water to North Infiltration Trench	**25.5 L/s**	**36%**	**52.3 L/s**
From South Infiltration to North Infiltration Trench	0.6 L/s	1%	9.0 L/s
From Quarry Sump to North Infiltration Trench	21.1 L/s	30%	31.5 L/s
From Buried Tile Drain to Northern Infiltration Trench	3.8 L/s	5%	11.8 L/s
WATER MANAGEMENT PLAN FEATURE	AVERAGE FLOW	% OF FLOW	PEAK FLOW

Total Flow of Water to South Infiltration Trench	**19.5 L/s**	**27%**	**53.3 L/s**
Between South and North Trench	0 L/s	0%	18.2 L/s
From Central Infiltration Pond to South Infiltration Trench	4.4 L/s	6%	12.4 L/s
From Quarry Sump to South Infiltration Trench	15.1 L/s	21%	22.7 L/s
Total Flow of Water to Central Infiltration Feature	**21.6 L/s**	**30%**	**36.3 L/s**
Total Flow of Water to South Infiltration Feature	**4.4 L/s**	**6%**	**12.3 L/s**
Total Flow of Water in Quarry	**71.0 L/s**	**100%**	**154.2 L/s**
Total Flow from Buried Tile Drain to Injection Wells	**12.0 L/s**	**100%**	**12.0 L/s**
Phase 4A			
Total Flow of Water to North Infiltration Trench	**11.2 L/s**	**26%**	**21.0 L/s**
Total Flow of Water to South Infiltration Trench	**13.0 L/s**	**30%**	**23.8 L/s**
Between South and North Trench	0 L/s	0%	0 L/s
From Central Infiltration Pond to South Infiltration Trench	1.8 L/s	4%	7.3 L/s
From Buried Tile Drain to South Infiltration Trench	11.2 l/s	26%	16.5 L/s
Total Flow of Water to Central Infiltration Feature	**16.6 L/s**	**39%**	**27.2 L/s**
From Buried Tile Drain to Central Infiltration Pond	7.8 L/s	18%	10.8 L/s
From Quarry Sump to Central Infiltration Pond	8.8 L/s	21%	16.4 L/s
Total Flow of Water to South Infiltration Feature	**1.8 L/s**	**4%**	**7.3 L/s**
Total Flow of Water in Quarry	**42.6 L/s**	**100%**	**79.3 L/s**
Total Flow from Buried Tile Drain to Injection Wells	**12 L/s**	**100%**	**12 L/s**

The water management plan has been developed to allow water to be transferred to the various on-site features as required to maintain dry operating conditions in the extraction and operations areas whiling mitigating potential impacts. The water management plan has been designed with operational flexibility so the water entering the quarry can be managed effectively and the water management plan can be optimized during operations.

7 Proposed Groundwater and Surface Water Monitoring Program

7.1 ON-SITE GROUNDWATER MONITORING

Key groundwater monitoring wells have been selected and incorporated into the long-term groundwater monitoring program. The groundwater monitoring program consists of water level and water quality monitoring at the locations identified in Figure 10 and summarized in Table 3 and Table 4. Further details are provided in Appendix E Section 4.1.

7.2 OFF-SITE DOMESTIC WATER WELLS

Key private domestic water wells have been selected and incorporated into the long-term groundwater monitoring program. The groundwater monitoring program consists of water level and water quality monitoring at the locations identified in Figure 11 and summarized in Table 5 and Table 6. Further details are provided in Appendix E Section 4.2.

7.3 SURFACE WATER MONITORING

Key surface water features have been identified through the impact assessment and incorporated into the long-term surface water monitoring program. The surface water monitoring program consists of water level monitoring and streamflow monitoring at the key locations identified in Figure 8 and summarized in Table 7 and Table 8. Further details are provided in Appendix E Section 5.

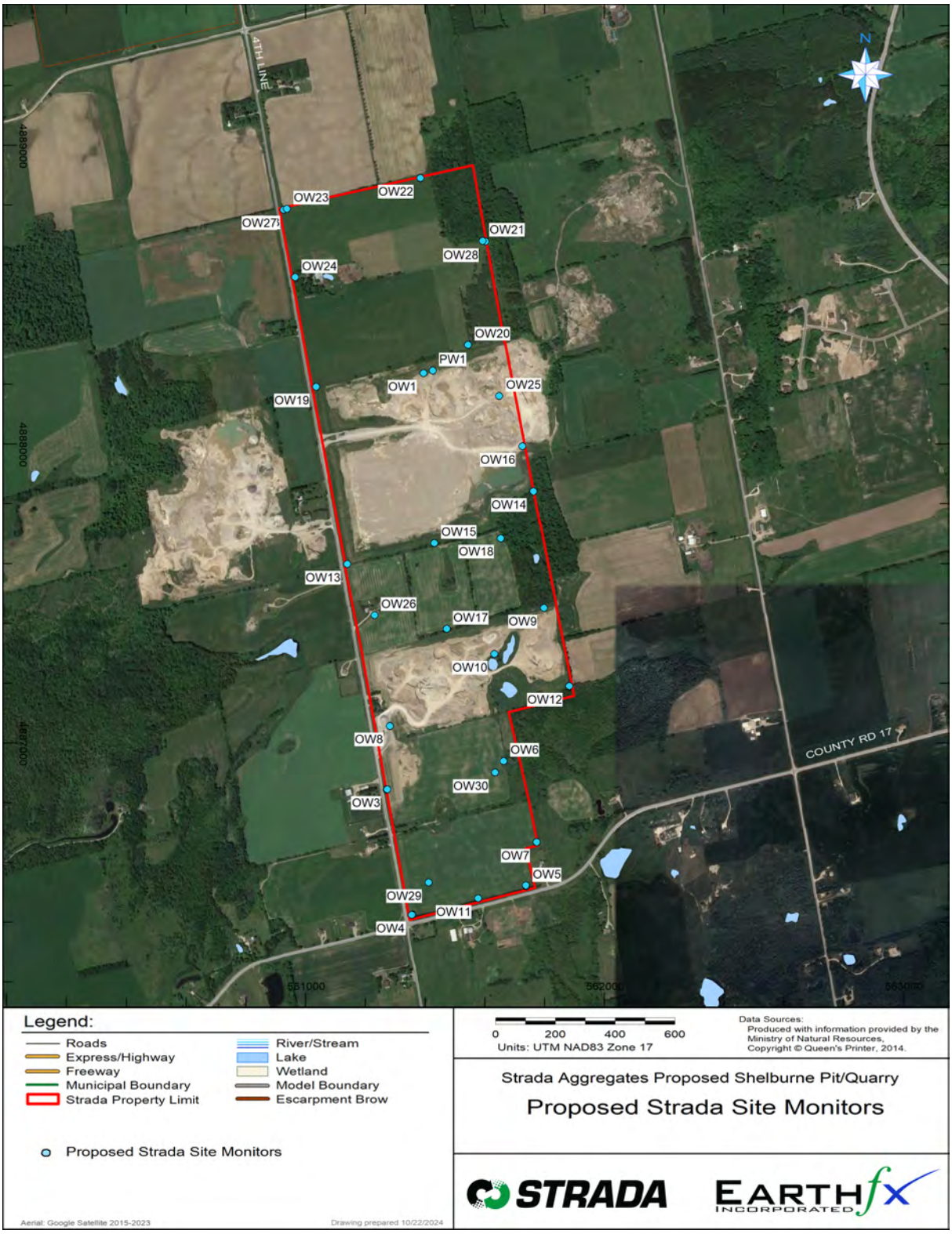


Figure 10: On-site Groundwater Monitoring Wells

Table 4: On-site Groundwater Monitoring Network

WELL NEST ID	MONITORING ID	LOCATION	WELL DEPTH (M)	HYDROSTATIC UNIT	WATER LEVEL MONITORING	WATER QUALITY MONITORING
PW1	PW1	17T 4888246N, 561425E	48.76	Bedrock	Yes	No
OW1	OW1	17T 4888238N, 561395 E	48.76	Bedrock	Yes	No
OW3	OW3B	17T 4886844N, 561273E	9.75	Tavistock Till and Bedrock Contact	Yes	Semi-Annual
	OW3C	17T 4886844N, 561271E	12.49	Bedrock	Yes	Semi-Annual
OW4	OW4A	17T 4886425N, 561355E	7.92	Sand and Gravel Overburden	Yes	Semi-Annual
	OW4B	17T 4886425N, 561355E	13.72	Tavistock Till and Bedrock Contact	Yes	Semi-Annual
	OW4C	17T 4886425N, 561359E	16.46	Bedrock	Yes	Semi-Annual[1]
OW5	OW5A	17T 4886523N, 561738E	5.70	Sand and Gravel Overburden	Yes	Semi-Annual & Annual
	OW5B	17T 4886523N,	10.05	Tavistock Till and Bedrock Contact	Yes	Semi-Annual

WELL NEST ID	MONITORING ID	LOCATION	WELL DEPTH (M)	HYDROSTATIC UNIT	WATER LEVEL MONITORING	WATER QUALITY MONITORING
		561738E				
	OW5C	17T 4886520N, 561738E	13.10	Bedrock	Yes	Semi-Annual[1]
OW6	OW6A	17T 4886939N, 561663E	7.80	Sand and Gravel Overburden	Yes	Semi-Annual & Annual
OW7	OW7A	17T 4886674N, 561771E	10.05	Sand and Gravel Overburden	Yes	Semi-Annual & Annual
	OW7C	17T 4886668N, 561773E	30.60	Bedrock	Yes	Semi-Annual
OW8	OW8A	17T 4887057N, 561282E	12.0	Sand and Gravel Overburden	Yes	Semi-Annual & Annual
OW9	OW9B	17T 4887451N, 561798E	18.20	Tavistock Till and Bedrock Contact	Yes	Semi-Annual & Annual
OW10	OW10B	17T 4887297N, 561632E	19.20	Tavistock Till and Bedrock Contact	Yes	Semi-Annual & Annual
OW12	OW12A	17T 4887192N, 561882E	7.62	Sand and Gravel Overburden	Yes	Semi-Annual & Annual
	OW12B	17T 4887190N,	21.03	Tavistock Till and Bedrock Contact	Yes	Semi-Annual[1]

WELL NEST ID	MONITORING ID	LOCATION	WELL DEPTH (M)	HYDROSTATIC UNIT	WATER LEVEL MONITORING	WATER QUALITY MONITORING
		561882E				
OW13	OW13A	17T 4887598N, 561140E	14.34	Sand and Gravel Overburden	Yes	Semi-Annual
	OW13C	17T 4887598N, 561140E	18.94	Bedrock	Yes	Semi-Annual
OW14	OW14A	17T 4887841N, 561763E	12.40	Sand and Gravel Overburden	Yes	Semi-Annual
	OW14C	17T 4887841N, 561763E	20.00	Bedrock	Yes	Semi-Annual & Annual
OW16	OW16A	17T 4887994N, 561726E	11.81	Sand and Gravel Overburden	Yes	No
	OW16C	17T 4887993N, 561726E	27.30	Bedrock	Yes	Semi-Annual & Annual
OW18	OW18A	17T 4887685N, 561653E	19.80	Sand and Gravel Overburden	Yes	Semi-Annual & Annual
	OW18C	17T 4887685N, 561653E	23.70	Bedrock	Yes	Semi-Annual

WELL NEST ID	MONITORING ID	LOCATION	WELL DEPTH (M)	HYDROSTATIC UNIT	WATER LEVEL MONITORING	WATER QUALITY MONITORING
OW19	OW19A	17T 4888192N, 561036E	14.40	Sand and Gravel Overburden	Yes	Semi-Annual
	OW19C	17T 4888192N, 561036E	35.50	Bedrock	Yes	Semi-Annual
OW20	OW20A	17T 4888333N, 561544E	21.64	Sand and Gravel Overburden	Yes	No
	OW20C	17T 4888333N, 561544E	26.40	Bedrock	Yes	Semi-Annual & Annual
OW21	OW21A	17T 4888680N, 561593E	22.20	Sand and Gravel Overburden	Yes	Semi-Annual[1]
	OW21C	17T 4888680N, 561593E	25.30	Bedrock	Yes	Semi-Annual & Annual
OW22	OW22A	17T 4888890N, 561384E	24.30	Sand and Gravel Overburden	Yes	Semi-Annual[1]
	OW22C	17T 4888890N, 561384E	27.50	Bedrock	Yes	Semi-Annual
OW23	OW23A	17T 4888787N, 560938E	20.40	Sand and Gravel Overburden	Yes	Semi-Annual[1]

WELL NEST ID	MONITORING ID	LOCATION	WELL DEPTH (M)	HYDROSTATIC UNIT	WATER LEVEL MONITORING	WATER QUALITY MONITORING
	OW23C	17T 4888787N, 560938E	29.50	Bedrock	Yes	Semi-Annual
OW24	OW24A	17T 4888558N, 560965E	30.57	Sand and Gravel Overburden	Yes	Semi-Annual[1]
	OW24C	17T 4888558N, 560965E	66.69	Bedrock	Yes	Semi-Annual[1]
OW25	OW25A	17T 4888161N, 561648E	19.23	Sand and Gravel Overburden	Yes	No
	OW25C	17T 4888161N, 561648E	46.08	Bedrock	Yes	No
OW26	OW26A	17T 4887427N, 561231E	30.41	Sand and Gravel Overburden	Yes	Semi-Annual[1]
	OW26C	17T 4887427N, 561231E	54.88	Bedrock	Yes	Semi-Annual[1]
OW27	OW27C	17T 4888785N, 560927E	71.88	Bedrock	Yes	Semi-Annual[1]
OW28	OW28A	17T 4888675N, 561602E	37.18	Sand and Gravel Overburden	Yes	Semi-Annual[1]

WELL NEST ID	MONITORING ID	LOCATION	WELL DEPTH (M)	HYDROSTATIC UNIT	WATER LEVEL MONITORING	WATER QUALITY MONITORING
	OW28C	17T 4888678N, 56160E	67.59	Bedrock	Yes	Semi-Annual[1]
OW29	OW29A	17T 4886532N, 561413E	25.96	Sand and Gravel Overburden	Yes	Semi-Annual[1]
	OW29C	17T 4886533N, 561412E	62.76	Bedrock	Yes	Semi-Annual[1]
OW30	OW30C	17T 4886901N, 561634E	56.62	Bedrock	Yes	Semi-Annual[1]
Injection Well 1	IW1	TBD	TBD	Guelph Bedrock	Yes	Semi-Annual[1]
Injection Well 2	IW2	TBD	TBD	Guelph Bedrock	Yes	Semi-Annual[1]
Injection Well 3	IW3	TBD	TBD	Gasport Bedrock	Yes	Semi-Annual[1]
Injection Well 4	IW4	TBD	TBD	Gasport Bedrock	Yes	Semi-Annual[1]

Note:

1. Not currently monitored as part of the existing Integrated Monitoring Program but are suggested as additional monitoring requirements moving forward.

Table 5: On-site Groundwater Quality Monitoring

WATER QUALITY SAMPLING FREQUENCY	PARAMETER
Semi-Annual	pH, Conductivity, Alkalinity, Bicarbonate, Chloride, Metals (Antimony, Arsenic, Barium, Beryllium, Boron, Cadmium, Calcium, Cobalt, Copper, Lead, Iron, Magnesium, Manganese, Mercury, Molybdenum, Nickel, Potassium, Selenium, Sodium, Silver, Strontium, Sulfur, Thallium, Thorium, Tin, Titanium, Tungsten, Uranium, Vanadium, Zinc), Nitrate/Nitrite, Sulphate
Annual	Petroleum Hydrocarbons Fractions F1 to F4, Benzene, Toluene, Ethylbenzene and Xylenes (BTEX), and Oil and Grease

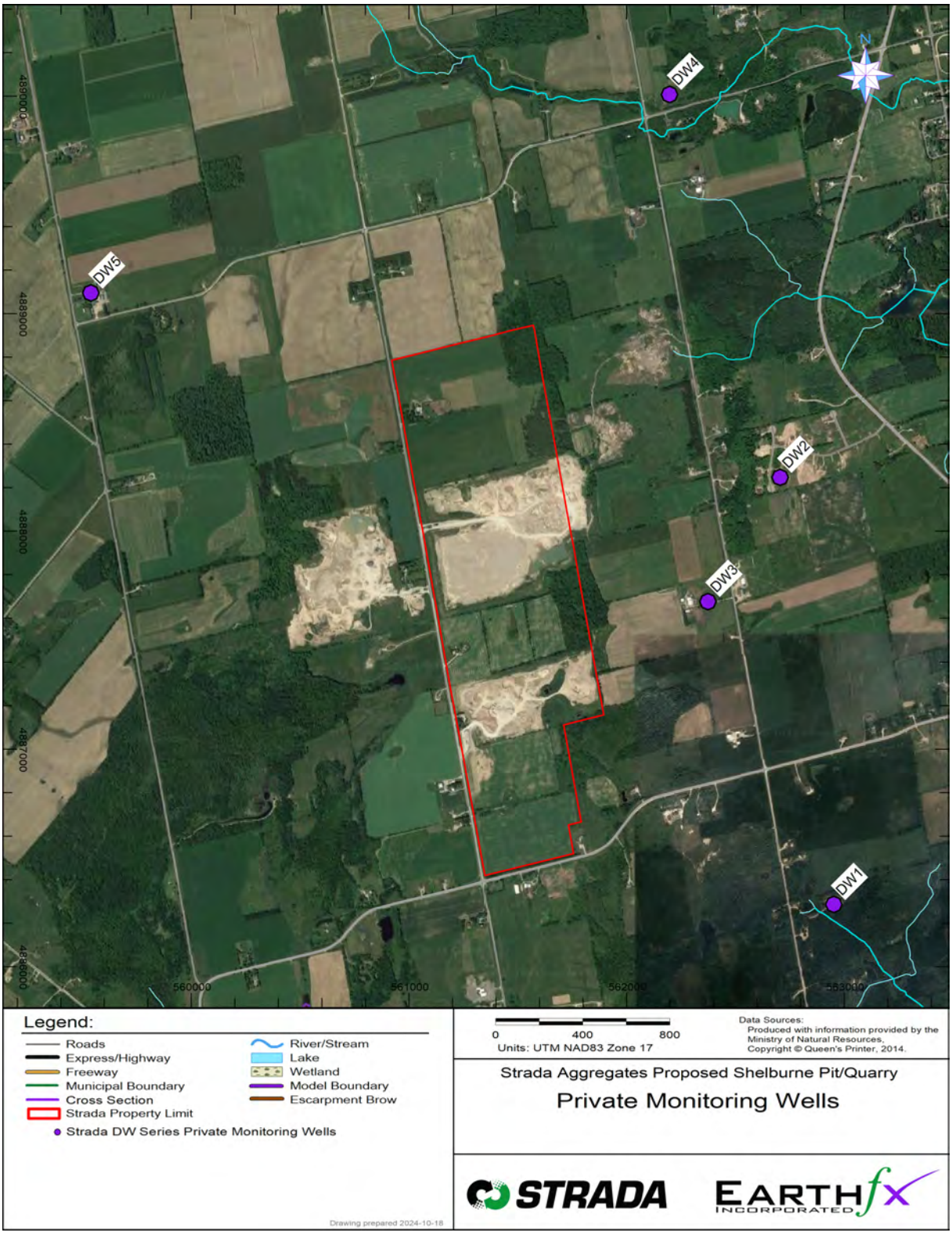


Figure 11: Off-Site Domestic Water Well Monitoring Locations

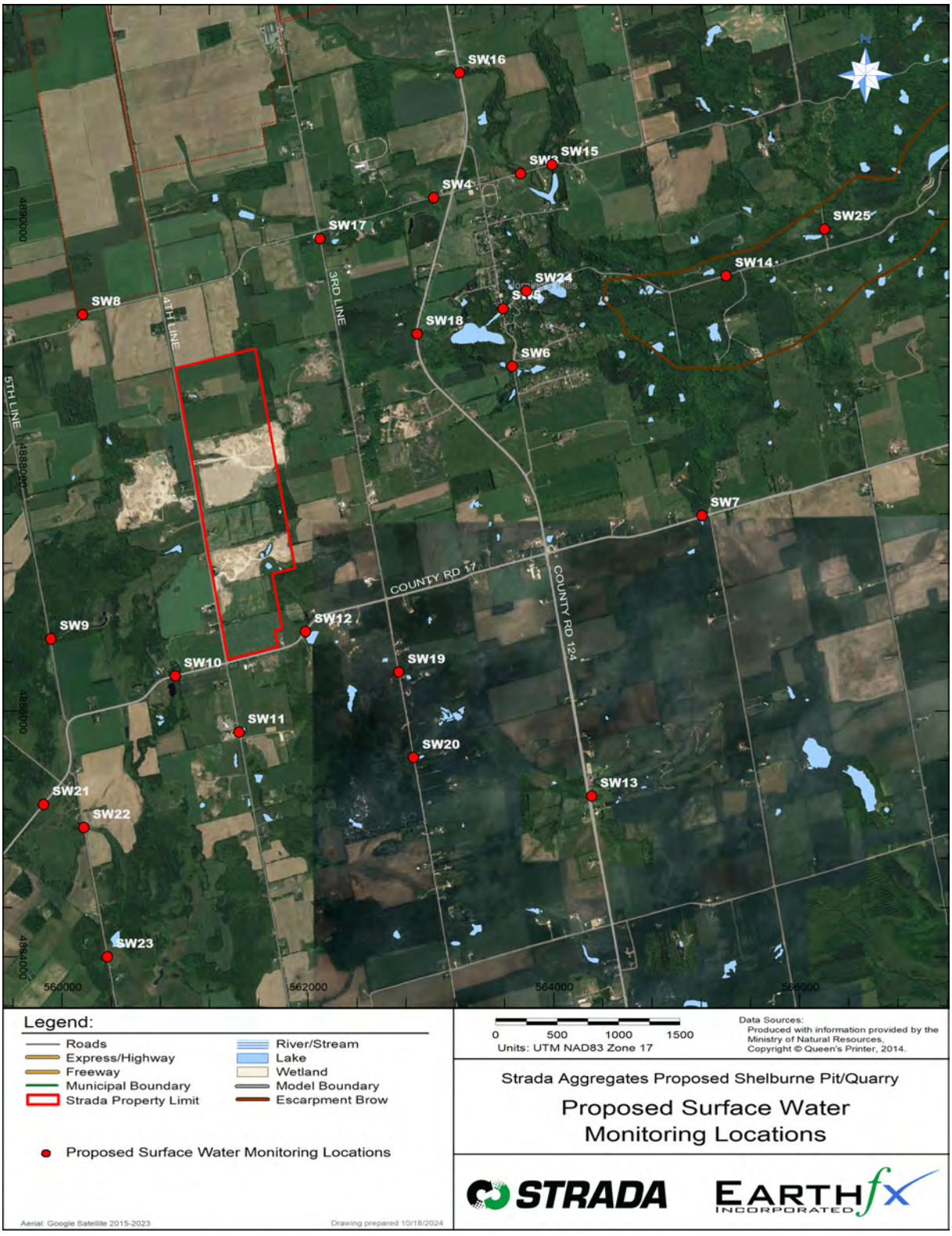


Figure 12: Surface Water Monitoring Locations

Table 6: Surface Water Level Monitoring Network

MONITORING LOCATION	LOCATION	WATER LEVEL MONITORING	WATER QUALITY MONITORING
North Pond	17T 4887268N, 561630E	Yes	Semi-Annual[1]
South Pond	17T 4887155N, 561778E	Yes	Semi-Annual[1]
SW1 (Wetland)	17T 4887622N, 561767E	Yes	Semi-Annual[1, 2]
SW2 (Vernal Pool)	17T 4887538N, 561734E	Yes	Semi-Annual[1, 2]
NAT-18	TBD	Yes[1]	Semi-Annual[1]
NAT-19	TBD	Yes[1]	Semi-Annual[1]

Note:

1. Not currently monitored as part of the existing Integrated Monitoring Program but are suggested as additional monitoring requirements moving forward.
2. Monitoring to discontinue when wetland has been removed and monitoring locations should be relocated and replaced in the reconstructed wetland.

Table 7: Surface Water Quality Monitoring

SAMPLING FREQUENCY	PARAMETER
Semi-Annual	Dissolved Oxygen, Conductivity, pH, Temperature

Table 8: Streamflow Monitoring Network

MONITORING LOCATION	LOCATION	CONTINUED STREAMFLOW MONITORING	WATER QUALITY MONITORING
SW4[2]	17T 4890176N, 563023E	Yes	Semi-Annual[1]
SW5[2]	17T 4889273N, 563588E	Yes[1]	Semi-Annual[1]
SW6[2]	17T 4888803N, 563662E	Yes[1]	Semi-Annual[1]
SW13[2]	17T 4885308N, 564305E	Yes	Semi-Annual[1]
SW14[2]	17T 4889540N, 565402E	Yes	Semi-Annual[1]
SW18[2]	17T 4889066N, 562888E	Yes[1]	Semi-Annual[1]

Note:

1. Not currently monitored as part of the existing Integrated Monitoring Program but are suggested as additional monitoring requirements.
2. Recommended continuously recording monitoring stations be established at these locations moving forward.

8 Well Complaints Procedure

A comprehensive complaints response program has been established for the site for the purpose of responding to water well interference complaints for water well users in the vicinity of the proposed pit/quarry. The program includes the following:

- Following receipt of a complaint from a water well user, Strada will notify the MNRF and MECP.
- Strada will ensure a Certified Well Inspector (i.e. licensed water well technician) and/or qualified hydrogeologist visits the site within 24 hours of receiving the complaint to investigate. The Certified Well Inspector and/or hydrogeologist will complete a well inspection including a review of the pump, well condition, pump depth and condition, etc.
- Strada will provide a temporary water supply to the well owner within 48 hours of receiving the complaint and thereafter until such time as the cause of the disruption has been determined. Strada will arrange temporary water system hook up and removal, and the first and subsequent loads of water to the system. Strada shall fund the temporary solution.
- If the well complaint can be definitively determined to not be a result of the pit/quarry operations (i.e. mechanical failure), Strada will continue to provide water for an additional week to allow the well owner to make alternative water supply arrangements.
- If the well complaint cannot be definitively determined to not be a result of the pit/quarry operations after the initial site visit, a hydrogeologist will review the water well inspection report and supporting information, water level data and on-going operations at the quarry/pit to provide an assessment of the cause of the complaint. The hydrogeologist will prepare an opinion letter to be provided to the MECP as to the likelihood the well complaint is related to the quarry/pit operation.
- Following the MECPs review if the well interference is determined to not be a result of the pit/quarry operations, Strada will continue to provide water for an additional week to allow the well owner to make alternative water supply arrangements.
- Following the MECPs review if the well interference is determined to be attributed to the quarry/pit operations and activities and the water supply is at risk, a water supply restoration program will be implemented.
- The water supply restoration program includes:
  - Step 1: Well system rehabilitation: this includes the replacement or lowering of pumps, flushing the pump lines, well deepening, etc.
  - Step 2: Well Replacements: if system rehabilitation is not an option, the well could be replaced with a new well further from the pit.
  - Step 3: Water treatment considerations: appropriate water treatment will be incorporated into any restored water supply.

9 Site Plan Recommendations

Based on the above findings the following conditions are to be included on the site plan:

- Water levels shall be collected continuously with automatic water level transducers, with manual measurements collected monthly at the following groundwater monitors: PW1, OW1, OW3B, OW3C, OW4A, OW4B, OW4C, OW5A, OW5B, OW5C, OW6A, OW7A, OW7C, OW8A, OW9B, OW10B, OW12A, OW12B, OW13A, OW13C, OW14A, OW14C, OW16A, OW16C, OW18A, OW18C, OW19A, OW19C, OW20A, OW20C, OW21A, OW21C, OW22A, OW22C, OW23A, OW23C, OW24A, OW24C, OW25A, OW25C, OW26A, OW26C, OW27C, OW28A, OW28C, OW29A, OW29C, OW30C, and the four Injection Wells, as shown on the Monitoring Locations schematic (MHBC Site Plan, Drawing 1 of 5).
- Considering the historical and monitoring data collected within 3 years of extraction extending below the groundwater table, baseline groundwater level conditions are to be established for OW3B, OW3C, OW4A, OW4B, OW4C, OW5A, OW5B, OW5C, OW6A, OW9B, OW10B, OW13A, OW13C, OW14A, OW14C, OW21A, OW21C, OW22A, OW22C, OW23A, OW23C, OW24A, OW24C, OW25A, OW25C, OW26A, OW26C, OW27, OW28A, OW28C, OW29A, OW29C, and OW30C, as shown on the Monitoring Locations schematic (MHBC Site Plan, Drawing 1 of 5). If water levels change more than the established thresholds developed for the Phases One through Four, and Rehabilitation conditions considering the predicted groundwater levels and established baseline conditions, a detailed investigation will be undertaken in regards to the potential impacts to local groundwater system. This investigation will include a review of current quarry activities, a review of on-site and off-site groundwater levels, and a review of climate data. Should quarry activities be found to be responsible for the change the licensee will discuss options with the MNR and consider the following:
    1. Suspension of below water table activities.
    2. Moving mining to a different phase.
    3. Conducting a detailed investigation including installing more observation wells
- Water levels shall be collected continuously with automatic water level transducers April through November, with monthly manual measurements collected during the same period at the following surface water monitors: North Pond, South Pond, SW1 and SW2, as shown on the Monitoring Locations schematic (MHBC Site Plan, Drawing 1 of 5).
- Water levels shall be collected continuously with automatic water level transducers April through November, with monthly manual measurements collected during the same period subject to landowner permission/access being granted at the following surface water monitors: NAT-18 and NAT-19, as shown on the Monitoring Locations schematic (MHBC Site Plan, Drawing 1 of 5).
- Water levels shall be collected continuously with automatic water level transducers, with manual measurements to be collected monthly subject to landowner permission/access being granted at the following private water wells: DW1, DW2, DW3, DW4, and DW5 as shown on the Monitoring Locations schematic (MHBC Site Plan, Drawing 1 of 5).
- Water levels and streamflow shall be collected continuously with automatic water level transducers April through November, with monthly manual measurements collected during the same period at the following surface water

monitors: SW4, SW5, SW6, SW13, SW14, SW18, and SW24, as shown on the Monitoring Locations schematic (MHBC Site Plan, Drawing 1 of 5).

- Considering the historical and monitoring data collected within 3 years of extraction extending below the groundwater table, baseline base flow conditions via a threshold are to be established for SW24. If base flows change more than the established thresholds for this location developed for the Phases One through Four, and Rehabilitation conditions considering the predicted base flows and confirmed baseline conditions, a detailed investigation will be undertaken in regard to the potential impacts to local groundwater-surface water system. This investigation will include a review of current quarry activities, a review of on-site and off-site groundwater and surface water flows at other monitoring locations, and a review of climate data. Should quarry activities be found to be responsible for the change the licensee will discuss options with the MNR and consider the following:

    1. Suspension of below water table activities.
    2. Moving mining to a different phase.
    3. Conducting a detailed investigation including installing more observation wells or surface water monitoring locations.

- Semi-annual water quality sampling for pH, Conductivity, Alkalinity, Bicarbonate, Chloride, Metals (Antimony, Arsenic, Barium, Beryllium, Boron, Cadmium, Calcium, Cobalt, Copper, Lead, Iron, Magnesium, Manganese, Mercury, Molybdenum, Nickel, Potassium, Selenium, Sodium, Silver, Strontium, Sulfur, Thallium, Thorium, Tin, Titanium, Tungsten, Uranium, Vanadium, Zinc), Nitrate/Nitrite, and Sulphate shall be conducted at the following groundwater monitors: OW3B, OW3C, OW4A, OW4B, OW4C, OW5A, OW5B, OW5C, OW6A, OW7A, OW7C, OW8A, OW9B, OW10B, OW12A, OW12B, OW13A, OW13C, OW14A, OW14C, OW16C, OW18A, OW18C, OW19A, OW19C, OW20C, OW21A, OW21C, OW22A, OW22C, OW23C, OW23A, OW24A, OW24C, OW26A, OW26C, OW27C, OW28A, OW28C, OW29A, OW29C, OW30C and the four Injection Wells, as shown on the Monitoring Locations schematic (MHBC Site Plan, Drawing 1 of 5).

- Semi-annual water quality sampling for pH, Conductivity, Alkalinity, Bicarbonate, Chloride, Metals (Antimony, Arsenic, Barium, Beryllium, Boron, Cadmium, Calcium, Cobalt, Copper, Lead, Iron, Magnesium, Manganese, Mercury, Molybdenum, Nickel, Potassium, Selenium, Sodium, Silver, Strontium, Sulfur, Thallium, Thorium, Tin, Titanium, Tungsten, Uranium, Vanadium, Zinc), Nitrate/Nitrite, and Sulphate shall be conducted subject to landowner permission/access being granted at the following private water wells: DW1, DW2, DW3, DW4 and DW5, as shown on the Monitoring Locations schematic (MHBC Site Plan, Drawing 1 of 5).

- Annual water quality sampling for Petroleum Hydrocarbons Fractions F1 to F4, Benzene, Toluene, Ethylbenzene and Xylenes, and Oil and Grease shall be conducted at the following groundwater monitors: OW5A, OW6A, OW7A, OW8A, OW9B, OW10B, OW12A, OW14C, OW16C, OW18A, OW20C, and OW21C, as shown on the Monitoring Locations schematic (MHBC Site Plan, Drawing 1 of 5).

- Semi annual water quality sampling for Dissolved Oxygen, Conductivity, pH, and Temperature shall be conducted at the following surface water monitors: North Pond, South Pond, SW1, SW2, SW4, SW5, SW6, SW13, SW14, and SW18, as shown on the Monitoring Locations schematic (MHBC Site Plan, Drawing 1 of 5).
- Semi annual water quality sampling for Dissolved Oxygen, Conductivity, pH, and Temperature shall be conducted subject to landowner permission/access being granted at the following surface water monitors: NAT-18 and NAT-19, as shown on the Monitoring Locations schematic (MHBC Site Plan, Drawing 1 of 5).
- Considering the historical and monitoring data collected within 3 years of extraction extending below the groundwater table, baseline groundwater quality conditions are to be established for OW19, OW23, OW24, OW27, and the four injection wells, as shown on the Monitoring Locations schematic (MHBC Site Plan, Drawing 1 of 5). If water quality results exceed the Ontario Drinking Water Quality Standards (ODWQS), a detailed investigation will be undertaken by a Qualified Hydrogeologist in regards to the potential impacts to local groundwater system. This investigation will include a review of current quarry activities, a review of the on-site groundwater quality, and a review of adjacent property uses. If the ODWQS exceed an ODWQS Maximum Allowable Concentration (MAC) the following actions are to be taken:

    1. A second water sample will be obtained and analyzed.
    2. On confirmation that the water quality exceeds the ODWQS MAC, the MNR and the Township of Melancton will be notified.
    3. A qualified professional will be retained to investigate, make recommendations for changes in the operation and report back to the MNR and the Township of Melancton once the water quality has been improved.

- If a water well complaint is received by the licensee, the following actions shall be taken by the licensee:
    - Notify the MNR and MECP.
    - Ensure a Certified Well Inspector (i.e. licensed water well technician) and/or qualified hydrogeologist visits the site within 24 hours of receiving the complaint to investigate. The Certified Well Inspector and/or hydrogeologist shall complete a well inspection including a review of the pump, well condition, pump depth and condition, etc.
    - Temporary water supply shall be provided by the licensee to the well owner within 48 hours of receiving the complaint and thereafter until such time as the cause of the disruption has been determined.
    - If the well complaint cannot be definitively determined to not be a result of the pit/quarry operations after the initial site visit, a hydrogeologist shall review the water well inspection report and supporting information, water level data and on-going operations at the quarry/pit to provide an assessment of the cause of the complaint. The hydrogeologist shall prepare an opinion letter to be provided to the MNR, MECP, and the complainant as to the likelihood that the well complaint is related to the quarry/pit operation.
    - If the well complaint is considered to be a result of the pit/quarry operations the following water supply restoration program shall be initiated at the expense of the licensee to the satisfaction of MECP:

  - Step 1: Well system rehabilitation: this includes the replacement or lowering of pumps, flushing the pump lines, well deepening, etc.
  - Step 2: Well Replacements: if system rehabilitation is not an option, the well shall be replaced with a new well further from the pit/quarry.
  - Step 3: Water treatment considerations: appropriate water treatment shall be incorporated into any restored water supply.

- The 2:1 backfilled side slope on quarry benches 1 and 3, as shown on the Rehabilitation Plan (Drawing 4 of 5), shall be constructed as a composite berm structure that shall include a sufficiently impermeable (i.e. clay-like) 'core' with a well compacted cohesionless granular shell or outer material comprising of the majority of the side slope backfill. As extraction of the quarry progresses, the 2:1 backfilled side slope shall be constructed, as soon as possible, to follow behind the working face along the quarry limit of extraction to provide a water management barrier during operations.
- Four injection wells shall be constructed along the east property limit behind the water control barrier prior to construction of the acoustic berm in the location as shown on the Operational Plan plan view (MHBC Site Plan, Drawing 2 of 5). Two injection wells shall be drilled into the Guelph formation and two injections wells shall be drilled into the Gasport formation. The Guelph formation and Gasport formation injection wells shall have a minimum total capacity of 5 and 7 L/s, respectively.
- The buried tile drain shall be constructed prior to extraction commencing in Phase 2 of extraction in the location as shown on the Operational Plan plan view (MHBC Site Plan, Drawing 2 of 5). The buried tile drain shall be constructed of perforated tile drain wrapped in filter sock behind the water control barriers along the western face of extraction at an elevation of 488 m asl. The buried tile drain shall be constructed in three segments totalling 1,105 m (minimum) with the north and central segments draining to the injection wells and the south segment draining to the central infiltration pond or injection wells. Water from the buried tile drain shall be conveyed to the injection wells and central infiltration pond through a passive drainage system and/or pumped.
- Inspection ports and control valves shall be incorporated into the buried tile drain and injection well systems so groundwater levels can be monitored, the systems can be inspected and maintained, and for operational flexibility so the water management system can be optimized during operations. The south segment of the buried drain shall be designed to drain to both the central infiltration pond and injection wells to allow additional non-contact water to drain to the injection wells should it be advantageous to do so from an operations and mitigation perspective.
- The infiltration trenches shall be constructed at a 2:1 slope (max). The location of the north infiltration trenches is shown on the Operation Plan (MHBC Site Plan, Drawing 2 of 5).
- The infiltration ponds shall be constructed at 2:1 slopes (max) where the pond walls will be formed by excavating the existing sand and gravel (e.g. permeable materials) and where the impermeable liner will be incorporated, except for the north and west banks of the central infiltration pond which shall be constructed with 3:1 slopes (max) with an impermeable liner. The locations of the central and south infiltration ponds are shown on the Operation Plan (MHBC Site Plan, Drawing 2 of 5).

- The infiltration trench and infiltration pond side slopes shall be protected from erosion with suitable erosion protection measures (e.g. topsoil, hydroseed and erosion control blanket, rip rap, etc.) approved by a geotechnical engineer at the time of trench and pond construction.
- The geotechnical suitability of the on-site till soils shall be confirmed by a geotechnical engineer prior to the construction of the 2:1 side sloping on quarry bench 1 and 3 and for the impermeable liner for the infiltration ponds. The north and west banks of the central and south infiltration ponds shall be constructed with an impermeable liner. If there is not sufficient on-site till soils suitable for this construction, suitable off-site soil shall be imported.
- In Phase Two, 2.0 m of the Ancaster/Niagara Formation is to remain above the Gasport Formation as shown on the maximum depth of extraction on the operational plan. The effects of groundwater uplift are to be confirmed in Phase Two when final depths of extraction are reached by a Professional Engineer utilizing recent water level monitoring data. To support the confirmation of design, a groundwater model update will be undertaken utilizing new water level monitoring data, measured flows and related hydrogeologic insights from the operations. Based on the updated uplift assessment, if groundwater uplift is anticipated, the thickness of the Ancaster/Niagara Formation in the remaining phases shall be increased based on the assessment or pressure relief sumps may need to be constructed within the extraction area. The assessment of groundwater uplift shall be provided to MNR and if required a site plan amendment will be submitted to MNR to implement the recommendations of the assessment.
- In Phase Four, uplift potential within the Cabot Head Formation is not anticipated. When extraction depths are within 2.0 m of the maximum depth of extraction on the operational plan, the effects of groundwater uplift are to be confirmed by a Professional Engineer utilizing recent water level monitoring data. However, if fractures or bulging due to groundwater uplift are observed depressurization sumps or drainage galleries should be constructed within the extraction area
- Water from the quarry sump or clean water pond shall be discharged to the north infiltration trenches, central infiltration pond, south infiltration pond and created wetland as necessary to maintain dry operating conditions in the Quarry and the hydrologic function of the created wetland during extraction. No process water will be discharged from the Quarry directly prior to being treated. There shall be no direct discharge of water off-site. There shall be no discharge of contact water into the injection wells.
- The sump discharge being directed to the infiltration trench and the north and south infiltration ponds will be tested monthly for Total Suspended Solids, ammonia, pH and Oil and Grease. In the event that the water quality exceeds Provincial Water Quality Objectives, the following actions are to be taken:

    1. A second water sample will be obtained and analyzed.
    2. On confirmation that the water quality exceeds PWQO the MNR and the Township of Melancton will be notified.
    3. Monitoring frequency would be increased to weekly for a month, and then a qualified professional is to re-evaluate frequency.
    4. A qualified professional will be retained to investigate, make recommendations for changes in the operation and report back to the MNR and the Township of Melancton once the water quality has been improved.

- During Phase 4 of extraction, a limited portion of the west face of bench 3 as shown on the Rehabilitation Plan plan view (MHBC Site Plan, Drawing 4 of 5). shall be left open (no water control barrier) to allow long-term drainage of the quarry lake into the Gasport aquifer. This portion of the quarry face shall be left open as part of the final rehabilitated landform.
- As part of the final rehabilitation of the site, a 365 m portion of the overburden water control barrier along the east face as shown on the Rehabilitation Plan plan view (MHBC Site Plan, Drawing 4 of 5) shall be removed to allow lateral seepage into the shallow overburden system east of the property.
- As part of final rehabilitation of the site, the north segment of the buried tile drain shall be extended through the west face water control barrier to discharge into the quarry lake.
- As part of final rehabilitation of the site, the buried tile drain, except for the north segment, shall be decommissioned.
- As part of final rehabilitation of the site, the injection wells shall be decommissioned in accordance with O.Reg.903.
- As part of final rehabilitation of the site, the infiltration features (north and south infiltration trenches and central and south infiltration ponds) shall be decommissioned.
- The licensee shall operate in accordance with the Environmental Compliance Approval (ECA) and Permit to Take Water (PTTW) requirements.
- The operation and rehabilitation of this site will not impact a Wellhead Protection Area or a Surface Water Intake Protection Zone and therefore, source water protection policies do not apply for this licence.

10 Conclusions

This Level 2 ARA Impact Assessment presents a detailed comparative evaluation of the effects of the proposed development of the Strada Pit/Quarry. The predicted effects of the development have been systematically evaluated across a range of seasonal and inter-annual (wet and dry year) climate conditions. The predicted effects on groundwater levels are minimal when compared to the extensive available drawdown in the bedrock aquifers. The streams and wetlands may see small changes in flows and levels, but the majority of these changes are likely below what is measurable in the field.

The final rehabilitation plan will restore near-baseline conditions for groundwater flow, streamflow and wetland water budgets and ensure that the final lake will not overflow and create surface water impacts.

At the subwatershed scale, the proposed pit/quarry will not change the overall surface water and groundwater flow system. There will be no cross-watershed impacts, groundwater recharge rates will be preserved, and groundwater and surface water in and around the quarry will continue to flow toward the Pine River Valley. The quality and quantity of groundwater needed for the natural environment and wells will be protected, and no municipal wellhead protection areas will be impacted. The evaluated rehabilitation option preserves the surface water and groundwater system. A comprehensive monitoring and response plan has been developed. The additional available groundwater resources have been quantified, and a well mitigation program has been proposed.

Appendix A and B:
Data Compilation and Methodology

TATHAM ENGINEERING

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EARTHfx INCORPORATED

EARTH SYSTEMS ANALYSIS

Strada Aggregates Proposed

Strada Pit/Quarry

Appendix A: Field Program Methodology

Appendix B: Field Program Data Assessment and Results

Document Control

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	Issue	Date	Description
	1	June 29, 2023	Release 1
	2	Aug. 15, 2024	Release 2
	3	Oct 17, 2024	Release 3
	4	Oct 22, 2024	Release 4

Strada Aggregates Proposed
Strada Pit/Quarry

Appendix A: Field Program Methodology
Appendix B: Field Program Data Assessment and Results

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A. Field Program Methodology

A.1 INTRODUCTION

Strada Aggregates is seeking a license to operate a pit/quarry at the site of their Shelburne pit, located at 437159 4th Line, Shelburne, Ontario. The location of the proposed pit/quarry is shown in Figure A.1. An aerial photograph of the site (Google Maps, 2020), presented in Figure A.2, illustrates local features (e.g., existing gravel operations, farms, wetlands, ponds, and streams) in the vicinity.

To assess the potential impacts of pit/quarry development on groundwater and surface water resources, an understanding of groundwater flow through the underlying overburden and fractured rock environment is required. This is developed through the collection of field data and the development of a site conceptual model. Once a sufficient level of understanding has been developed, the conceptual representation of the fractured bedrock is translated into a mathematical model for the purpose of impact assessment.

Among the data required for this analysis are geologic logs, water levels, estimates of the aquifer and aquitard properties, and other flows and levels that control groundwater flow and groundwater interaction with surface water features.

The purpose of Appendix A is to document the extensive site data that has been collected over the last 16 years at the site. This includes the methodology used to collect new data, including recent core drilling, monitoring and testing to support the new ARA license application.

The purpose of Appendix B is to integrate and summarize site information. For example, rock cores are presented in terms of the latest Ontario Geological Survey nomenclature. Appendix B also presents hydrographs of the water levels and water chemistry present on a piper plot.

The information in Appendix A and B will be interpreted and integrated with additional local and regional data for the purpose of developing a Conceptual Model of the site and surrounding area. The Conceptual Model is presented in Appendix C.

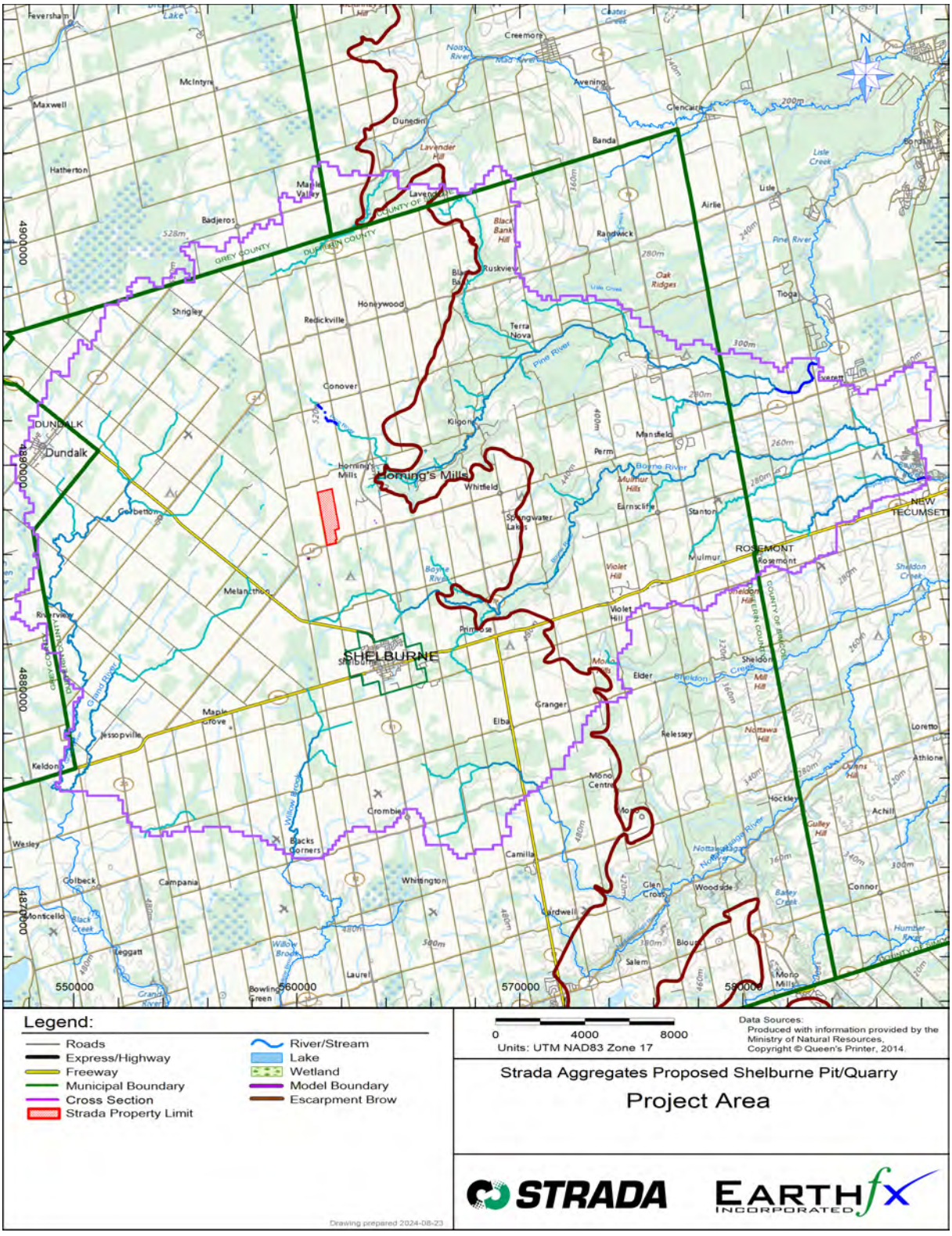


Figure A.1: Location of the proposed Strada Aggregates Shelburne Quarry.

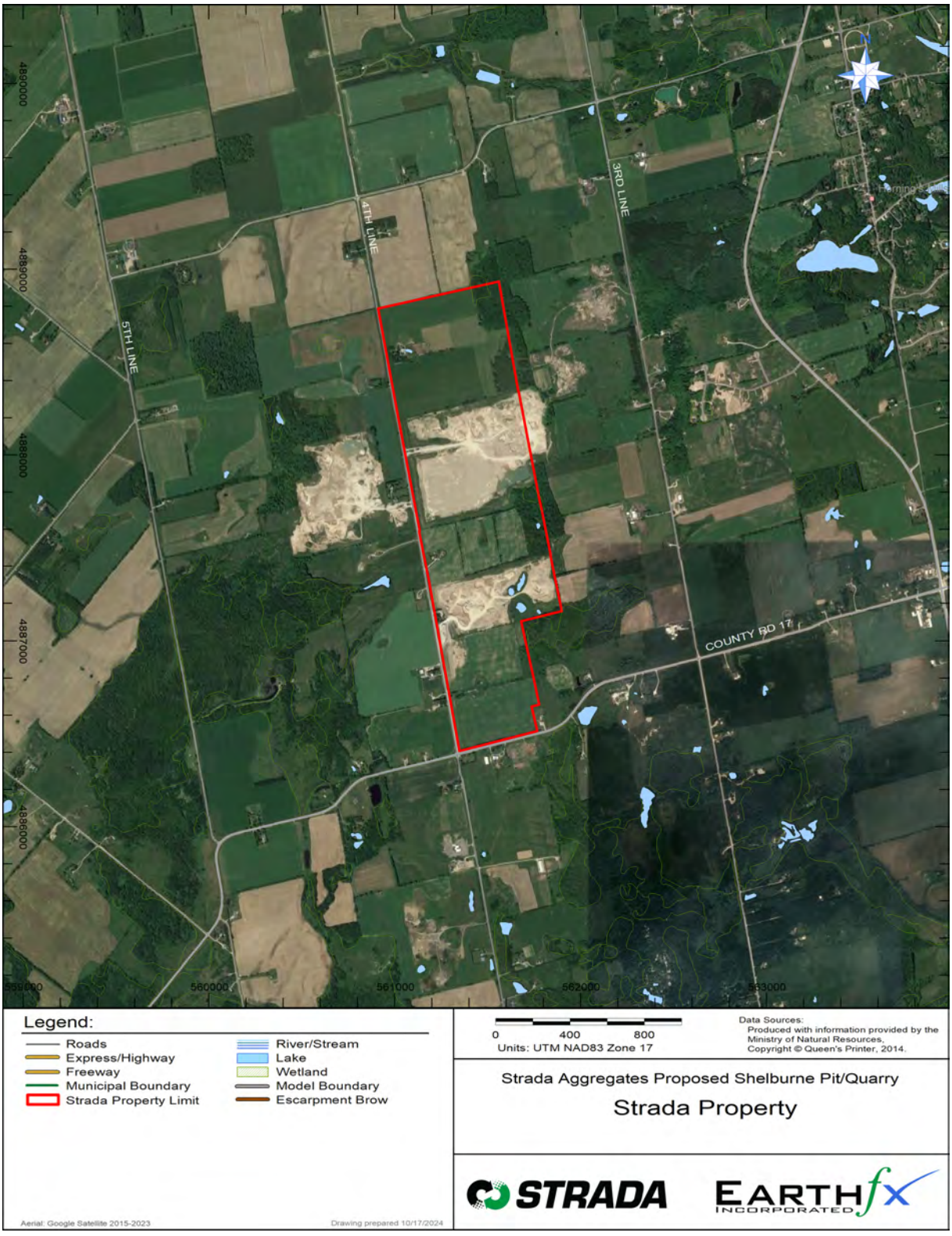


Figure A.2: Aerial photograph showing site setting.

A.2 TOPOGRAPHIC SETTING

A.2.1 Survey Control and Groundwater Monitoring Well Survey

Strada retains FS Survey Solutions to conduct periodic surveys of the site to confirm details such as pit floor elevations and extraction set back distances. During these surveys, the groundwater monitoring wells are also tied in to ensure that measuring point elevations have not changed over time. The measurement points are taken from the top of the steel well casings (TOC). Over time, these casings can settle or shift and some monitors may be removed as extraction progresses. Therefore, for data quality control, these elevations need to be confirmed year to year. The last complete site survey was completed in the fall of 2023.

A.2.2 Ground Surface - Digital Elevation Model

In late September, 2023 the Province of Ontario released detailed LiDAR ground elevation survey data covering the entire Strada study area (CGVD2013 Datum). This information provides extensive high-resolution terrain information that has been incorporated into the project analysis. A map showing the LiDAR data on a local scale is shown in Figure A.3, and in the vicinity of the site is included in Figure A.4.

The borehole and monitoring data at the site has been collected over a 16-year period. Initially, the reporting was divided across three properties, with three annual monitoring reports. In 2017 the 3 annual reports were merged into a singe report, and the monitoring networks were integrated and optimized. As some of the monitoring names were duplicated across the different sites, many monitors needed to be re-named. Further, redundant and destroyed monitors were removed from the active monitoring program. A table containing all borehole and monitor information, including inactive and destroyed monitors, was compiled and is presented in Table A.1.

In the fall of 2023, all accessible boreholes and active monitors were re-surveyed. The elevations in Table A.1 are provided in CGVD2013. The data was surveyed on the CANNET GNSS Network referencing PRS10026721483 referencing station using the Canada Geoid Model HT2_2010v70 (CGVD28). The data was then transformed in Trimble Business Centre using the NAD83 CANADA Molodensky Transformation to the Canadian geoid model CGVD2013A (NDA83). The historic, inactive and destroyed monitors which were unavailable for survey, are reported utilizing historic elevation data.

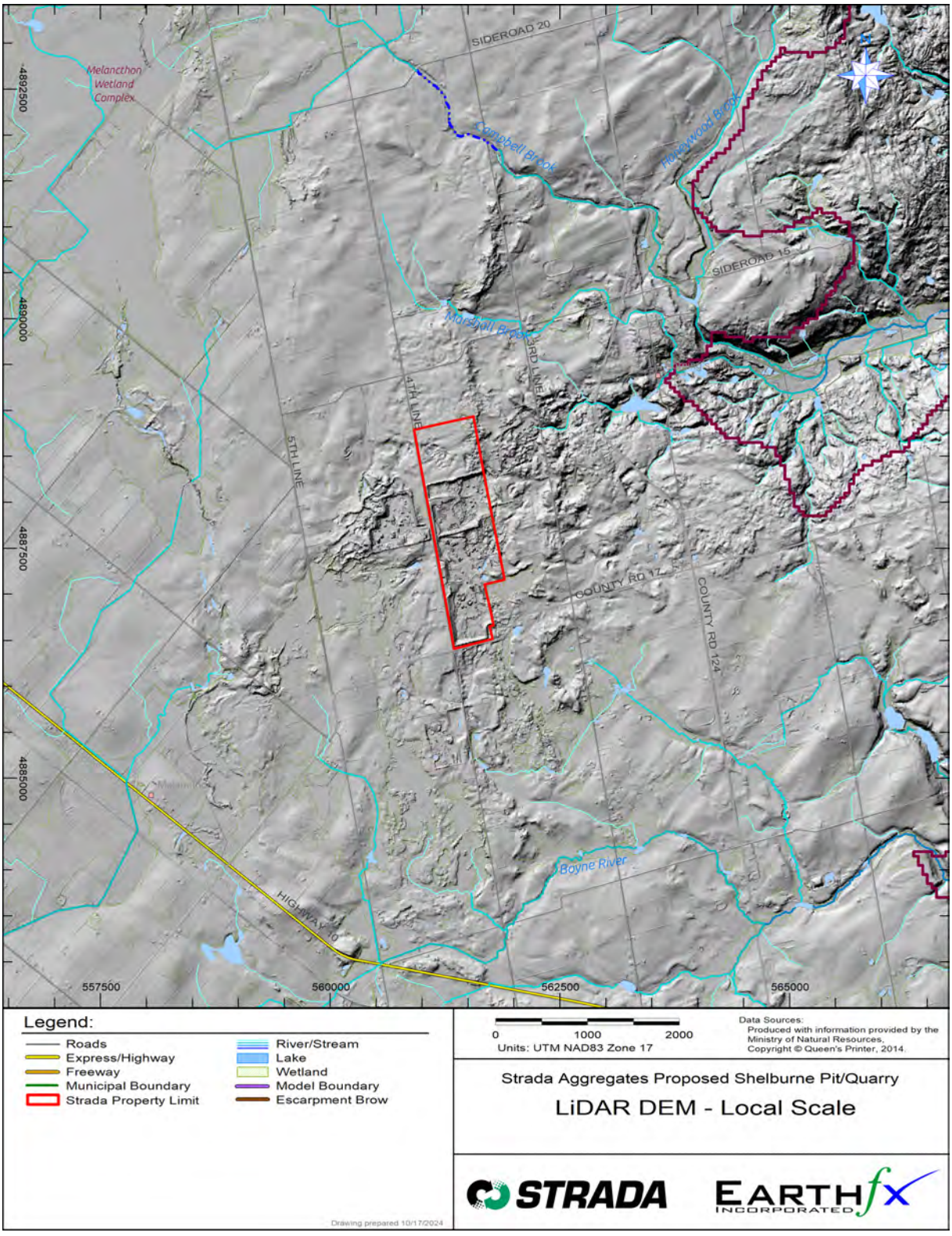


Figure A.3: 2023 Provincial LiDAR Digital Elevation Model (DEM) (masl) for the local area (CGVD2013 Datum).

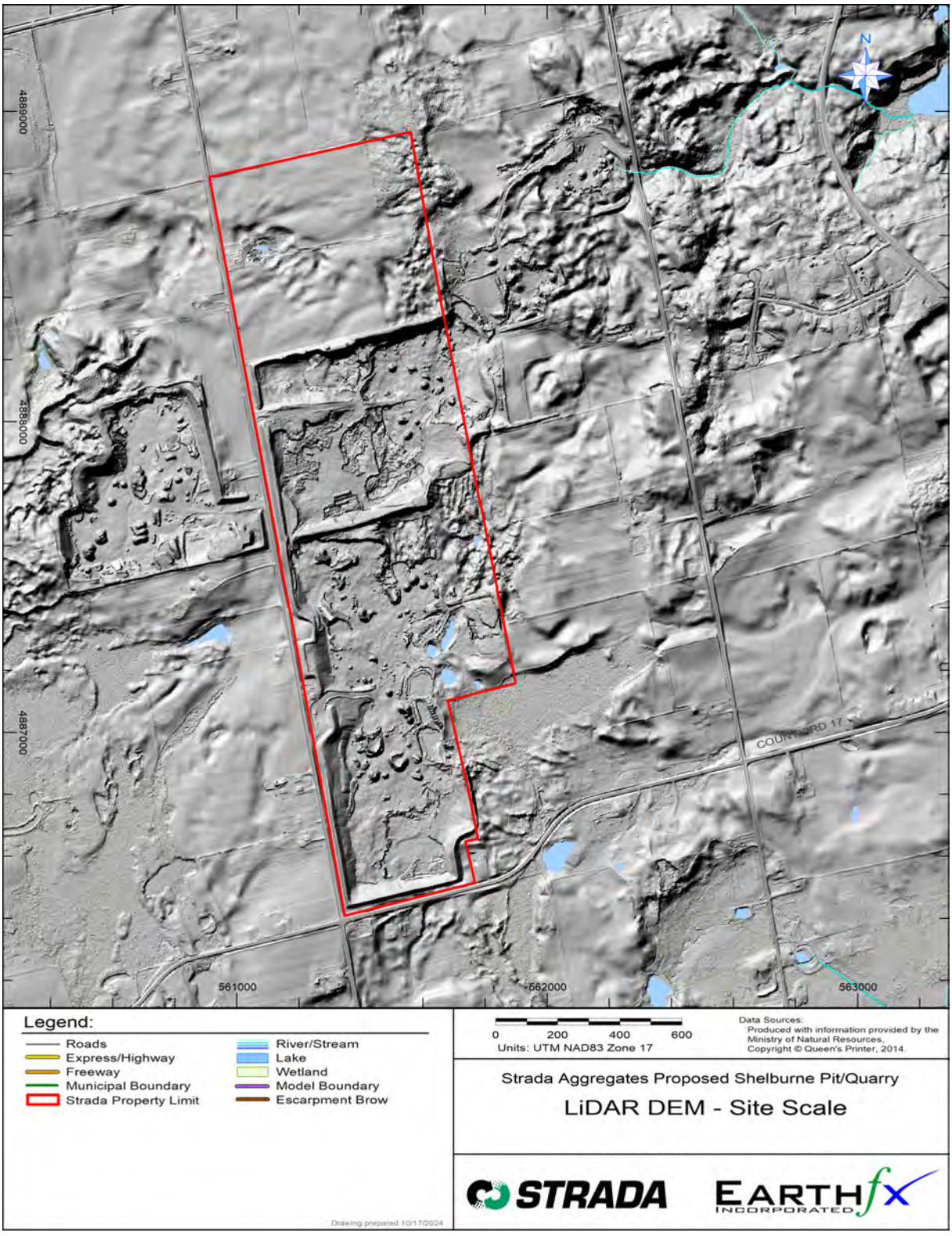


Figure A.4: 2023 Provincial LiDAR Digital Elevation Model (CGVD2013 Datum)- Site Scale

A.3 DRILLING PROGRAM OVERVIEW

The development of the Shelburne property has evolved since the licensing of the North Pit in 2001. Several groundwater monitoring well drilling and coring programs were conducted over that time. The drilling programs were designed to allow for a detailed characterization of the groundwater regimes and to enhance the understanding of the water level responses in the overburden and bedrock aquifer and aquitard systems to rainfall and snowmelt events as well as to overburden removal and pumping. The network has been upgraded and expanded to specifically support the ARA pit/quarry license application.

There is an extensive network of drilling and monitoring wells at the site, including monitor nests, core holes and pumping wells (Table A.1). The current primary monitoring network is shown in Figure A.5. Due to extraction activities, several of these wells are not active at the current time (either destroyed, pulled/decommissioned, or no longer accessible). There are currently 21 active groundwater well nest locations that monitor 41 discrete aquifer/aquitard intervals in the overburden and bedrock aquifers at the property.

In general, monitors labelled with an “A” as suffix are screened at the base of the sand and gravel unit (water table aquifer). Monitors labelled with a “B” are screened at the base of the Tavistock Till (just above the bedrock contact). Monitors labelled with a “C” as suffix are constructed within the bedrock aquifer. Borehole logs for all the monitoring wells are included at the end of this chapter, in Section A.10.2.

Key well data (Well ID, depth, screen setting, etc.) are presented in Table A.1. A summary of the groundwater monitoring data obtained from these wells is provided in Section B.

A.4 PRIVATE WELL MONITORING NETWORK

In addition to the on-site monitoring wells, a series of 5 Domestic Wells have been actively monitored with data loggers since October 2022. These “DW” wells are listed in Table A.1 and are shown as magenta circles on Figure A.6.

In conjunction with NDACT, more than 144 domestic wells (to date) have been added to an active monitoring program. Thes locations have been correlated with public information in the MECP Water Well Record database and are shown as yellow circles in Figure A.6. Well site visits are expected to occur in the spring and summer of 2024.

Figure A.7 shows all well locations in the vicinity of the site in the current modelling database, including MECP well records, private monitoring wells, and high-quality monitoring locations on the Strada site, nearby wellfields, and from other high quality monitoring investigations with extended water level monitoring. The active and high-quality monitoring network extends in all directions from the Strada site and represents an exceptional network of data and monitoring.

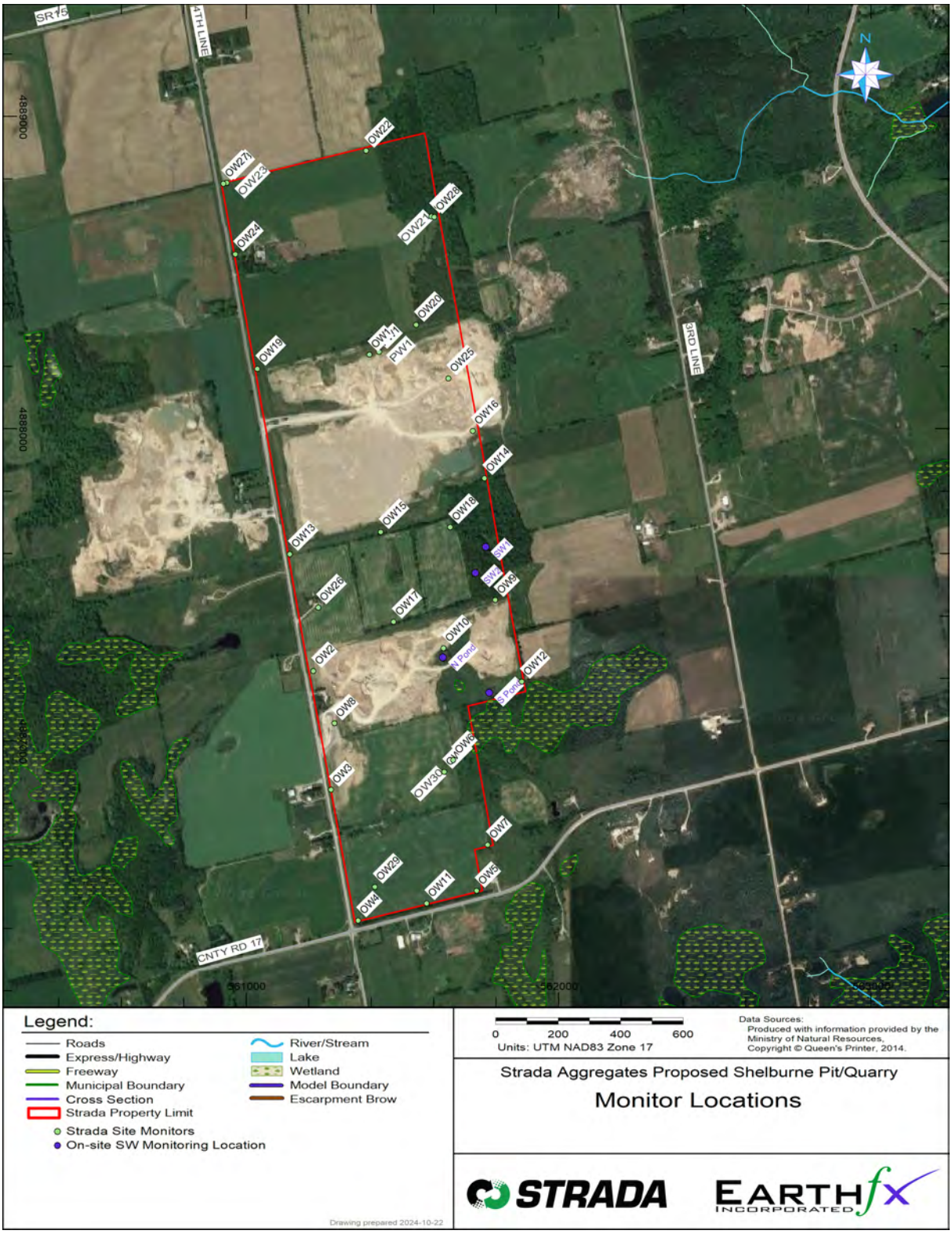


Figure A.5: Groundwater and surface water monitoring locations at the Strada site.

Table A.1: Groundwater Monitoring Well Network

Current Well Nest ID	Current Well Monitor ID	2016 Pit Name	Status[2]	Well Tag Number	MECP ID	Easting	Northing	Survey Elevation (masl)[1]	Stick up (m)	Top of Casing (masl)	Borehole Depth (m)	Borehole Bottom Elevation (masl)	Top Monitor Depth (m)	Bottom Monitor Depth (m)	Top Monitor Elevation (masl)	Bottom Monitor Elevation (masl)
PW1	PW1	PW1	Inactive	A006812	17-06267	561425	4888246	503.37	0.48	503.85	48.76	454.61	20.11	48.76	483.26	454.61
OW1	OW1	OW1	Inactive	A006830	17-06269	561395	4888238	504.12	0.21	504.33	48.76	455.36	18.28	48.76	485.84	455.36
OW2	OW2A-08		Destroyed	A047161	71-06056	561215	4887224	509.69	0.55	510.24	25.60	484.09	7.05	10.10	502.64	499.59
OW2	OW2B-08		Destroyed	A047161	71-06056	561215	4887224	509.69	0.55	510.24	25.60	484.09	22.55	25.60	487.14	484.09
OW2-07	OW2C-07		Destroyed	A049591	70-43351	561218	4887224	509.48	0.64	510.12	72.24	437.24	26.52	72.24	482.96	437.24
OW3	OW3A-08		Dry	A047166	71-06057	561273	4886844	504.47	1.41	505.88	12.80	491.67	2.44	3.96	502.03	500.51
OW3	OW3B-08		Active	A047166	71-06057	561273	4886844	504.47	1.41	505.88	12.80	491.67	9.75	12.80	494.72	491.67
OW3-C	OW3C-07		Active	A049601	70-45010	561271	4886844	504.04	0.37	504.41	15.54	488.50	12.49	15.54	491.55	488.50
OW4	OW4A-08		Active	A047165	71-06048	561355	4886425	505.52	0.63	506.15	13.72	491.80	5.14	7.92	500.38	497.60
OW4	OW4B-08		Active	A047165	71-06048	561355	4886425	505.52	0.63	506.15	13.72	491.80	10.54	13.72	494.98	491.80
OW4-C	OW4C-07		Active	A049604	70-45013	561359	4886425	505.38	0.56	505.94	17.06	488.32	13.41	16.46	491.97	488.92
OW5	OW5A-08		Active	A047164	71-06047	561738	4886523	493.51	0.65	494.16	10.67	482.84	2.50	5.70	491.01	487.81
OW5	OW5B-08		Active	A047164	71-06047	561738	4886523	493.51	0.65	494.16	10.67	482.84	7.00	10.05	486.51	483.46
OW5-C	OW5-C		Active	A049603	70-45012	561738	4886520	493.61	0.69	494.30	13.10	480.51	10.00	13.10	483.61	480.51
OW6	OW6-A		Active	A146152	72-21960	561663	4886939	494.13	0.62	494.75	7.90	486.23	1.80	7.80	492.33	486.33
OW7-A	OW7-A		Active	A146161	72-21961	561771	4886674	497.18	0.64	497.82	10.15	487.03	2.13	10.05	495.05	487.13
OW7-C	OW7-C		Active	A133144	72-21962	561773	4886668	496.98	0.78	497.76	30.60	466.38	18.00	30.60	478.98	466.38
OW8	OW8-A		Active	A172376	72-39322	561282	4887057	504.93	0.94	505.87	12.60	492.33	4.00	12.00	500.93	492.93
OW9	OW9A-08		Dry	A047160	71-06055	561798	4887451	496.51	0.42	496.93	18.59	477.92	3.40	6.40	493.11	490.11
OW9	OW9B-08		Active	A047160	71-06055	561798	4887451	496.51	0.42	496.93	18.59	477.92	15.20	18.20	481.31	478.31
OW10	OW10A-08		Dry	A047162	71-06053	561632	4887297	495.45	0.57	496.02	19.51	475.94	2.00	3.00	493.45	492.45
OW10	OW10B-08		Active	A047162	71-06053	561632	4887297	495.45	0.57	496.02	19.51	475.94	16.00	19.20	479.45	476.25
OW11-A	OW11-A		Destroyed	A133145	72-21963	561574	4886478	494.70	1.20	495.90	16.50	478.20	2.90	8.60	491.80	486.10
OW11-C	OW11-C		Destroyed	A133145	72-21964	561578	4886480	494.80	1.20	496.00	16.50	478.30	13.50	16.50	481.30	478.30
OW12-A	OW12A-08		Active	A047149	71-06054	561882	4887192	495.70	0.87	496.57	7.62	488.08	4.57	7.62	491.13	488.08
OW12-B	OW12B-08		Active	A047149	71-06054	561882	4887190	495.13	0.53	495.66	21.64	473.49	17.98	21.03	477.15	474.10
OW13	OW13-A	MW1A	Active	--	--	561140	4887598	506.78	0.75	507.53	19.00	487.78	11.34	14.34	495.44	492.44
OW13	OW13-C	MW1B	Active	--	--	561140	4887598	506.78	0.75	507.53	19.00	487.78	15.94	18.94	490.84	487.84
OW14	OW14-A	MW2A	Dry	A006815	17-06268	561763	4887841	496.82	1.01	497.83	20.10	476.72	9.60	12.40	487.22	484.42
OW14	OW14-C	MW2B	Active	A006815	17-06268	561763	4887841	496.82	1.01	497.83	20.10	476.72	17.00	20.00	479.82	476.82
OW15	OW15-A	MW5A	Destroyed	A006826	17-06274	561431	4887669	510.48	1.13	511.61	30.80	479.68	18.00	20.50	492.48	489.98
OW15	OW15-C	MW5B	Destroyed	A006826	17-06274	561431	4887669	510.48	1.13	511.61	30.80	479.68	26.87	29.87	483.61	480.61
OW16-A	OW16-A		Active	A115091	71-85600	561726	4887994	497.06	0.56	497.62	11.81	485.25	10.29	11.81	486.77	485.25
OW16-C	OW16-C	MW8B	Active	A115091	71-85600	561726	4887993	497.11	0.56	497.67	27.30	469.81	8.00	27.30	489.11	469.81
OW17	OW17-B		Destroyed	A193020	72-79229	561472	4887382	502.61	1.00	503.61	27.50	475.11	20.40	23.60	482.21	479.01
OW17	OW17-C		Destroyed	A193020	72-79229	561472	4887382	502.61	1.00	503.61	27.50	475.11	24.30	27.50	478.31	475.11
OW18	OW18-A		Active	A193021	72-79230	561653	4887685	501.21	0.66	501.87	23.70	477.51	17.00	19.80	484.21	481.41
OW18	OW18-C		Active	A193021	72-79230	561653	4887685	501.21	0.66	501.87	23.70	477.51	20.40	23.70	480.81	477.51
OW19	OW19-A		Active	A218812	72-88078	561036	4888192	510.32	1.12	511.44	35.50	474.82	11.20	14.40	499.12	495.92
OW19	OW19-C		Active	A218813	72-88079	561036	4888192	510.32	1.12	511.44	35.50	474.82	34.00	35.50	476.32	474.82

Current Well Nest ID	Current Well Monitor ID	2016 Pit Name	Status	Well Tag Number	MECP ID	Easting	Northing	Survey Elevation (masl)[1]	Stick up (m)	Top of Casing (masl)	Borehole Depth (m)	Borehole Bottom Elevation (masl)	Top Monitor Depth (m)	Bottom Monitor Depth (m)	Top Monitor Elevation (masl)	Bottom Monitor Elevation (masl)
OW20	OW20-A		Dry	A218820	72-88077	561544	4888333	509.30	1.18	510.48	26.40	482.90	20.12	21.64	489.18	487.66
OW20	OW20-C		Active	A218819		561544	4888333	509.30	1.18	510.48	26.40	482.90	25.00	26.40	484.30	482.90
OW21	OW21-A		Dry	A218822	72-88038	561593	4888680	511.41	0.95	512.36	25.30	486.11	20.80	22.20	490.61	489.21
OW21	OW21-C		Active	A218823	72-88076	561593	4888680	511.41	0.95	512.36	25.30	486.11	23.60	25.30	487.81	486.11
OW22	OW22-A		Dry	A218821	A-218821	561384	4888890	513.66	1.01	514.67	27.50	486.16	22.80	24.30	490.86	489.36
OW22	OW22-C		Active	A218818	A-218818	561384	4888890	513.66	1.01	514.67	27.50	486.16	26.00	27.50	487.66	486.16
OW23	OW23-A		Dry	A218815	72-88037	560938	4888787	510.31	0.75	511.06	29.50	480.81	18.90	20.40	491.41	489.91
OW23	OW23-C		Active	A218816	72-88036	560938	4888787	510.31	0.75	511.06	29.50	480.81	27.90	29.50	482.41	480.81
Core #3	OW24-H		Inactive	A353622	A-353622	560965	4888558	508.90	0.41	509.31	71.02	437.88	25.00	71.02	483.90	437.88
Core #3	OW24-A		Active	A353622	A-353622	560965	4888558	508.90	0.41	509.31	71.02	437.88	27.52	30.57	481.38	478.33
Core #3	OW24-C		Active	A353622	A-353622	560965	4888558	508.90	0.41	509.31	71.02	437.88	63.64	66.69	445.26	442.21
Core #1	OW25-H		Inactive	A266920	17-04295	561648	4888161	490.62	0.68	491.30	50.47	440.15	4.00	50.47	486.62	440.15
Core #1	OW25-A		Active	A266920	17-04295	561648	4888161	490.62	0.68	491.30	50.47	440.15	16.18	19.23	474.44	471.39
Core #1	OW25-C		Active	A266920	17-04295	561648	4888161	490.62	0.68	491.30	50.47	440.15	43.03	46.08	447.59	444.54
Core #2	OW26-H		Inactive	A353621	A-353621	561231	4887427	499.22	0.40	499.62	62.41	436.81	25.00	62.41	474.22	436.81
Core #2	OW26-A		Active	A353621	A-353621	561231	4887427	499.22	0.40	499.62	62.41	436.81	27.36	30.41	471.86	468.81
Core #2	OW26-C		Active	A353621	A-353621	561231	4887427	499.22	0.40	499.62	62.41	436.81	51.83	54.88	447.39	444.34
OW27-C	OW27-C		Active	A391976	A-391976	560927	4888785	510.26	0.61	510.87	71.88	438.38	68.83	71.88	441.43	438.38
OW28-A	OW28-A		Active	A391975	A-391975	561602	4888675	511.51	1.05	512.56	37.18	474.33	34.13	37.18	477.38	474.33
OW28-C	OW28-C		Active	A391972	A-391972	561602	4888678	510.98	0.35	511.33	67.59	443.39	64.54	67.59	446.44	443.39
OW29-A	OW29-A		Active	A391974	A-391974	561413	4886532	499.80	0.98	500.78	25.96	473.84	22.91	25.96	476.89	473.84
OW29-C	OW29-C		Active	A391973	A-391973	561412	4886533	499.90	0.93	500.83	62.76	437.14	59.71	62.76	440.19	437.14
OW30	OW30-C		Active	A374686	A-374686	561634	4886901	494.35	0.60	494.95	56.62	437.73	53.57	56.62	440.78	437.73
Legacy wells included in compliance reports dating back to 2007. Ground elevation does not correspond to LiDAR nor to the most current survey but to elevations taken from compliance reports.																
MW3	MW3A-04	MW3A	Dry	A006796	17-06273	561740	4887987	508.33	0.70	509.03	22.86	485.47	23.39	26.43	484.94	481.90
MW3	MW3B-04	MW3B	Dry	A006796	17-06273	561740	4887987	508.33	0.70	509.03	22.86	485.47	29.18	32.23	479.15	476.10
MW4	MW4A-04	MW4A	Destroyed	A006827	17-06272	561230	4888243	510.28	0.91	511.19	24.07	486.21	13.64	16.40	496.64	493.88
MW4	MW4B-04	MW4B	Dry	A006827	17-06272	561230	4888243	510.28	0.91	511.19	24.07	486.21	18.53	21.58	491.75	488.70
MW7	MW7A-07		Destroyed	A047147	71-06065	561284	4887645	507.00	--	--	18.28	--	4.20	7.25	502.80	499.75
MW7	MW7B-07		Destroyed	A047147	71-06065	561284	4887645	507.00	--	--	18.28	--	14.26	17.31	492.74	489.69
MW9	MW9-A	MW9A	Destroyed	A115096	71-85598	561634	4887857	498.35	--	--	8.23	--	1.46	4.51	496.89	493.84
MW9	MW9-B	MW9B	Destroyed	A115096	71-85598	561634	4887857	498.35	--	--	8.23	--	4.81	7.86	493.54	490.49
MW10	MW10-A	MW10A	Destroyed	A115117	71-78110	561271	4887681	500.63	0.80	501.43	10.80	489.83	4.13	6.13	496.50	494.50
MW10	MW10-B	MW10B	Destroyed	A115117	71-78110	561271	4887681	500.63	0.80	501.43	10.80	489.83	7.63	10.43	493.00	490.20
Domestic wells currently involved in the Target Participation Area (TPA) for long-term monitoring. Elevation obtained from Provincial LiDAR coverage.																
DW1	DW1		Active	A000438	17-06362	562951	4886286	479.67	--	--	11.60	--	--	--	--	--
DW2	DW2		Active	A104771	71-99024	562704	4888248	482.36	--	--	44.80	--	--	--	--	--
DW3	DW3		Active	--	--	562373	4887677	493.92	--	--	--	--	--	--	--	--
DW4	DW4		Active	A051672	71-22047	562197	4890008	486.02	--	--	24.40	--	--	--	--	--
DW5	DW5		Active	--	--	559538	4889095	517.26	--	--	--	--	--	--	--	--

Notes: [1] Originally surveyed on the vertical datum CGVD28, then converted to CGVD13 using the Canada Geoid Model HT2_2010v70 (CGVD28), and the NAD83 Canada Molodensky Transformation.

[2] The ground elevations of destroyed monitoring locations were assumed to be in the CGVD28 datum and a gross conversion factor of (0.37m) was applied to the original elevations.

[3] (-H) Suffix refers to initial open hole condition at the borehole. A water level timeseries was measured during this period and labeled -H as well.

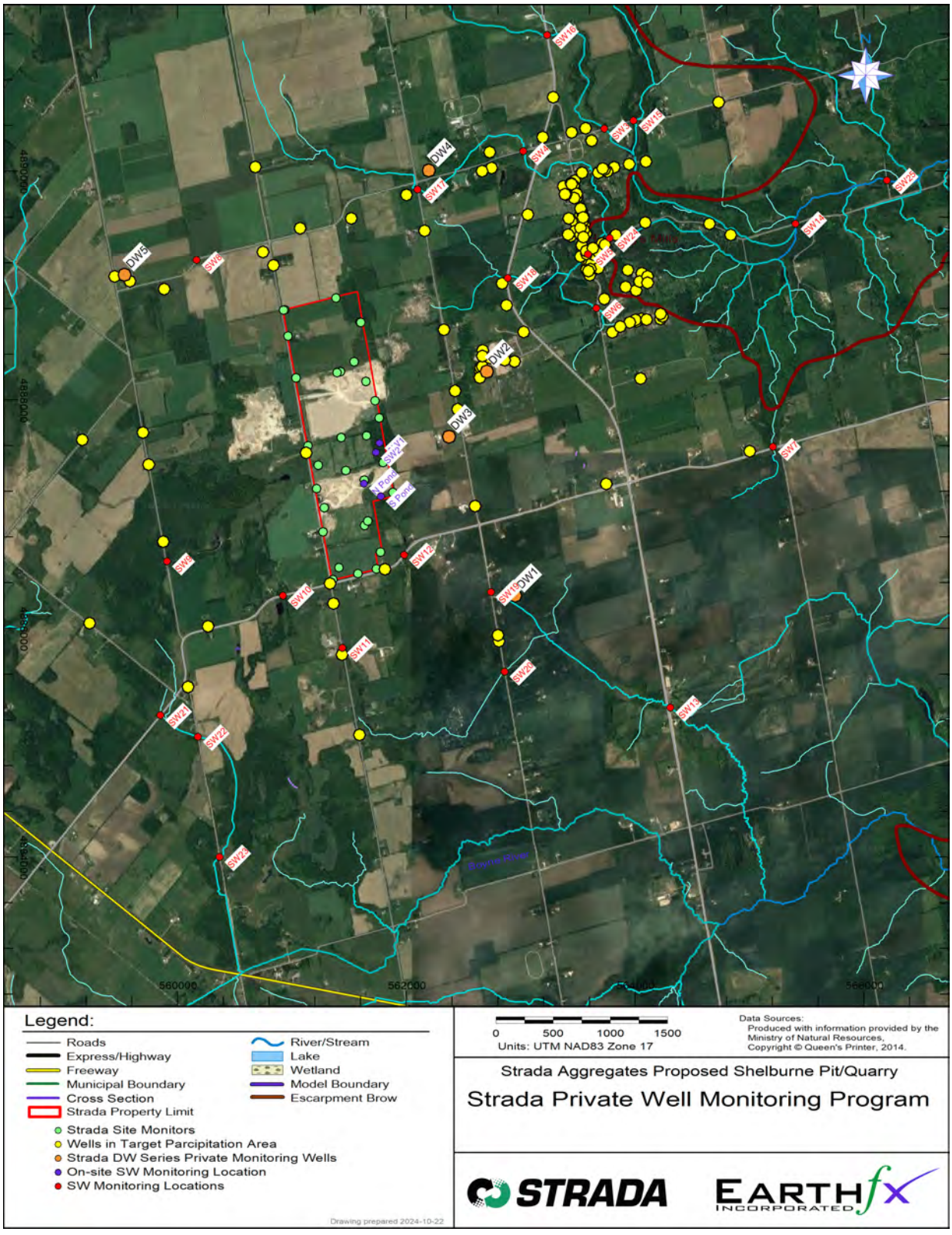


Figure A.6: Location of domestic (DW) monitoring wells and Private Monitoring Network

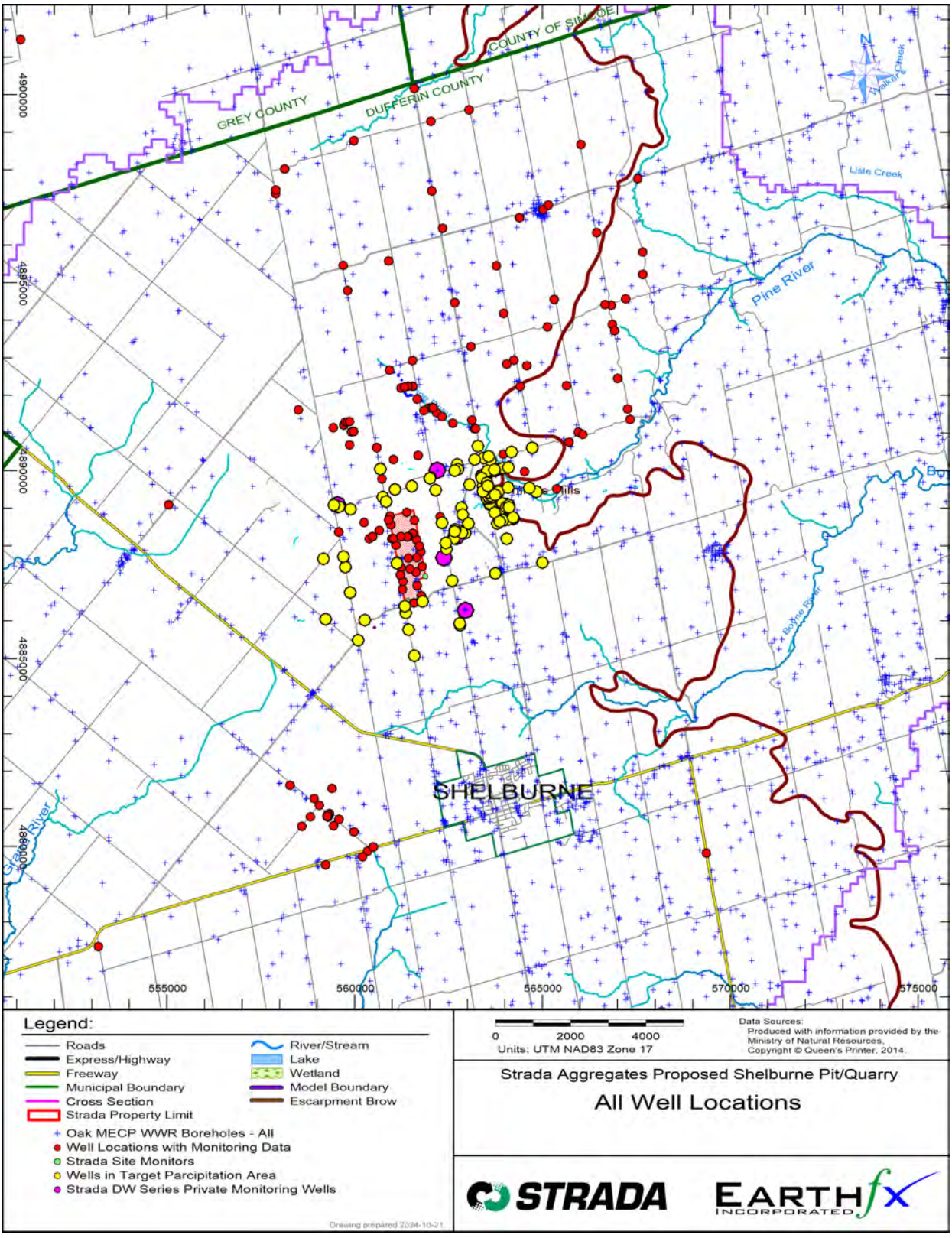


Figure A.7: All Well Locations

A.5 BEDROCK STRATIGRAPHY AND ROCK QUALITY ANALYSIS

In addition to the long-term monitoring network, seven fully-cored boreholes have been drilled at the site. Core samples were collected for more detailed geologic, hydrogeologic, and rock property analysis. The boreholes were drilled through the entire dolostone unit, down to the underlying shale unit. The core was photographed, logged based on visual characteristics, and samples were submitted for physical testing. Core logging details are included at the end of this chapter, in A.10.1.

These core data have been used to confirm the bedrock stratigraphy and corresponding quality of the dolostone beneath the site. These core holes have been evaluated using the most up to date geologic and hydrogeologic conceptual models developed by the OGS and University of Guelph G360 research groups.

To aid in the development of the operations plan, an understanding of the aggregate quality was required. OW25C (Core #1) was sent to PNJ Engineering in 2020 and OW26C (Core #2) and OW24C (Core #3) were sent to AME in 2022. Results confirmed that the rock material is of high quality and meets or is likely to meet the physical requirements of CSA and MTO for concrete aggregate and of MTO asphalt aggregate.

A.6 HYDRAULIC TESTING PROGRAM

A.6.1 On-Site Pumping Tests

Two on-site aquifer tests (pumping tests) were completed. The first aquifer test was conducted by Goffco Limited in November 2004 to support a Permit to Take Water for the washing of aggregate (Goffco, 2005). The second aquifer test was conducted in May 2007 at location OW2-07 to support an Aggregate Resources Act application for the pit expansion. Testing was done at two locations: PW1 and OW2 (Goffco, 2007). Both on-site and off-site pump test data and test details are presented together in Appendix C.

A.6.2 On-site Pumping Operations

A pumping well was operated on-site between 2007 and 2012. Water levels were recorded in nearby monitoring wells, providing hydraulic information across a range of seasonal and inter-annual climatic conditions. Together with the on-site pumping tests, this long-term pumping provides very useful information on the hydrogeologic characteristics of the bedrock and overburden units across a range of seasonal and interannual climate conditions. Of particular note is the recorded response to the periodic shutdown, well recovery, and restart of the pumping well.

A.6.3 On-Site Lugeon/Packer Testing

Detailed hydraulic testing was completed using the Lugeon testing methodology (Lugeon, 1933) in the three open core holes (OW24, OW25, and OW26, or Core #2, Core #1, and Core #3, respectively) (Figure A.5). The Lugeon test is an in-situ packer testing methodology widely used to estimate the average hydraulic conductivity of rock mass. The Lugeon test is a type of constant head permeability test carried out in a portion of a borehole isolated by pneumatic packers. Water is injected at multiple pressures. Analysis of the test results provides information about hydraulic conductivity of the rock mass including the rock matrix and fractures. A detailed discussion of the test procedure, interpretation of results and applications is presented in Quiñones-Rozo, 2010. The relationship between Lugeon results and hydraulic conductivity is presented in Table A.2.

This length of test zone depends on the expected fracture spacing with depth. Too short of an interval leads to an unnecessarily large number of tests, while too long of an interval would prevent identifying specific transmissivity zones within the boreholes. For these tests, the separation between the two rubber packers was set at 1 m. To ensure full coverage of the borehole, the packer system was only raised 0.9 m before another test event was conducted; thereby yielding a 0.3 m overlap. The packer testing completely covered the entire length of the open borehole.

The test was carried out at five stages including increasing and decreasing pressure between zero and maximum pressure. At each stage, a constant pressure was applied for an interval of 5 minutes while pumping. Flow rates were recorded and analyzed as described below.

The average hydraulic conductivity of the rock mass can be determined using the average values of water pressure and flow rate measured at each stage. Hydraulic conductivity is expressed in terms of Lugeon units. A Lugeon value is defined as the loss of water (in L/min/m) at an overpressure of 1 mPa. The Lugeon value for each test is calculated as:

$$L = \frac{10\,Q}{P}$$

L = Lugeon Value
Q = water taken in the test (L/m/min)
P = Test Pressure (bars)
10 as correction for standard test pressure of 10 bar

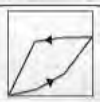
Assuming homogenous and isotropic conditions, one Lugeon will be equal to 1.3×10^{-7} m/s. The hydraulic conductivity of the rock mass is influenced by both the bulk matrix and rock discontinuities (fractures). Therefore, the Lugeon value represents not only the matrix conductivity but also the rock jointing condition. The following table (Table A.2) describes the conditions regarding the rock discontinuities typically associated with different Lugeon Values (Quiñones-Rozo, 2010). (To better understand the reporting ranges and precision please refer to the more detailed table 2 in Quiñones-Rozo, 2010).

Table A.2: Lugeon Values vs. Hydraulic Conductivity (after Quiñones-Rozo, 2010).

LUGEON RANGE	CLASSIFICATION	HYDRAULIC CONDUCTIVITY RANGE (CM/SEC)	CONDITION OF ROCK MASS DISCONTINUITIES
<1	Very Low	$<1x10^{-7}$	Very Tight
1-5	Low	$1x10^{-7} – 6x10^{-7}$	Tight
5-15	Moderate	$6x10^{-7} – 2x10^{-6}$	Few Partly Open
15-35[1]	Medium	$2x10^{-6} – 6x10^{-6}$	Some Open
35-100[1]	High	$6x10^{-6} – 1x10^{-5}$	Many Open
>100	Very High	$>1x10^{-5}$	Open with Closely Spaced or Voids

1. Note: A gap between 20 and 50 exists in the original table reported in Quiñones-Rozo, 2010. The boundary has been estimated

Flow conditions within the borehole interval can also be assessed based on the Lugeon pattern when pressure steps are plotted against the Lugeon value (Houlsby, 1976).

Behaviour	Lugeon Pattern	Flow vs. Pressure Pattern	Representative Lugeon Value
Laminar Flow			Average of Lugeon values for all steps
Turbulent Flow			Lugeon value corresponding to the highest water pressure (3rd step)
Dilation			Lowest Lugeon value recorded, corresponding either to low or medium water pressures (1st, 2nd, 4th, 5th step)
Wash-out			Highest Lugeon value recorded (5th step)
Void Filling			Final Lugeon value (5th step)

- Laminar Flow: The hydraulic conductivity of the rock mass is independent of the water pressure employed. This behavior is characteristic of rock masses with low hydraulic conductivities, where seepage velocities are relatively small (i.e., less than 4 Lugeons).
- Turbulent Flow: The hydraulic conductivity of the rock mass decreases as the water pressure increases. This behavior is characteristic of rock masses exhibiting partly open to moderately wide cracks.
- Dilation: Similar hydraulic conductivities are observed at low and medium pressures; however, a much greater value is recorded at the maximum pressure. This behavior – which is sometimes also observed at medium pressures – occurs when the water pressure applied is greater than the minimum principal stress of the rock mass, thus causing a temporary dilatancy (hydro-jacking) of the

fractures within the rock mass. Dilatancy causes an increase in the cross-sectional area available for water to flow, and thereby temporarily increases the hydraulic conductivity. The smallest test value is more representative of the rock properties than the average value in these cases.

- Wash-Out: Hydraulic conductivities increase as the test proceeds, regardless of the changes observed in water pressure. This behavior indicates that seepage induces permanent and irrecoverable damage on the rock mass, usually due to wash out of material infilling the fractures and/or permanent rock movements.
- Void Filling: Hydraulic conductivities decrease as the test proceeds, regardless of the changes observed in water pressure. This behavior indicates that either (a) water progressively fills isolated/non-persistent discontinuities; (b) swelling occurs in the discontinuities, or (c) fine material flows slowly into the discontinuities building up a cake layer that clogs them.

The results and interpretation of the Lugeon testing completed at the site is presented in the next section of the report.

A.6.4 Off-Site Aquifer Testing Programs

Considerable additional hydraulic and pumping test information is available in the area. A summary of these test programs is provided below. Further presentation and discussion of the key data is covered in Appendix C (Conceptual Model) and use in model calibration is covered in Appendix D (Model Development and Calibration). (While the test results are discussed in those appendices, the reader should refer to the detailed test data, borehole logs and monitor details in the original technical reports as necessary.)

Highland Group of Companies

In 2011, the Highland Group of Companies submitted an ARA application for the lands located on Part of Lots 18 to 23 in Concession 1OS Part of Lots 18 and 19 in Concession 2OS, Part of Lots 17 to 21 in Concession 3OS, Part of original road allowance between Lots 20 and 21, Concession 3OS, and Part of Lots 16 to 19 in Concession 4OS in the Township of Melancthon, Dufferin County (located immediately north of the proposed Strada Quarry).

Although this application was withdrawn, a considerable volume of hydrogeological data was obtained from the field testing programs and remained available to the public (Genivar, 2011). These data have been reviewed and incorporated into the site conceptualization, including but not limited to packer tests, slug tests, step test, and long-term aquifer testing. The assessment of the data allowed for an improved understanding of the Highland site hydrostratigraphy, and was incorporated into the development of the regional-scale conceptual and numerical models.

As part of the aquifer characterization program, Genivar (2011) completed:

- packer tests at 20 locations through the bedrock profile.
- 37 slug (in-situ) tests within the overburden as well as within the upper and lower bedrock
- 16 step-tests on production wells drilled into the bedrock (open-hole tests).
- 5 long-term constant pumping tests were completed.

Bonnefield Financial (Formerly Downey Farms)

Following the withdrawal of the Highland Group of Companies ARA application, the lands were sold to Bonnefield Financial, an asset management firm. With the lands under new ownership, Bonnefield secured a PTTW for two production wells on the property for crop irrigation. To support the PTTW application, the two irrigation wells were tested to assess the hydraulic characteristics of the bedrock aquifer and sustainable well yield (Whitewater, 2013). The PTTW was issued in 2014; and the daily operation of the production wells and the influence they have had on the groundwater regime since that time has been well documented. This information is presented and discussed in the model development and calibration report section of this application.

Town of Shelburne Wellfield Expansion

The Town of Shelburne completed drilling, pumping tests, and numerical modelling to delineate the wellhead protection areas (WHPA) for an expansion of the wellfield to the west of town (Earthfx, 2022). The results of testing of Wells 7 and 8 and the WHPA analyses are discussed in the model development and calibration portion of the application.

A.7 HYDROGEOCHEMICAL TESTING

A.7.1 Water Quality Monitoring

Groundwater quality monitoring commenced in 2002 and has evolved with the site development. Sampling began with the collection of three samples annually in 2002 and has grown to the current program which commenced in 2018. The program includes collection of 27 samples twice a year for general water quality and 13 samples annually for Petroleum Hydrocarbons (PHCs). Over the course of this monitoring period, more than 380 general water quality groundwater samples have collected, analyzed, and used to characterize the overburden and bedrock aquifer. An additional 146 groundwater samples have been analyzed for PHC.

In addition to the on-site groundwater quality monitoring program, the five domestic water wells were incorporated into the program in 2022 and similarly groundwater samples are collected twice a year for general water quality parameters.

A.7.2 Hydrochemical Assessment

The major ions in groundwater are sodium, magnesium, calcium, chloride, bicarbonate, and sulphate. The total concentration of these six major ions normally comprises more than 90 % of the total dissolved solids in groundwater. The chemical signature of water begins to change as it dissolves aquifer material and transitions from oxidized to reducing conditions along the flow path from areas of groundwater recharge to areas of groundwater discharge. The dominant ion concentrations in the groundwater correlate with distance along the flow path and residence time or age of the groundwater.

Piper diagrams (Piper, 1944) aid in the chemical characterization of groundwater and provide insight on the hydrochemical processes, which are influenced by rates of dissolution of minerals, oxidation/reduction, cation and anion exchanges, and mixing. The Piper diagram helps in the segregation of analytical data necessary for the characterization of the water type, and can help identify aquifer recharge areas, aquifer flow processes, and the degree of hydraulic connection between neighbouring aquifer units.

Groundwater samples from each monitoring interval have been characterized based on the major ion concentrations (expressed in milliequivalents per litre (meq/L)) based on the average reported concentrations. Results of the analysis are presented and discussed Section B.

A.8 WATER USE ASSESSMENT

A.8.1 Permit to Take Water Review

The existing extraction of groundwater or surface water from within the study area is an important component in establishing baseline conditions. A compilation of the permitted water use has been completed for all water takings from within 5 km of the proposed Strada Quarry. A summary of these water takings is provided in Table A.3. Water use will be discussed in more detail in Appendix C and D.

Table A.3: PTTW Summary

PTTW NO.	PURPOSE	SOURCE	MAX DAILY TAKING (M^3)	DAYS PER YEAR
6653-A7BND2	Agricultural: Field / Pasture Crops	Groundwater • PW1 • PW2 • Irrigation Pond	 3,273 2,304 8,100	 60 60 48
7121-9Y7HP7	Commercial: Aquaculture	Surface Water / Groundwater • Springs • Pine River #1 • Pine River #2	 179 65 216	 180 365 365
3210-AKRL9C	Industrial: Aggregate Washing (Strada)	Groundwater • Wash Pond	 2400	 230

A.9 WATER LEVEL MONITORING

A.9.1 On-site Water Level Monitoring

There are currently 22 groundwater well nests that monitor 30 discrete aquifer intervals in the overburden and bedrock aquifers at the site (Table A.1, and Figure A.5). The groundwater monitoring network has evolved since the Strada Site began operations in Melancthon in 2002 with the number and location of wells and sampling frequency changing over time. As mentioned earlier, several wells have been destroyed, pulled, or replaced. This has resulted in a water level database that contains focused datasets spanning a considerable time period. This includes two key sub-periods, an early period where well pumping was used for onsite wash-water use, and a later time period where wash water was derived from on-site ponds. Each of these time periods provide useful insight into the site conditions and local

hydrogeologic response. The early period also coincides with the extensive monitoring undertaken to support the Highland quarry application. An integrated interpretation of the water level data is presented in the model development and calibration report.

A.9.2 Private Water Wells

A component of the field program included a Private Water Well Survey which was completed for all properties located within 1 kilometre (km) from the site. The objective of the survey was three-fold:

1. to provide an opportunity for the residents to ask freely any questions they may have regarding the hydrogeologic assessment and proposed quarry operations.
2. to collect information from the residents about their well and their water supply. Specifically, the well Ministry of the Environment, Conservation and Parks (MECP) tag ID, well depth, drill date, and if they have had historical issues with the groundwater quality or quantity. This information assisted in matching the well to a water well record that may be on file with the MECP.
3. to obtain permission to monitor their well for both groundwater quality and water levels. If permission was granted, this allowed for the documentation of existing conditions of the water supply. The purpose was to document baseline conditions should the resident experience issues with either the groundwater quality or quantity at some time in the future should rock extraction take place.

The survey commenced in September 2022, and involved a door-to-door visit to each property located within 1 km of the proposed Strada Quarry. Of the 24 properties visited, 5 residents who had accessible wells agreed to participate in the monitoring program (at the time of this reporting).

There are plans to expand and revisit the private well survey based on new agreements that have been reached with NDACT.

A.9.3 Off-Site Water Level Monitoring

There are currently 5 domestic water wells which are currently monitored as part of the on-going groundwater monitoring program (Table A.1, and 6). The off-site domestic water well monitoring program started in 2022.

Section A.6.4. summarizes a number of local hydrogeological studies that provide useful geologic and aquifer characterization information outside of the site vicinity. Water level monitoring data from those sites have been compiled and used in the model development and calibration process.

A.9.4 Surface Water Monitoring

A surface water monitoring program has been developed and implemented to establish existing baseline conditions for the surface water features on-site and in the surrounding area. The surface water program includes the monitoring of streamflow, wetland hydroperiod, and shallow groundwater levels. In 2024, baseflow was measured at 13 locations at two points in time (spring and summer).

The surface water monitoring has been carried out to monitor streamflow, water quality, wetland hydroperiods and surface and groundwater interactions in order to establish baseline conditions.

Surface water level monitoring has been historically carried out during unfrozen periods as part of the on-going compliance monitoring program. The surface water monitoring program consists of water level monitoring. The on-site surface water monitoring locations are shown on Figure A.5 enclosed. Details are provided in Table 5.

Table A.4: Surface Water Level Monitoring Network

Monitoring Location	Location
North Pond	17T 4887268N, 561630E
South Pond	17T 4887155N, 561778E
SW1 (Wetland)	17T 4887622N, 561767E
SW2 (Vernal Pool)	17T 4887538N, 561734E

A continuously recording pressure transducer measuring water level and water temperature has been installed in a drive point well in each wetland and pond location. Manual in-situ water level measurements are collected monthly at each shallow groundwater monitoring location. The field measurements are used to calibrate the continuously recording pressure transducer data.

Baseline streamflow monitoring has been initiated in 2024. Baseline streamflow monitoring was carried out in May and August 2024 at 13 locations. Details are provided in Table A.5.

Table A.5: Streamflow Monitoring Network

Monitoring Location	Location
SW3	17T 4890372N, 563730E
SW4	17T 4890176N, 563023E
SW5	17T 4889273N, 563588E
SW6	17T 4888803N, 563662E
SW7	17T 4887588N, 565205E
SW8	17T 4889224N, 560167E
SW9	17T 4886586N, 559909E
SW10	17T 4886286N, 560921E
SW11	17T 4885828N, 561440E
SW12	17T 4886643N, 561981E
SW13	17T 4885308N, 564308E
SW14	17T 4889540N, 565402E
SW15	17T 4890444N, 563986E
SW16	17T 4891192N, 563232E
SW17	17T 4889841N, 562098E
SW18	17T 4889066N, 562888E
SW19	17T 4886317N, 562739E
SW20	17T 4885622N, 562859E
SW21	17T 4885241N, 559850E
SW22	17T 4885052N, 560178E
SW23	17T 4884000N, 560368E
SW24	17T 4889416N, 563777E
SW25	17T4889920N, 566202E

A.10 BOREHOLE LOGS

A.10.1 Borehole Logs: Cored Boreholes

Detailed rock core was collected at seven locations across the site. The formation units, nomenclature and interpretation are discussed in more detail in the following report sections and appendices. Core hole locations are shown in Figure A.5, and Summary logs, core photo logs and detailed description tables are presented below in Figure A.8 through Figure A.21.

The core was laid out in a top-to-bottom core box presentation and high-resolution photographs were captured. OW25C (Core #1) was sampled for rock quality analysis prior to photo log collection so it incorrectly *appears* that core recovery is low. OW24C, and OW26C through OW30C were photographed prior to rock quality sampling and show that core recovery exceeded 95%.

Detailed logging and interpretation of the rock core was completed by Chris Rogers and Dirk Kassenaar. The geological nomenclature of OW26C (Core #2) was further reviewed and confirmed by Dr. Frank Brunton of the Ontario Geological Survey in October 2022.

Deep monitoring well screens (“C” series monitors) were installed in each of the cored boreholes providing information in the deep groundwater levels across the site.

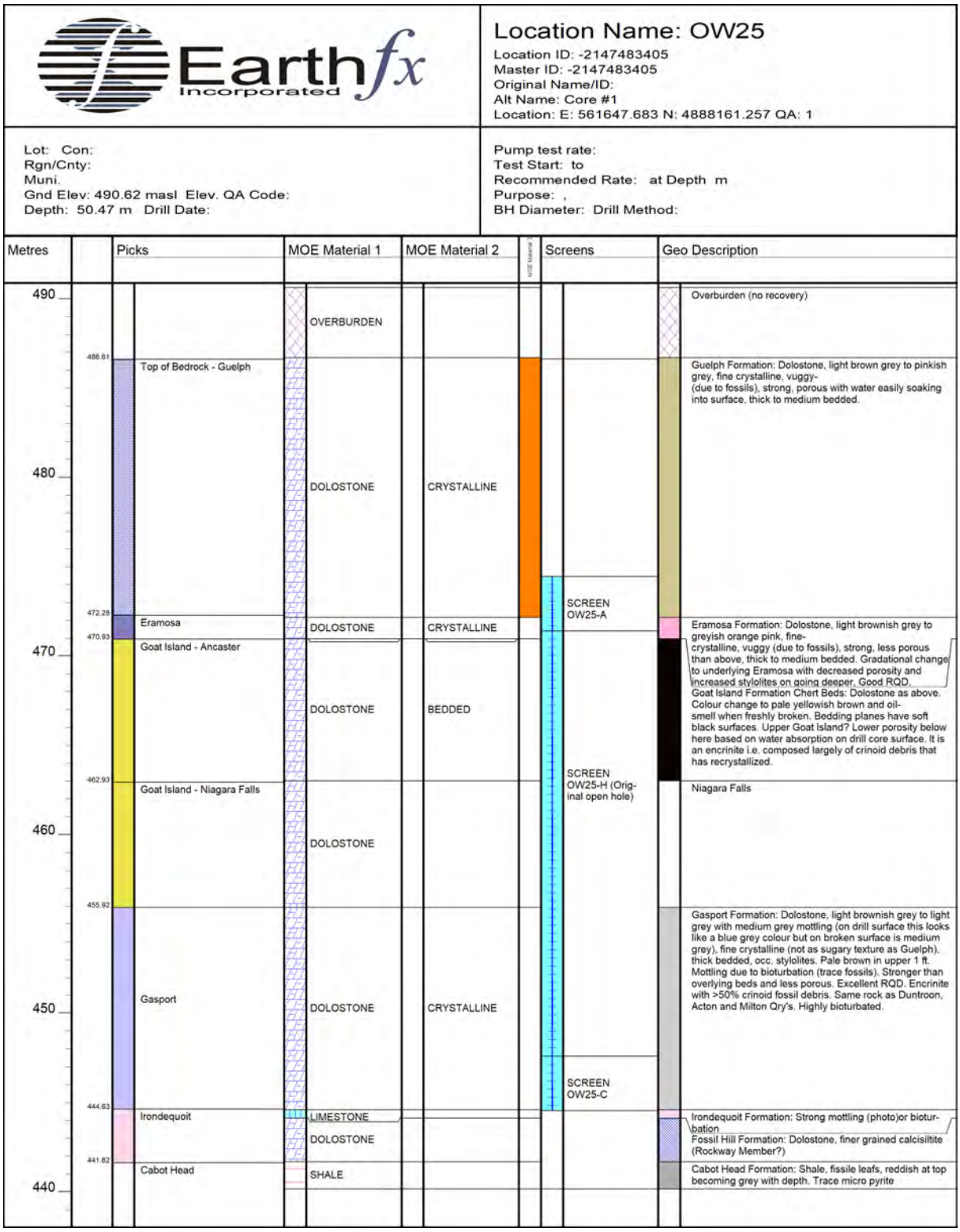


Figure A.8: Borehole Log–- OW25C – Core #1.



Figure A.9: Core Image: OW25C–- Core #1.

Table A.6: Detailed Core Description OW25C–- Core #1.

Diamond Drill Hole, Feb 2020. Logged Jan 2022.

Box No	Depth	Geological Nomenclature	Description	Features and comments
1	0-12'10"	= 3.90 m	No recovery - overburden?	Formations of Lockport Group of Silurian Age ex Cabot Head
	12'10"	Guelph Formation	Probable top of bedrock	Core removed for testing
	14'9"		Start of rock core. Dolostone, light brown grey to pinkish grey, fine crystalline, vuggy (due to fossils), strong, porous with water easily soaking into surface, thick to medium bedded.	Dolomite crystals show saccharoidal (sugary) texture, size about 0.1mm (majority of crystals all about same size). Good RQD (most pieces > 100mm)
	16'2"			Void and possible silica?
	20' 9"		Crinoid stems visible	chalky section, soft, 2" thick
2	21'		Dolostone as above	
	24'6"			stylolite
	25'			Finer grained
	29'3"			Clay nodule, orange, soft weathered
	29'9"			Clay nodule, orange, soft weathered. 60 x 50 mm
3	30'7"		Dolostone as above	
4	40'?		Dolostone as above	occ. large vugs and voids as above, black stylolitic partings on bedding plane surfaces, some areas with no vugs but with thin shale stylolitic leafs
5	49'		Dolostone as above	
6	58'		Dolostone as above	
	60'		Dolostone as above	Increasing thin stylolitic leafs
	60'7"	Eramosa Formation?	Dolostone, light brownish grey to greyish orange pink, fine crystalline, vuggy (due to fossils), strong, less porous than above, thick to medium bedded	Gradational change to underlying Eramosa with decreased porosity and increased stylolites on going deeper, Good RQD.
	64'6"	Goat Island Formation Chert beds	Dolostone as above. Colour change to pale yellowish brown and oil smell when freshly broken. Bedding planes have soft black surfaces. Upper Goat Island ?	Lower porosity below here based on water absorption on drill core surface. It is an encrinite i.e. composed largely of crinoid debris that has recrystallized.
7	65'7"		Dolostone as above	Crystal size up to 0.4mm
	67'6"			Clear micro quartz Xtals replacing fossils with thin seams white chalcedonic chert to 70'. ASR!
8	75'8"		Dolostone as above	RQD excellent
	80'7"		Chert nodule, soft, white, porous	Thin white vertical cracks. ASR!

Box No	Depth	Geological Nomenclature	Description	Features and comments
9	82'		Dolostone, pale yellowish brown and oil smell on freshly broken surfaces, fine crystalline, vuggy (due to fossils?), thick to medium bedded	Rock continues to be less porous than Guelph Formation. Good RQD. Strong.
	88'5"		Chert nodule, soft, white, porous (leached chert). Oil smell on freshly broken dolostone.	Alkali-silica reactive!
	89'		Rubble- possible karstic zone?	photo
	90'			Small vugs (photo)
10	90'7"	Gasport Formation	Dolostone, light brownish grey to light grey with medium grey mottling (on drill surface this looks like a blue grey colour but on broken surface is medium grey), fine crystalline (not as sugary texture as Guelph), thick bedded, occ. stylolites. Pale brown in upper 1 ft. Mottling due to bioturbation (trace fossils)	Stronger than overlying beds and less porous. Excellent RQD. Encrinite with >50% crinoid fossil debris. Same rock as Duntroon, Acton and Milton Qry's. Highly bioturbated.
	91'6"			Thick shale leaf to 4mm
11	100'7"		Dolostone as above, colour change to pinkish grey or very light grey, no stylolites	Vugs to 50 mm with crystalline druse
12	106'		Dolostone as above	Mottled banding photo @ 107, Vug photo @ 108'
	112'6"		Dolostone, pinkish grey with darker (medium grey) mottled areas, coarser crystalline to 0.3mm, vuggy, thick bedded.	Very strong and hard, trace micro galena (PbS)and sphalerite (ZnS)
13	115'7"		Dolostone as above	
14	125'7"		Dolostone as above	
15	135'7"		Dolostone as above	Druse Xtals to 1mm
	138'		Mottled very light grey to light grey intraformational conglomerate? to 142'	
16	142'8"		Dolostone as above mottled appearance	
	150'	= 45.72m		Vuggy calcarenite with stylolites
17	150'7"		Dolostone as above	
	151'	Irondequoit Formation.		Strong mottling (photo)or bioturbation
	152'7"	Fossil Hill Formation	Dolostone, finer grained calcisiltite	Rockway Member?
18	160		ditto	
	160'7"	Cabot Head Formation	Shale, fissile leafs, reddish at top becoming grey with depth	Trace micro pyrite
	165'7"		Bottom of hole in shale	

Note: Rock colours based on AGI rock colour chart on broken fresh surface. Note significant sections of core had been removed, crushed and tested for physical properties, thus description is based on incomplete core.

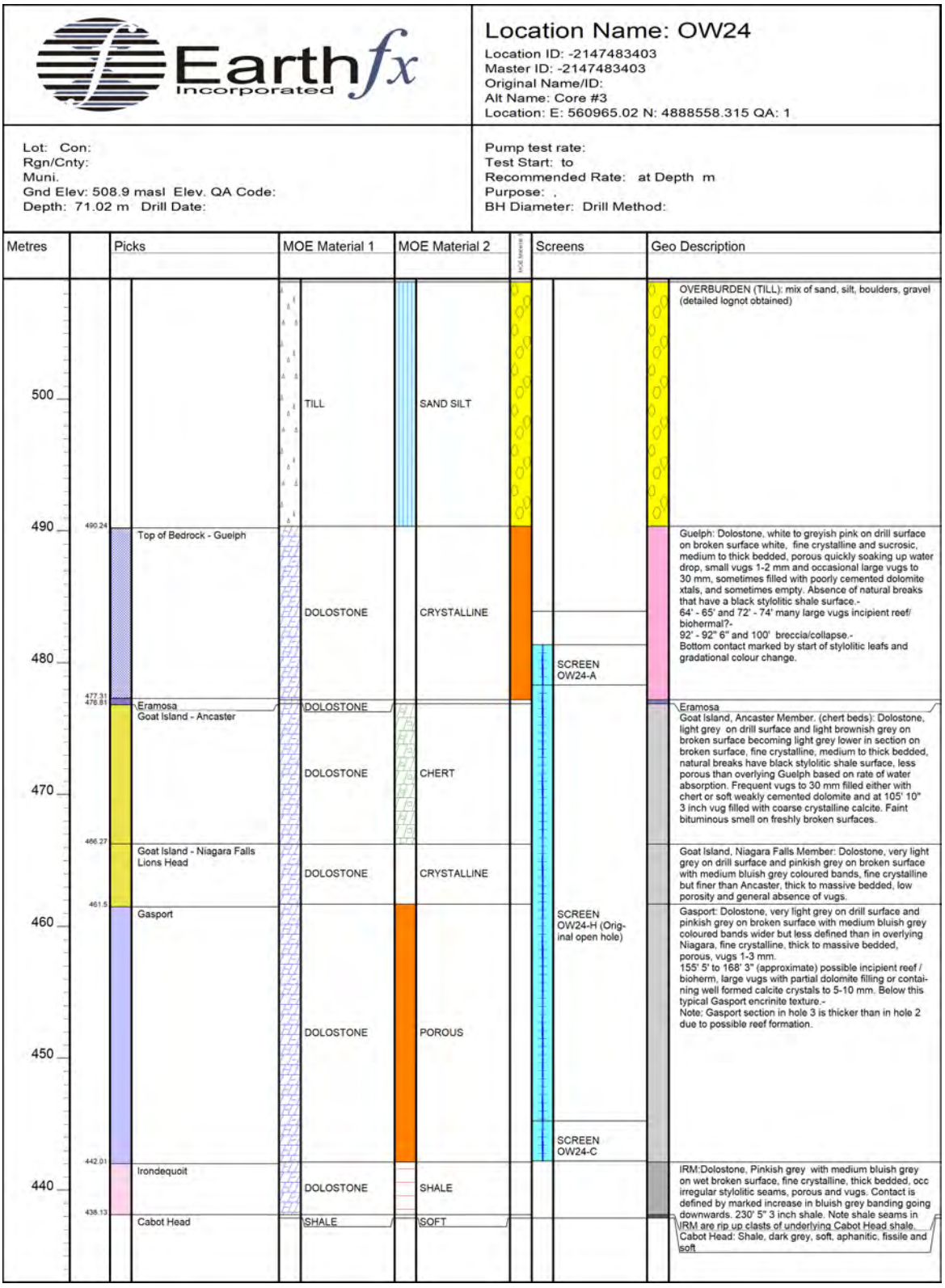


Figure A.10: Borehole Log – OW24C – Core #2.



Figure A.11: Core Image – OW24C – Core #2 (Note: core box length is 1.52 m).

Table A.7: Detailed Core Description OW24C – Core #2

Hole 2 drilled July 2022. Geological Nomenclature confirmed by Frank Brunton (OGS) October 2022

Depth from surface	Formation name	Description
57' 4"		Top of rock
Thickness 44' 2"	Guelph, Upper Member	Dolostone, white to greyish pink on drill surface on broken surface white, fine crystalline and sucrosic, medium to thick bedded, porous quickly soaking up water drop, small vugs 1-2 mm and occasional large vugs to 30 mm, sometimes filled with poorly cemented dolomite xtals, and sometimes empty. Originally a bioturbated mud. Recrystallization has destroyed most fossils but mold of gastropod found at 61'. Absence of natural breaks that have a black stylolitic shale surface. Lower member, reefal in nature is missing. Bottom contact marked by start of stylolitic leafs and gradational colour change
101'6" Thickness 39' 9"	Goat Island, Ancaster Member. (chert beds)	Contact at 101' 6" at start of first significant stylolite leafs. Dolostone, light grey on drill surface and light brownish grey on broken surface becoming light grey lower in section on broken surface, fine crystalline, medium to thick bedded, natural breaks have black stylolitic shale surface, less porous than overlying Guelph based on rate of water absorption. Frequent vugs to 30 mm filled either with chert or soft weakly cemented dolomite. Faint bituminous smell on freshly broken surfaces.
141' 3" Thickness 15' 3"	Goat Island, Niagara Falls Member	Dolostone, very light grey on drill surface and pinkish grey on broken surface with medium bluish grey coloured bands, fine crystalline but finer than overlying Ancaster, thick to massive bedded, low porosity and general absence of vugs.
156' 6" Thickness 30' 2"	Gasport	Dolostone, very light grey on drill surface and pinkish grey on broken surface with medium bluish grey coloured bands wider but less defined than in overlying Niagara, fine crystalline, thick to massive bedded, porous, vugs 1-3 mm, some discrete areas high concentration of vugs resulting in weak, porous and brittle rock. A grain stone. Extensive bioturbation giving a mottled fabric.
186' 5" Thickness 17' 2"	IRM	Contact with Irondequoit Formation. Dolostone, Pinkish grey with medium bluish grey on wet broken surface, fine crystalline, thick bedded, occ irregular stylolitic seams, porous and vugs. Upper contact is defined by marked increase in bluish grey banding going downwards. At 191’0” contact with Rockway Formation. At 199’ 11” contact with Merriton Formation (aka Fossil Hill). 203' 2" 1 inch shale. Note shale seams in IRM are rip up clasts of underlying Cabot Head shale.
203' 6"	Cabot Head	Shale, dark grey, soft, aphanitic, fissile and soft
204' 9"		Bottom of Hole

Note Colours based on AGI rock colour chart.

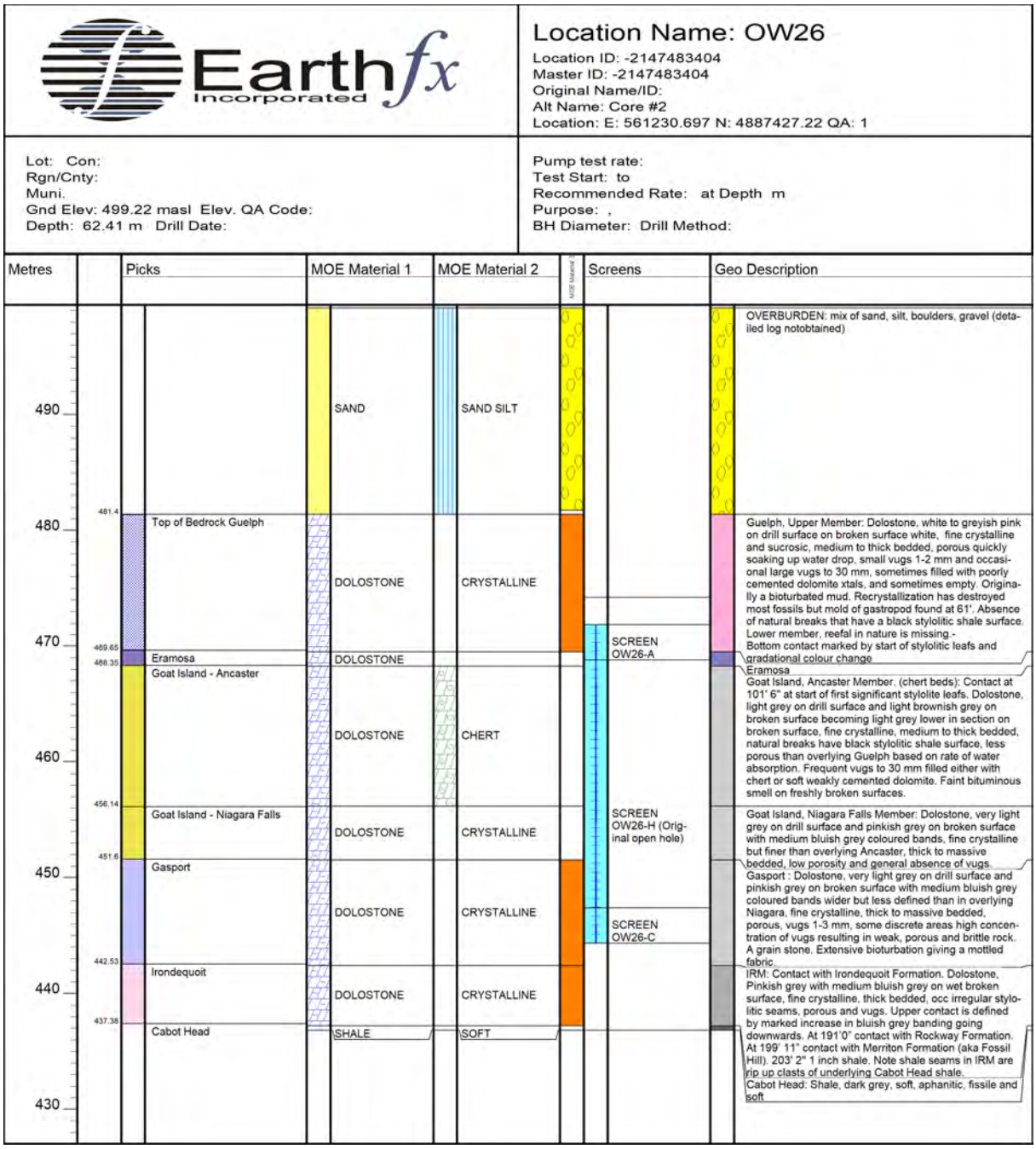


Figure A.12: Borehole Log – OW26C – Core #3.



Figure A.13: Core Image – OW26C – Core #3.

Table A.8: Detailed Core Description – OW26c – Core #3.

Hole 3 drilled July 2022 – not inspected by Frank Brunton.

Depth from surface	Formation name	Description
60' 10"		Top of rock
Thickness 44' 2"	Guelph	Dolostone, white to greyish pink on drill surface on broken surface white, fine crystalline and sucrosic, medium to thick bedded, porous quickly soaking up water drop, small vugs 1-2 mm and occasional large vugs to 30 mm, sometimes filled with poorly cemented dolomite xtals, and sometimes empty. Absence of natural breaks that have a black stylolitic shale surface. 64' - 65' and 72' - 74' many large vugs incipient reef/ biohermal? 92' - 92" 6" and 100' breccia/collapse. Bottom contact marked by start of stylolitic leafs and gradational colour change.
105' Thickness 34' 11"	Goat Island, Ancaster Member. (chert beds)	Dolostone, light grey on drill surface and light brownish grey on broken surface becoming light grey lower in section on broken surface, fine crystalline, medium to thick bedded, natural breaks have black stylolitic shale surface, less porous than overlying Guelph based on rate of water absorption. Frequent vugs to 30 mm filled either with chert or soft weakly cemented dolomite and at 105' 10" 3 inch vug filled with coarse crystalline calcite. Faint bituminous smell on freshly broken surfaces.
139' 11" Thickness 14' 11"	Goat Island, Niagara Falls Member	Dolostone, very light grey on drill surface and pinkish grey on broken surface with medium bluish grey coloured bands, fine crystalline but finer than Ancaster, thick to massive bedded, low porosity and general absence of vugs.
154' 10" Thickness 64' 3"	Gasport	Dolostone, very light grey on drill surface and pinkish grey on broken surface with medium bluish grey coloured bands wider but less defined than in overlying Niagara, fine crystalline, thick to massive bedded, porous, vugs 1-3 mm. 155' 5' to 168' 3" (approximate) possible incipient reef / bioherm, large vugs with partial dolomite filling or containing well formed calcite crystals to 5-10 mm. Below this typical Gasport encrinite texture. Note: Gasport section in hole 3 is thicker than in hole 2 due to possible reef formation.
219' 1" Thickness 13' 1"	IRM	Dolostone, Pinkish grey with medium bluish grey on wet broken surface, fine crystalline, thick bedded, occ irregular stylolitic seams, porous and vugs. Contact is defined by marked increase in bluish grey banding going downwards. 230' 5" 3 inch shale. Note shale seams in IRM are rip up clasts of underlying Cabot Head shale.
232' 2"	Cabot Head	Shale, dark grey, soft, aphanitic, fissile and soft
233'		Bottom of Hole

Note Colours based on AGI rock colour chart.

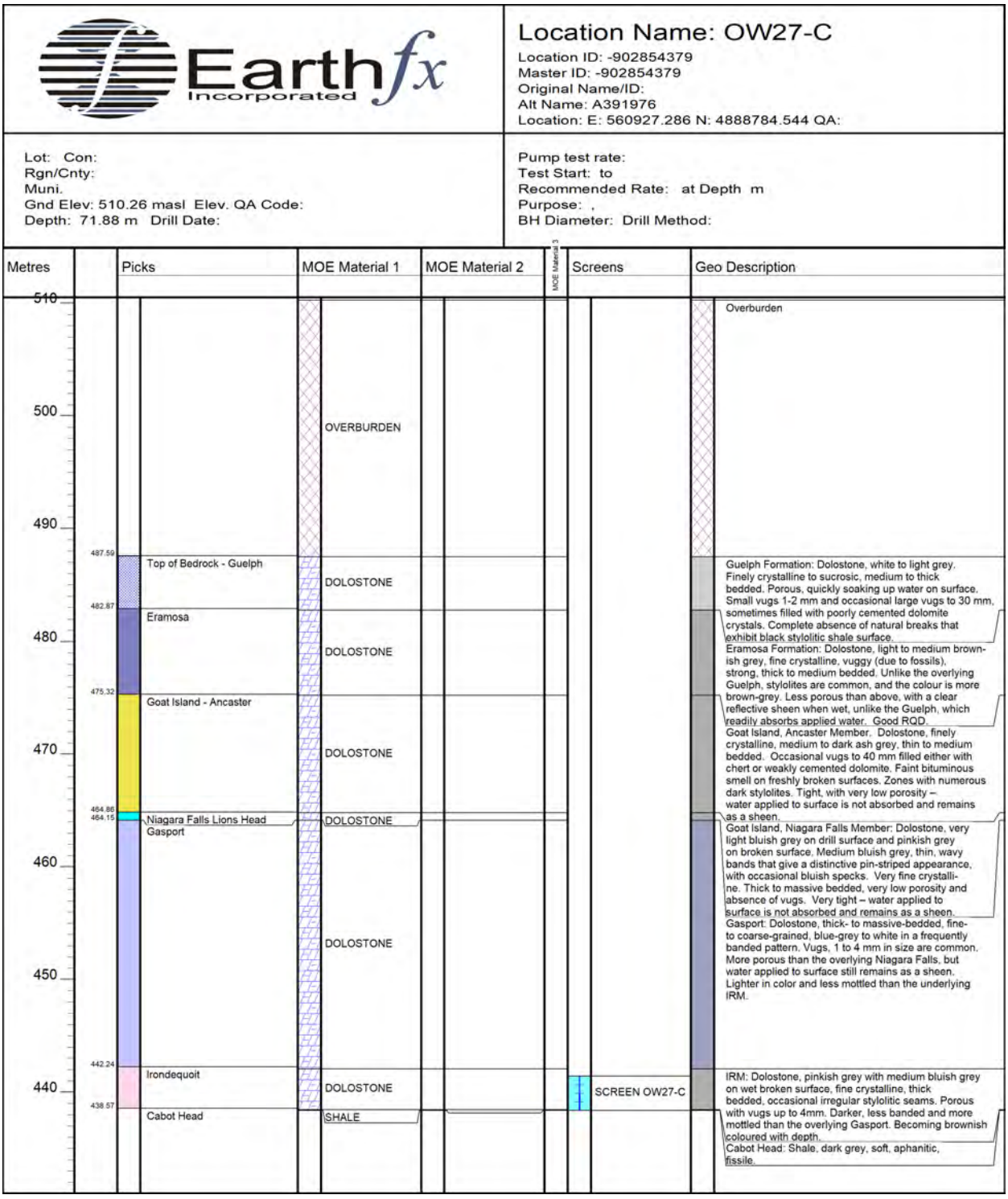


Figure A.14: Borehole log for monitor OW27-C



Figure A.15: Core photo log for monitor OW27-C

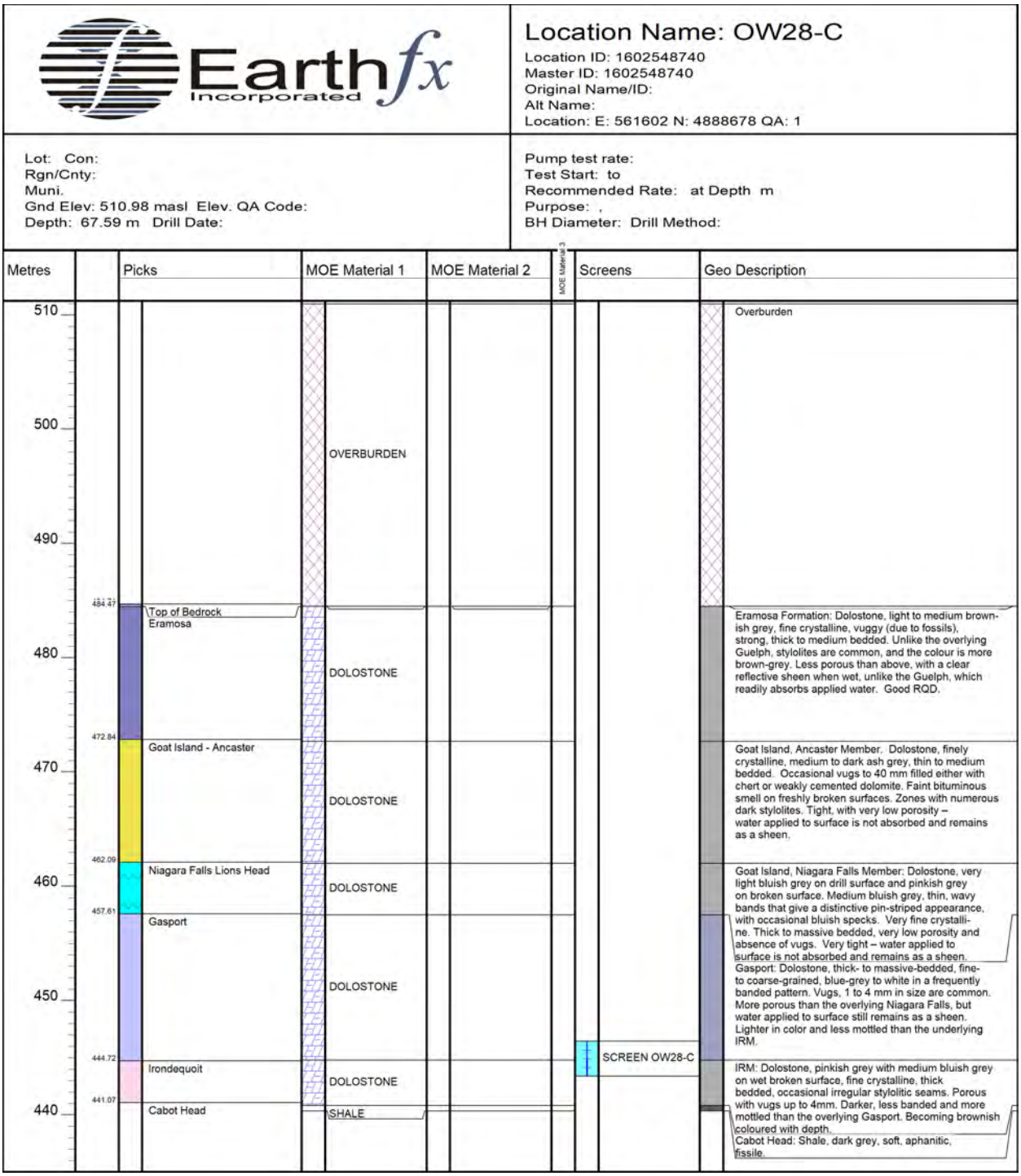


Figure A.16: Borehole log for monitor OW28-C



Figure A.17: Core photo log for monitor OW28-C

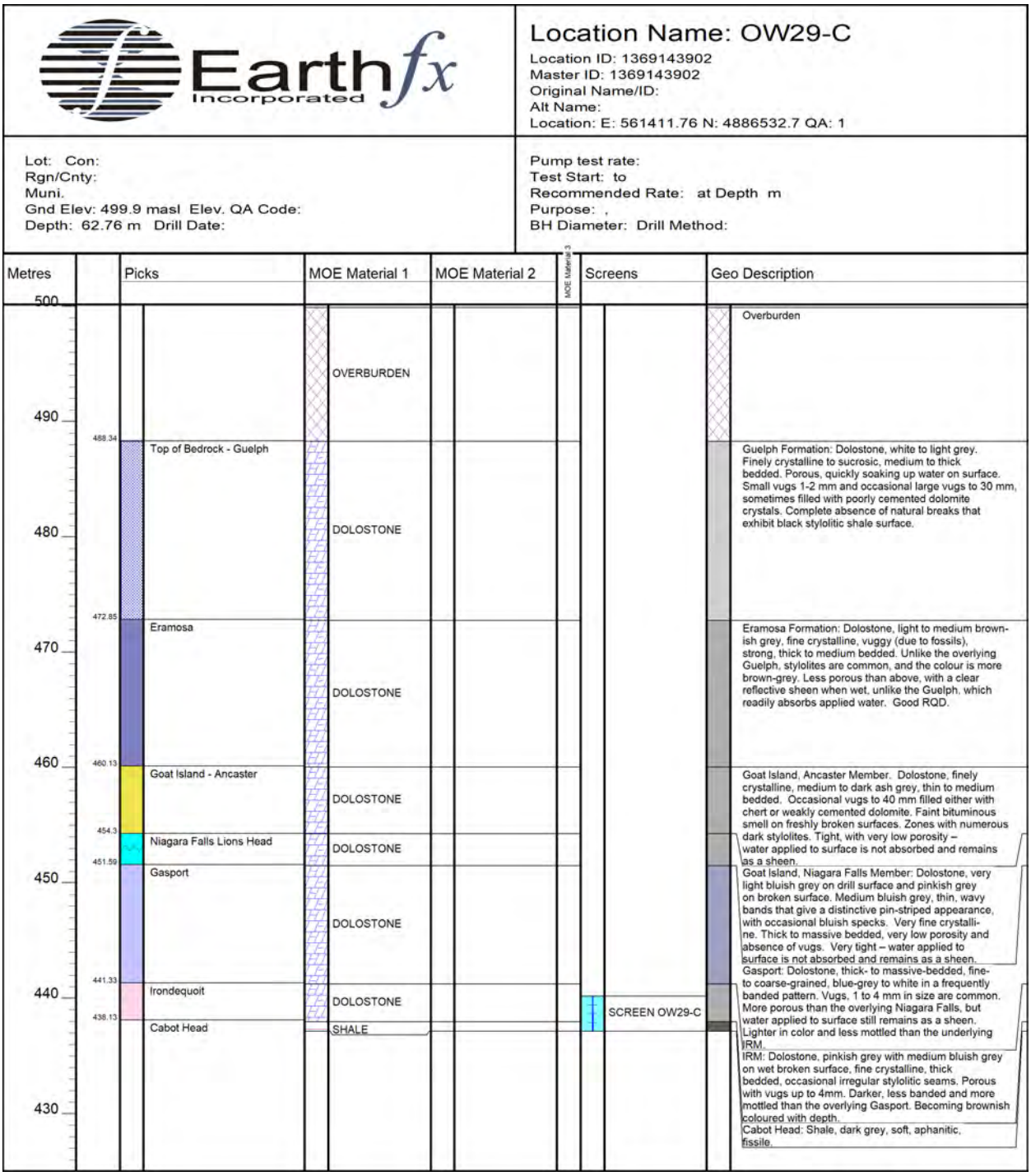


Figure A.18: Borehole log for monitor OW29-C



Figure A.19: Core photo log for monitor OW29-C

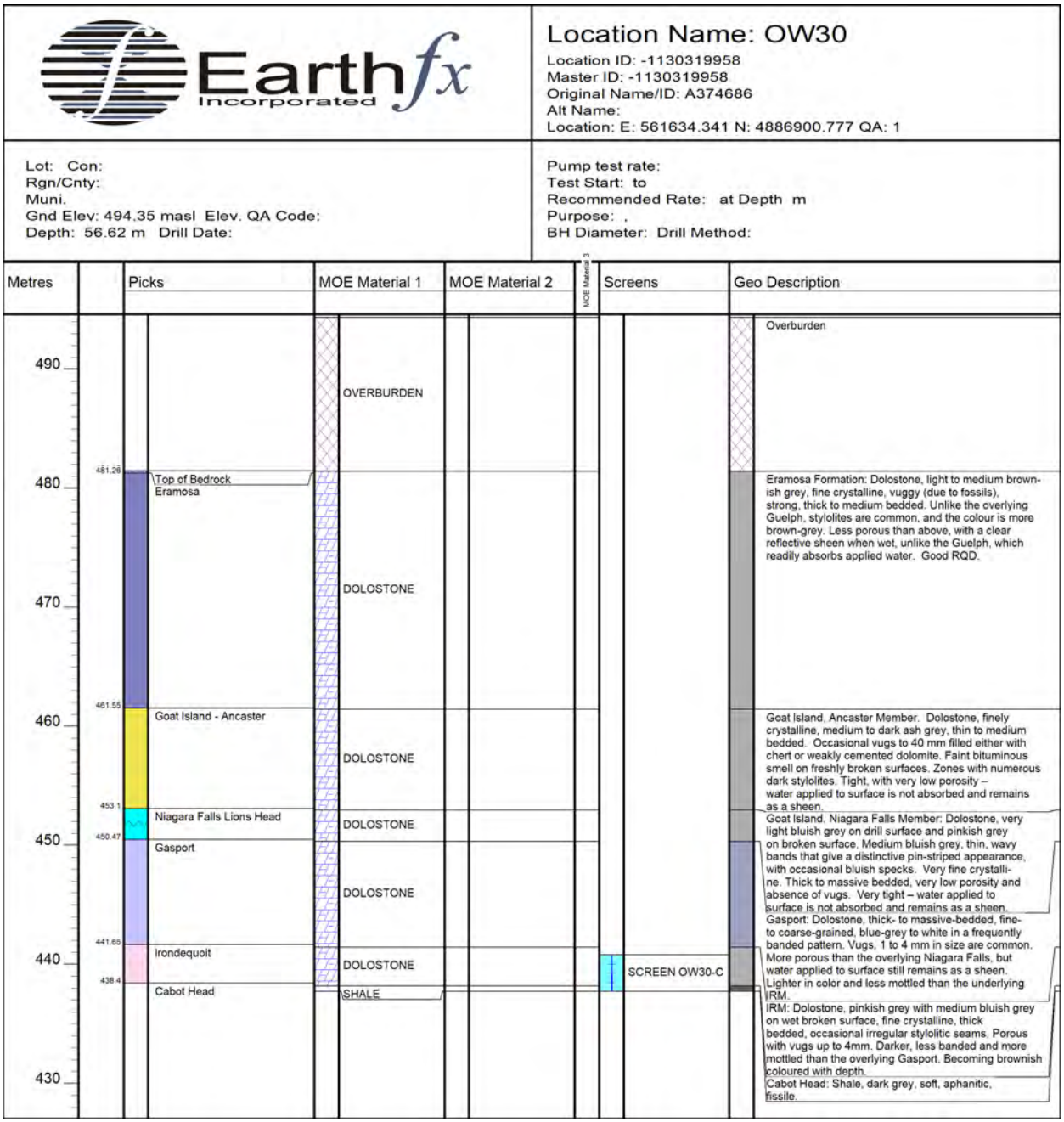


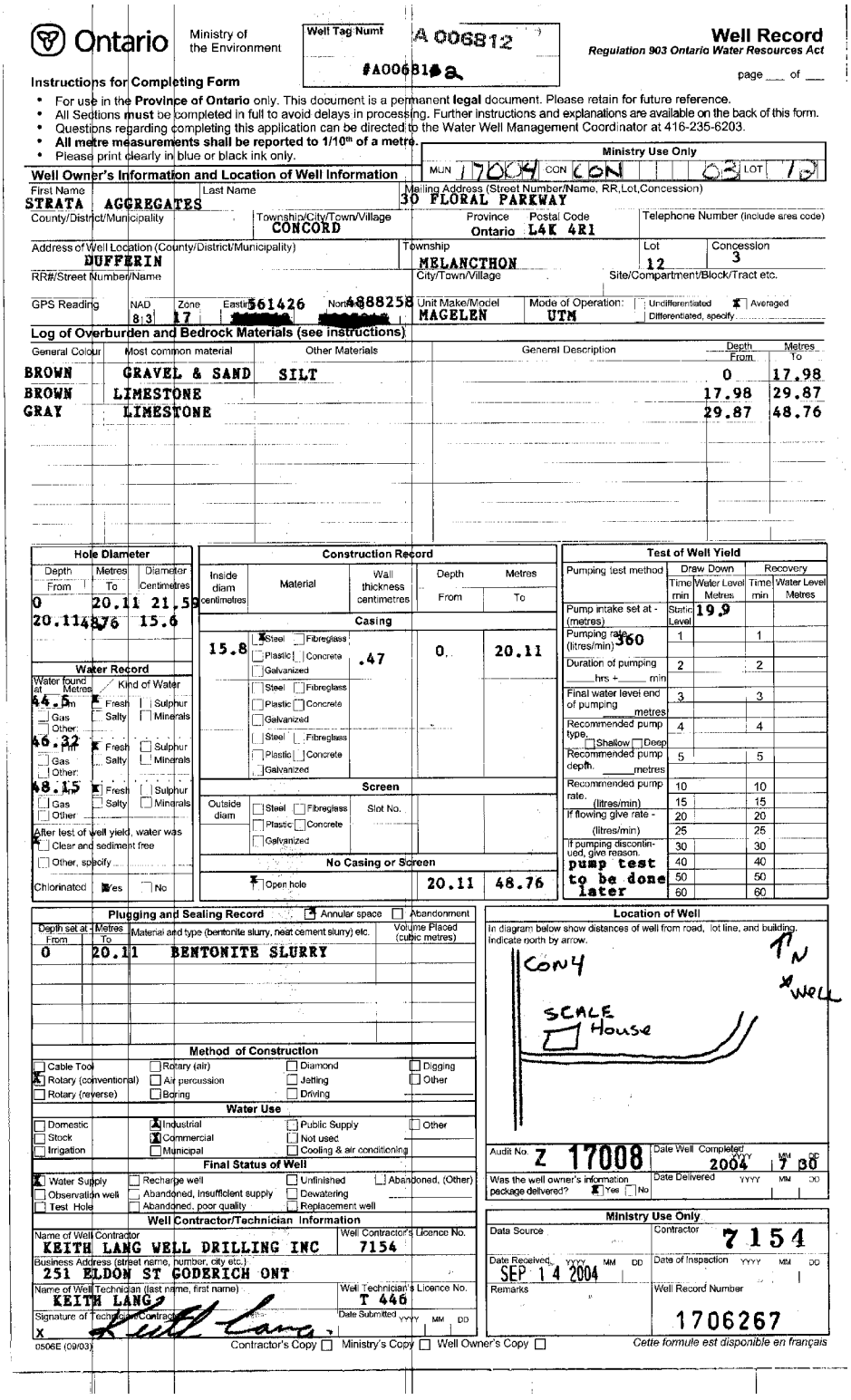
Figure A.20: Borehole log for monitor OW30-C



Figure A.21: Core photo log for monitor OW30-C

A.10.2 Borehole Logs: Monitoring Wells

As noted in Section A.3, an extensive network of monitoring wells was installed at the site (and many more at nearby sites, as shown in Figure A.7). A list of monitors is included in Table A.1 and a location map is shown in Figure A.5. As noted, the monitors were completed over many years and contain an extensive record of water level conditions. Note that in some cases the shallow monitor became dry over time, and the monitors within the nest were re-named. For example, at OW2, the original OW2-A monitor became dry, and was removed from the monitoring program. The monitors OW2-B was renamed OW2-A, and similarly, OW2-C was renamed OW2-B. Both Original and new borehole logs are included. Borehole logs for the monitoring wells are shown in Figure A.22 through Figure A.52.



Ontario Ministry of the Environment

Well Tag Num: A 006812 #A006812

Well Record
Regulation 903 Ontario Water Resources Act

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- All Sections **must** be completed in full to avoid delays in processing. Further instructions and explanations are available on the back of this form.
- Questions regarding completing this application can be directed to the Water Well Management Coordinator at 416-235-6203.
- **All metre measurements shall be reported to 1/10m of a metre.**
- Please print clearly in blue or black ink only.

Ministry Use Only
MUN 17004 CON CON 02 LOT 12

Well Owner's Information and Location of Well Information

First Name	Last Name	Mailing Address (Street Number/Name, RR,Lot,Concession)
STRATA	AGGREGATES	30 FLORAL PARKWAY

County/District/Municipality	Township/City/Town/Village	Province	Postal Code	Telephone Number (include area code)
	CONCORD	Ontario	L4K 4R1	

Address of Well Location (County/District/Municipality)	Township	Lot	Concession
DUFFERIN	MELANCTHON	12	3

RR#/Street Number/Name — City/Town/Village — Site/Compartment/Block/Tract etc.

GPS Reading: NAD 83 | Zone 17 | Easting 561426 | Northing 4888258 | Unit Make/Model: MAGELEN | Mode of Operation: UTM | ☐ Undifferentiated ☒ Averaged ☐ Differentiated, specify

Log of Overburden and Bedrock Materials (see instructions)

General Colour	Most common material	Other Materials	General Description	Depth From	Depth To
BROWN	GRAVEL & SAND	SILT		0	17.98
BROWN	LIMESTONE			17.98	29.87
GRAY	LIMESTONE			29.87	48.76

Hole Diameter

Depth From	Depth To	Diameter Centimetres
0	20.11	21.59
20.11	48.76	15.6

Water Record

Water found at Metres	Kind of Water	
44.5 m	☒ Fresh ☐ Sulphur ☐ Gas ☐ Salty ☐ Minerals ☐ Other	
46.32 m	☒ Fresh ☐ Sulphur ☐ Gas ☐ Salty ☐ Minerals ☐ Other	
48.15 m	☒ Fresh ☐ Sulphur ☐ Gas ☐ Salty ☐ Minerals ☐ Other	

After test of well yield, water was ☒ ☐ Clear and sediment free ☐ Other, specify

Chlorinated ☒ Yes ☐ No

Construction Record

Inside diam centimetres	Material	Wall thickness centimetres	Depth From	Depth To
Casing				
15.8	☒ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized	.47	0	20.11
	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized			
	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized			
Screen				
Outside diam	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized	Slot No.		
No Casing or Screen				
	☒ Open hole		20.11	48.76

Test of Well Yield

Pumping test method	Draw Down Time min	Draw Down Water Level Metres	Recovery Time min	Recovery Water Level Metres
Pump intake set at - (metres)	Static Level	19.9		
Pumping rate (litres/min) 360	1		1	
Duration of pumping ____ hrs + ____ min	2		2	
Final water level end of pumping ____ metres	3		3	
Recommended pump type, ☐ Shallow ☐ Deep	4		4	
Recommended pump depth. ____ metres	5		5	
Recommended pump rate. (litres/min)	10		10	
	15		15	
If flowing give rate - (litres/min)	20		20	
	25		25	
If pumping discontinued, give reason.	30		30	
pump test	40		40	
to be done	50		50	
later	60		60	

Plugging and Sealing Record ☒ Annular space ☐ Abandonment

Depth set at - Metres From	To	Material and type (bentonite slurry, neat cement slurry) etc.	Volume Placed (cubic metres)
0	20.11	BENTONITE SLURRY	

Location of Well

In diagram below show distances of well from road, lot line, and building. Indicate north by arrow.

Method of Construction

☐ Cable Tool ☐ Rotary (air) ☐ Diamond ☐ Digging
☒ Rotary (conventional) ☐ Air percussion ☐ Jetting ☐ Other
☐ Rotary (reverse) ☐ Boring ☐ Driving

Water Use

☐ Domestic ☒ Industrial ☐ Public Supply ☐ Other
☐ Stock ☒ Commercial ☐ Not used
☐ Irrigation ☐ Municipal ☐ Cooling & air conditioning

Final Status of Well

☒ Water Supply ☐ Recharge well ☐ Unfinished ☐ Abandoned, (Other)
☐ Observation well ☐ Abandoned, insufficient supply ☐ Dewatering
☐ Test Hole ☐ Abandoned, poor quality ☐ Replacement well

Audit No. Z 17008 | Date Well Completed: YYYY 2004 MM 7 DD 30

Was the well owner's information package delivered? ☒ Yes ☐ No | Date Delivered YYYY MM DD

Well Contractor/Technician Information

Name of Well Contractor	Well Contractor's Licence No.
KEITH LANG WELL DRILLING INC	7154

Business Address (street name, number, city etc.): 251 ELDON ST GODERICH ONT

Name of Well Technician (last name, first name)	Well Technician's Licence No.
KEITH LANG	T 446

Signature of Technician/Contractor: X Keith Lang | Date Submitted YYYY MM DD

Ministry Use Only

Data Source | Contractor 7154

Date Received SEP 14 2004 | Date of Inspection YYYY MM DD

Remarks | Well Record Number 1706267

0506E (09/03) Contractor's Copy ☐ Ministry's Copy ☐ Well Owner's Copy ☐ *Cette formule est disponible en français*

Figure A.22: Well Record for PW1

Ontario Ministry of the Environment

Well Tag No. A006830

#A006830

Well Record
Regulation 903 Ontario Water Resources Act

page ___ of ___

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- **All metre measurements shall be reported to 1/10th of a metre.**
- Please print clearly in blue or black ink only.

Ministry Use Only
MUN 17004 CON CON 02 LOT 17

Well Owner's Information and Location of Well Information

First Name	Last Name	Mailing Address (Street Number/Name, RR,Lot,Concession)
STRATA	AGGREGATES	30 FLORAL PARKWAY

County/District/Municipality	Township/City/Town/Village	Province	Postal Code	Telephone Number (include area code)
	CONCORD	Ontario	L4K 4R1	

Address of Well Location (County/District/Municipality)	Township	Lot	Concession
DUFFERIN	MELANCTON	12	3

RR#/Street Number/Name | City/Town/Village | Site/Compartment/Block/Tract etc.

GPS Reading: NAD 83 | Zone 17 | Easting 561395 | Northing 4888240 | Unit Make/Model MAGELEN | Mode of Operation: UTM | ☐ Undifferentiated ☒ Averaged ☐ Differentiated, specify

Log of Overburden and Bedrock Materials (see instructions)

General Colour	Most common material	Other Materials	General Description	Depth From	Depth To
BROWN	GRAVEL SAND SILT			0	17.98
BROWN	LIMESTONE			17.98	30.78
GRAY	LIMESTONE			30.78	48.76
			MONITOR WELL		

Hole Diameter

Depth From	Metres To	Diameter Centimetres
0	18.28	21.59
18.28	48.76	15.6

Water Record

Water found at Metres	Kind of Water			
38.4	☒ Fresh	☐ Sulphur	☐ Gas	☐ Other:
44.8	☒ Fresh	☐ Salty	☐ Minerals	☐ Gas ☐ Other:
47.54	☒ Fresh	☐ Salty	☐ Minerals	☐ Gas ☐ Other:

After test of well yield, water was ☒ Clear and sediment free ☐ Other, specify

Chlorinated ☒ Yes ☐ No

Construction Record

Inside diam centimetres	Material	Wall thickness centimetres	Depth From	Depth To
Casing				
15.8	☒ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized	.47	0	18.28
	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized			
	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized			
Screen				
Outside diam	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized	Slot No.		
No Casing or Screen				
	☒ Open hole		18.28	48.76

Test of Well Yield

Pumping test method	Draw Down Time min	Draw Down Water Level Metres	Recovery Time min	Recovery Water Level Metres
Pump intake set at - (metres)	Static Level	20.9		
Pumping rate (litres/min) 204	1		1	
Duration of pumping ____hrs +____ min	2		2	
Final water level end of pumping ____metres	3		3	
Recommended pump type. ☐ Shallow ☐ Deep	4		4	
Recommended pump depth. ____metres	5		5	
Recommended pump rate. (litres/min)	10		10	
If flowing give rate - (litres/min)	15		15	
If pumping discontinued, give reason.	20		20	
	25		25	
	30		30	
	40		40	
	50		50	
	60		60	

Plugging and Sealing Record ☒ Annular space ☐ Abandonment

Depth set at - Metres From	To	Material and type (bentonite slurry, neat cement slurry) etc.	Volume Placed (cubic metres)
0	18.28	BENTONITE SLURRY	

Method of Construction

☒ Cable Tool ☐ Rotary (air) ☐ Diamond ☐ Digging
☐ Rotary (conventional) ☐ Air percussion ☐ Jetting ☐ Other
☐ Rotary (reverse) ☐ Boring ☐ Driving

Water Use

☐ Domestic ☐ Industrial ☐ Public Supply ☐ Other
☐ Stock ☐ Commercial ☐ Not used
☐ Irrigation ☐ Municipal ☐ Cooling & air conditioning

Final Status of Well

☐ Water Supply ☐ Recharge well ☐ Unfinished ☐ Abandoned, (Other)
☒ Observation well ☐ Abandoned, insufficient supply ☐ Dewatering
☐ Test Hole ☐ Abandoned, poor quality ☐ Replacement well

Well Contractor/Technician Information

Name of Well Contractor: KEITH LANG WELL DRILLING INC | Well Contractor's Licence No.: 7154

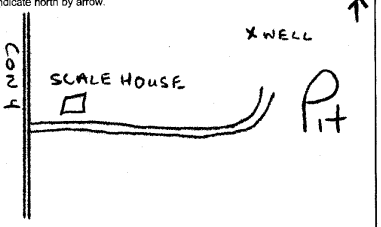
Business Address (street name, number, city etc.): 251 ELDON ST GODERICH ONT

Name of Well Technician (last name, first name): KEITH LANG | Well Technician's Licence No.: T 446

Signature of Technician/Contractor: X Keith Lang | Date Submitted YYYY MM DD

Location of Well

In diagram below show distances of well from road, lot line, and building. Indicate north by arrow.



Audit No. Z 17010 | Date Well Completed YYYY MM DD: 2004 8 2

Was the well owner's information package delivered? ☒ Yes ☐ No | Date Delivered YYYY MM DD

Ministry Use Only

Data Source | Contractor: 7154

Date Received YYYY MM DD: SEP 14 2004 | Date of Inspection YYYY MM DD

Remarks | Well Record Number: 1706269

0506E (09/03) Contractor's Copy ☐ Ministry's Copy ☐ Well Owner's Copy ☐ *Cette formule est disponible en français*

Figure A.23: Well Record for OW1

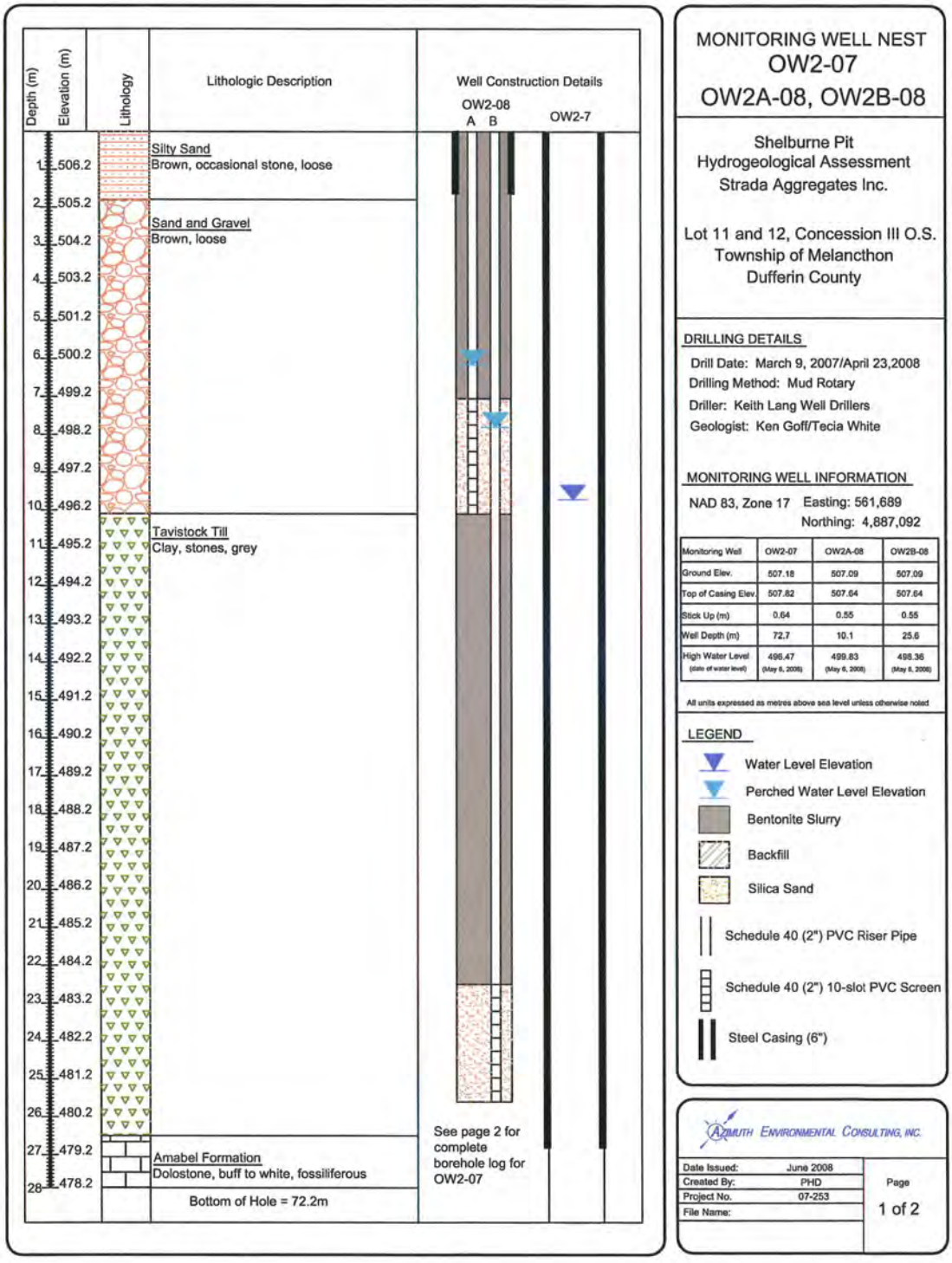


Figure A.24: Original Borehole Logs for OW2 Nest - Page 1/2

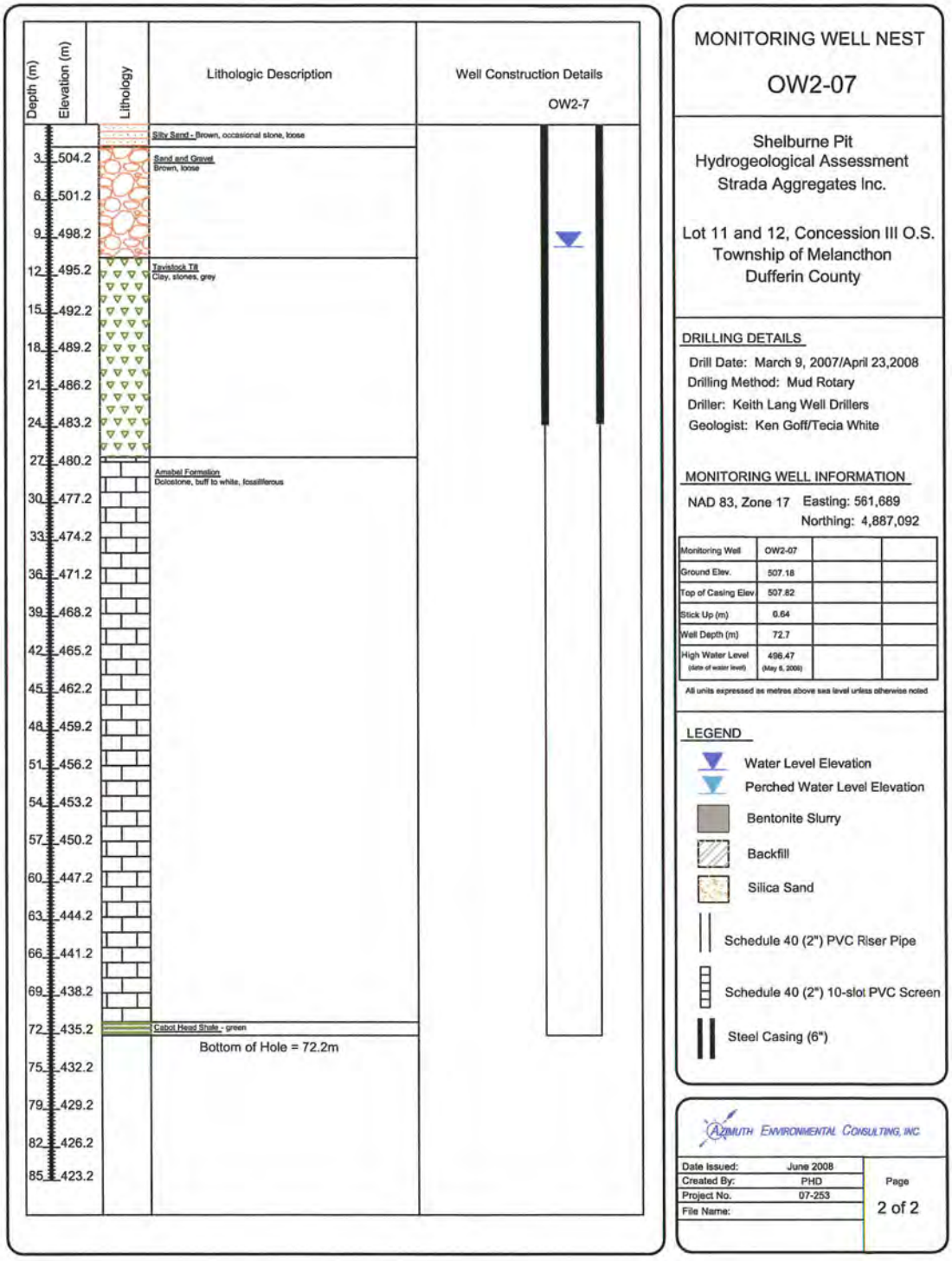


Figure A.25: Original Borehole Logs for OW2 Nest - Page 2/2

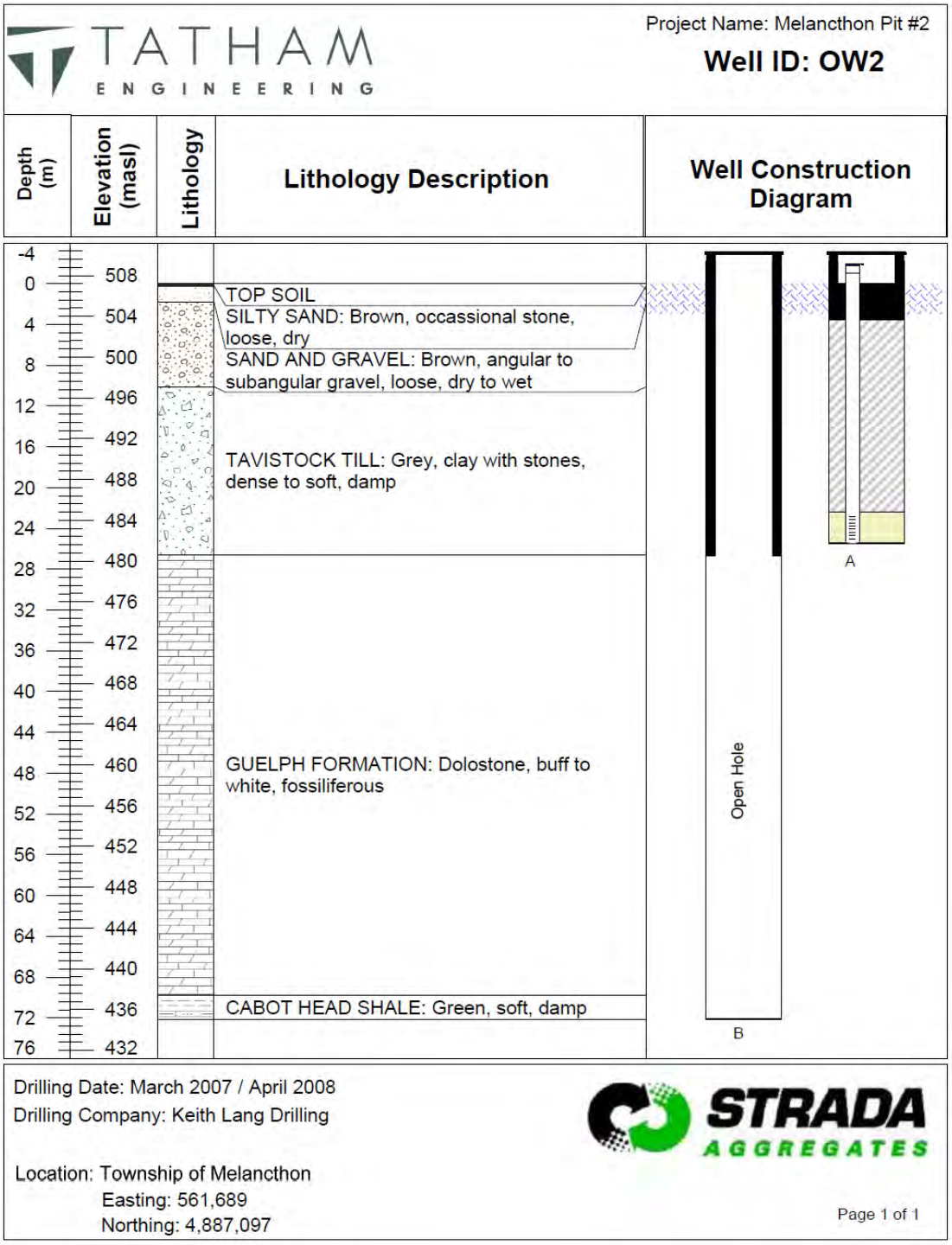


Figure A.26: Updated Borehole log for Well OW2.

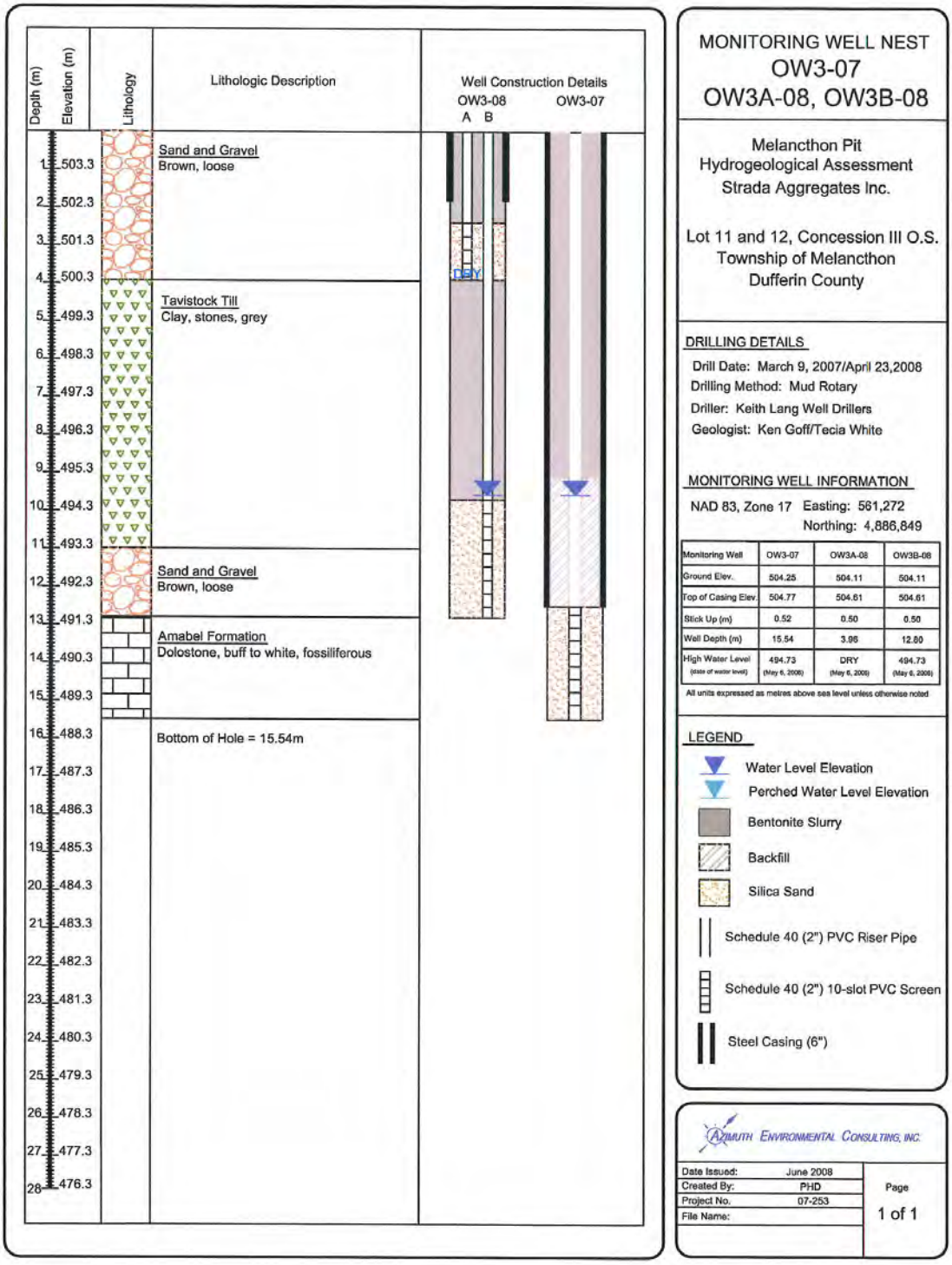


Figure A.27: Original Borehole logs for OW3 Nest

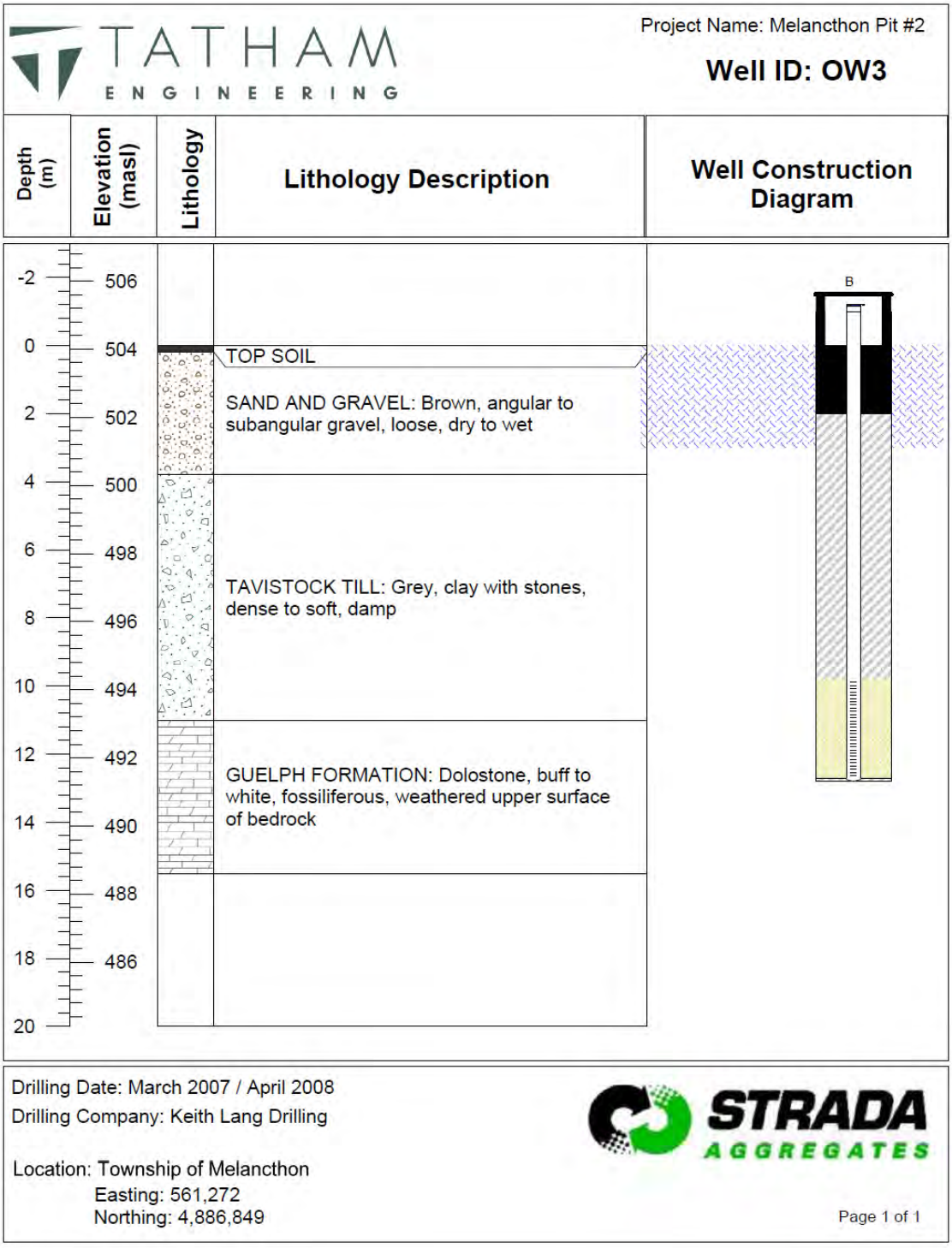


Figure A.28: New Borehole log for Well OW3.

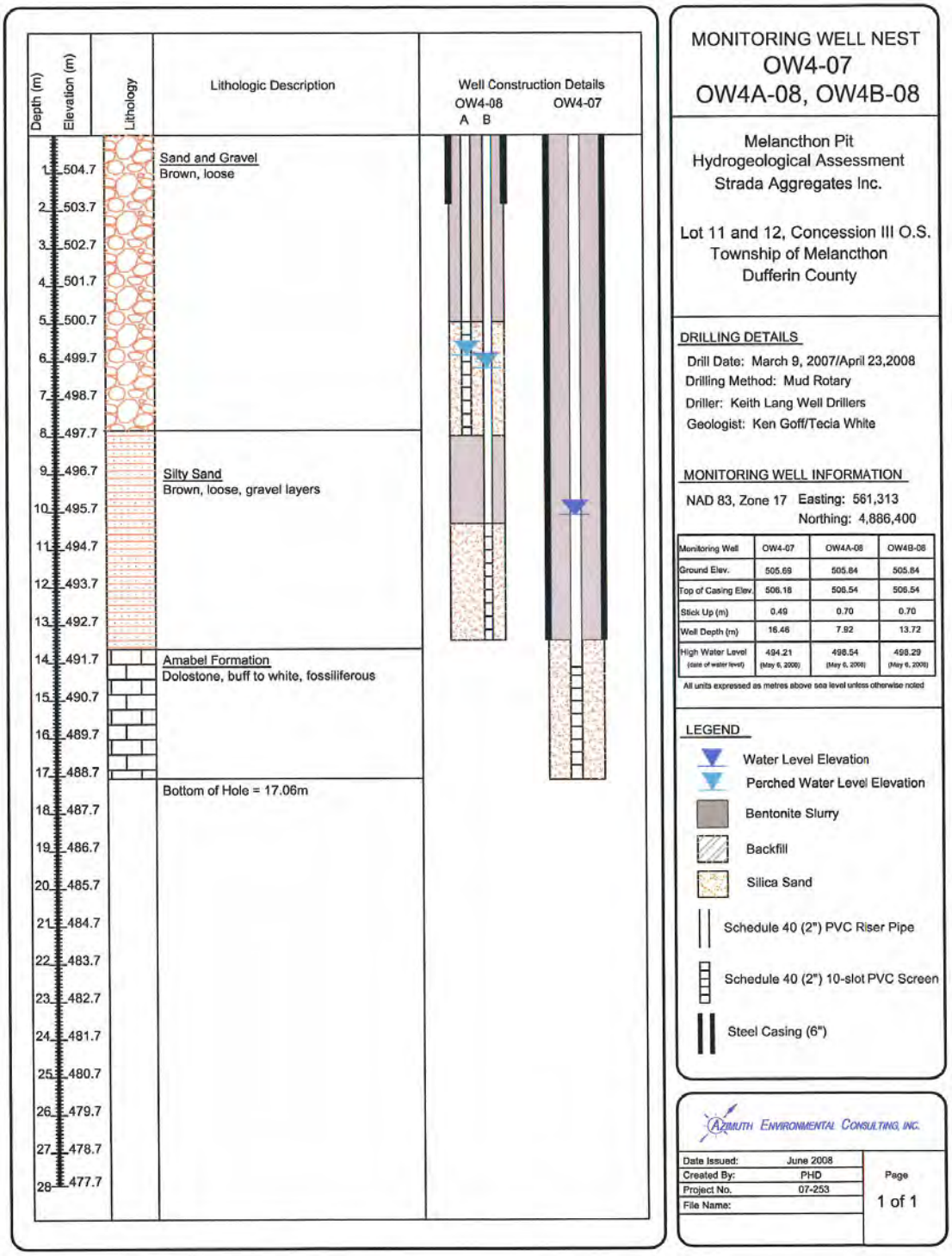


Figure A.29: Original Borehole Log for OW4

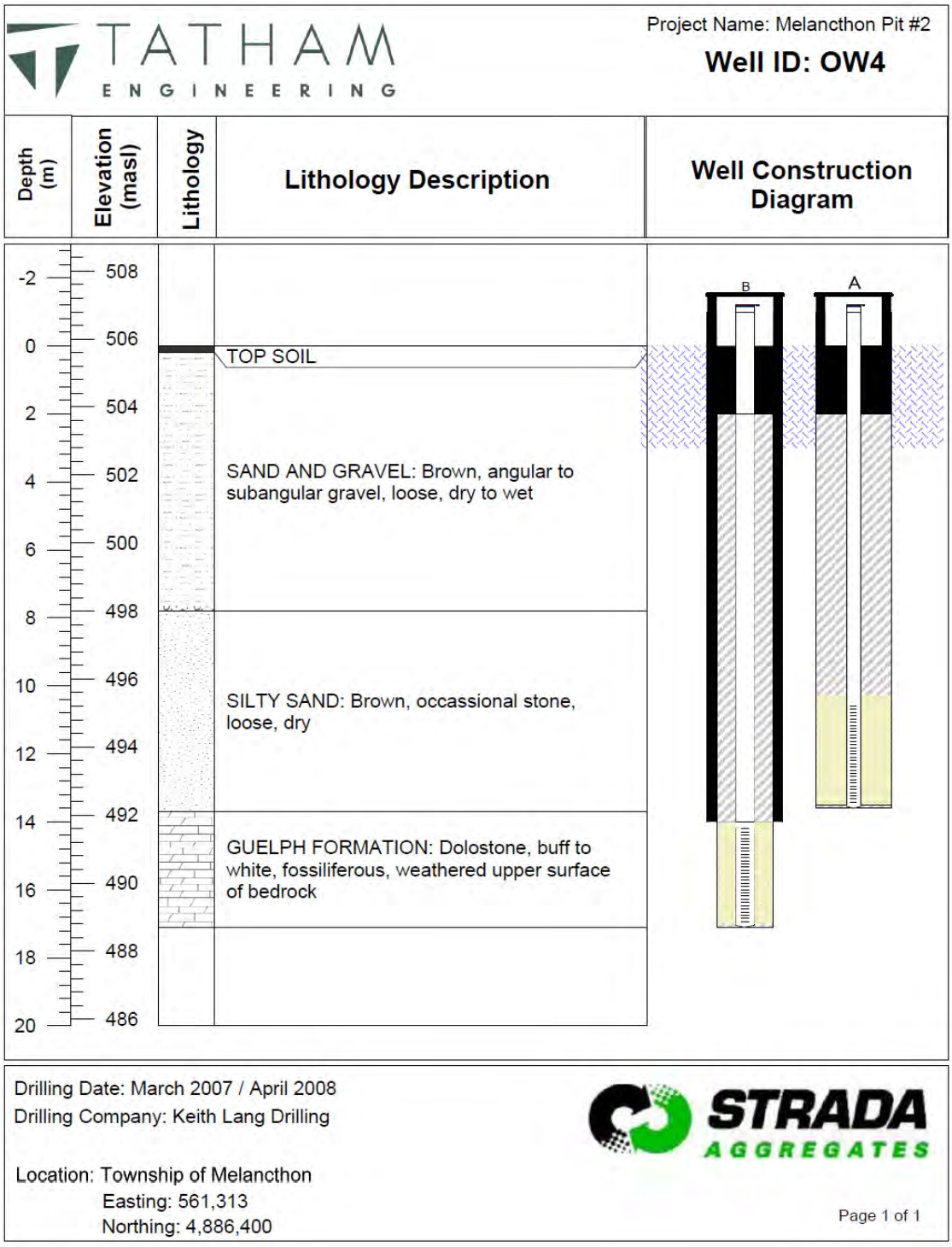


Figure A.30: New Borehole log for Well OW4.

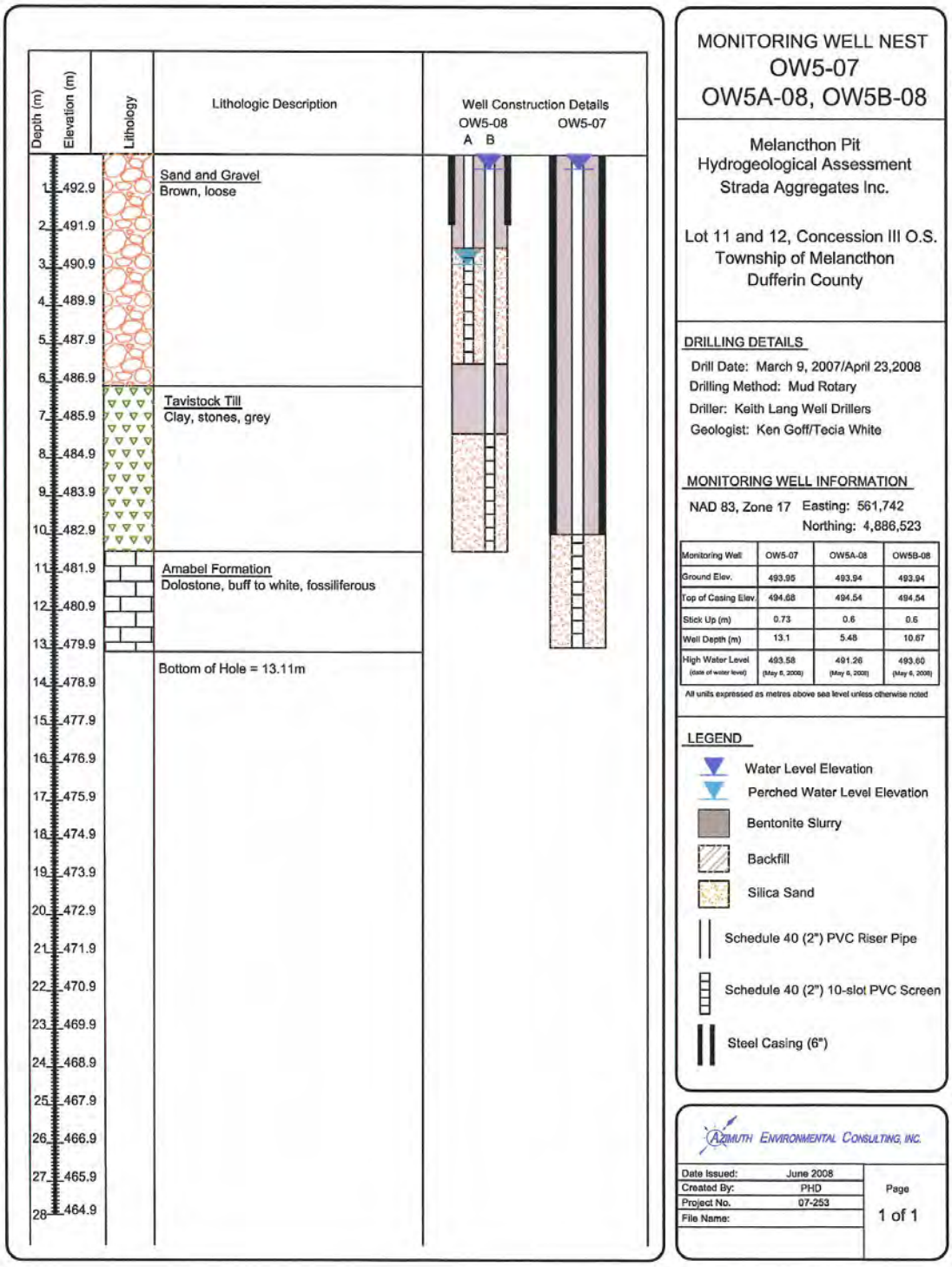


Figure A.31: Original Borehole log for OW5 Nest

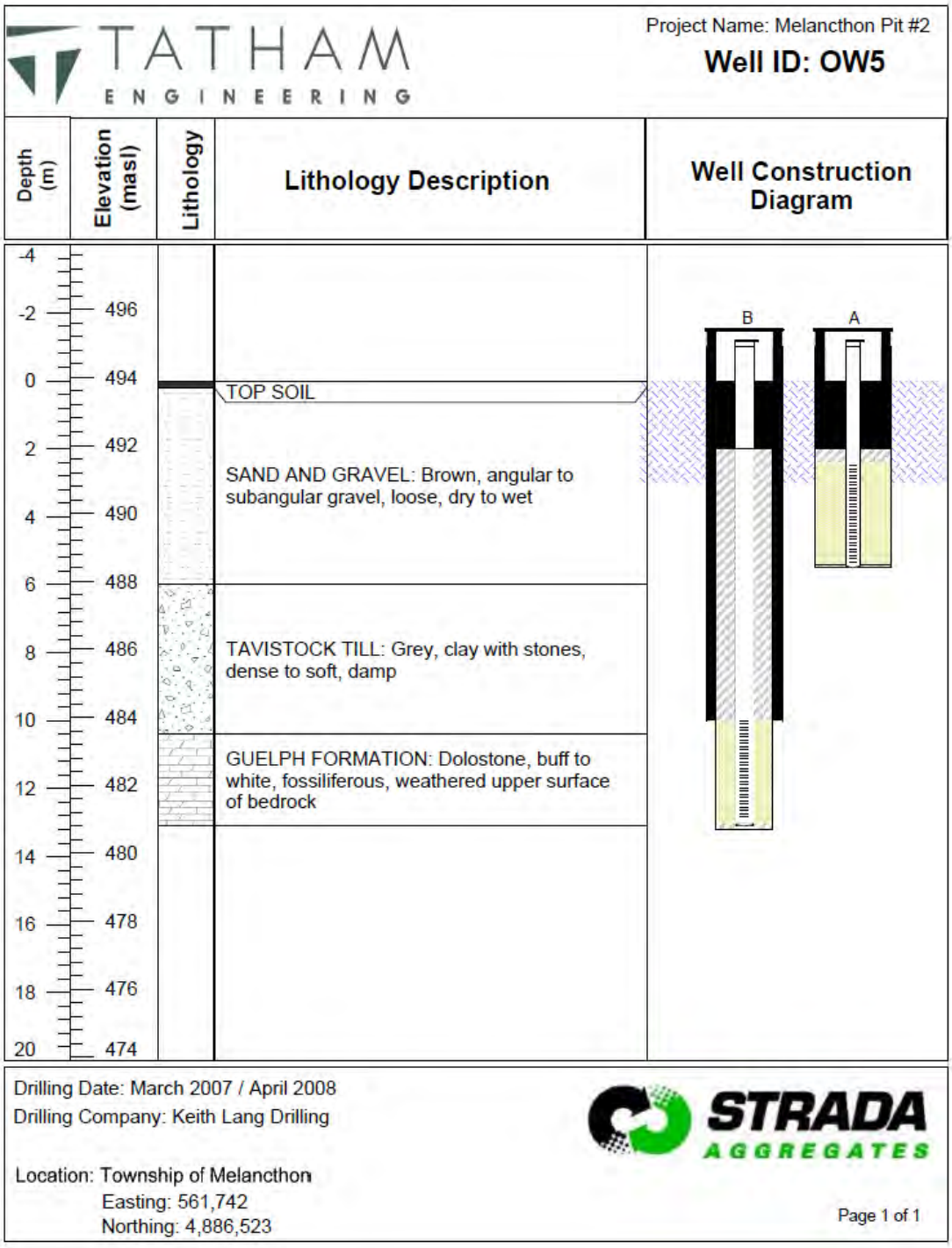


Figure A.32: Updated Borehole log for Well OW5.

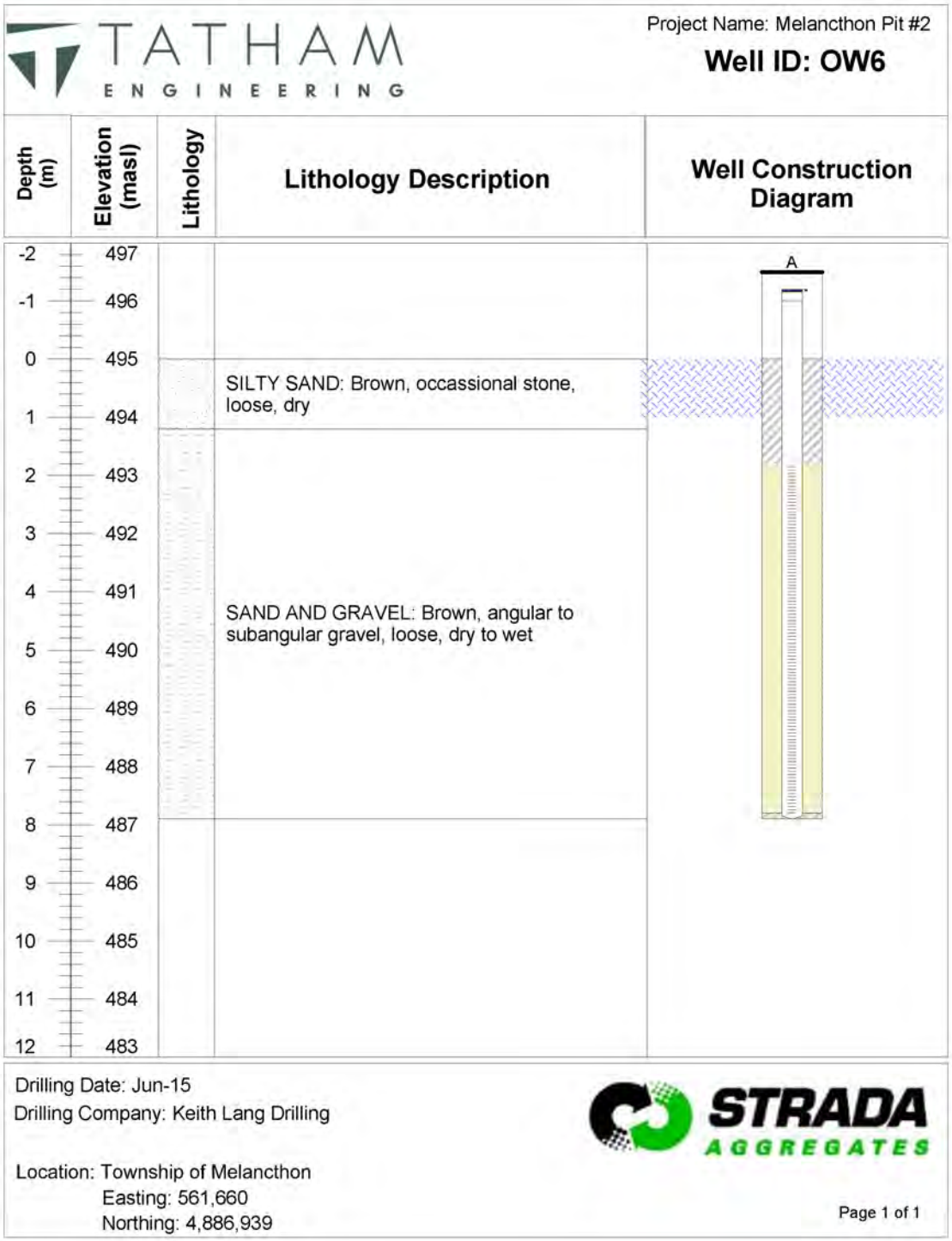


Figure A.33: Borehole log for Well OW6-A.

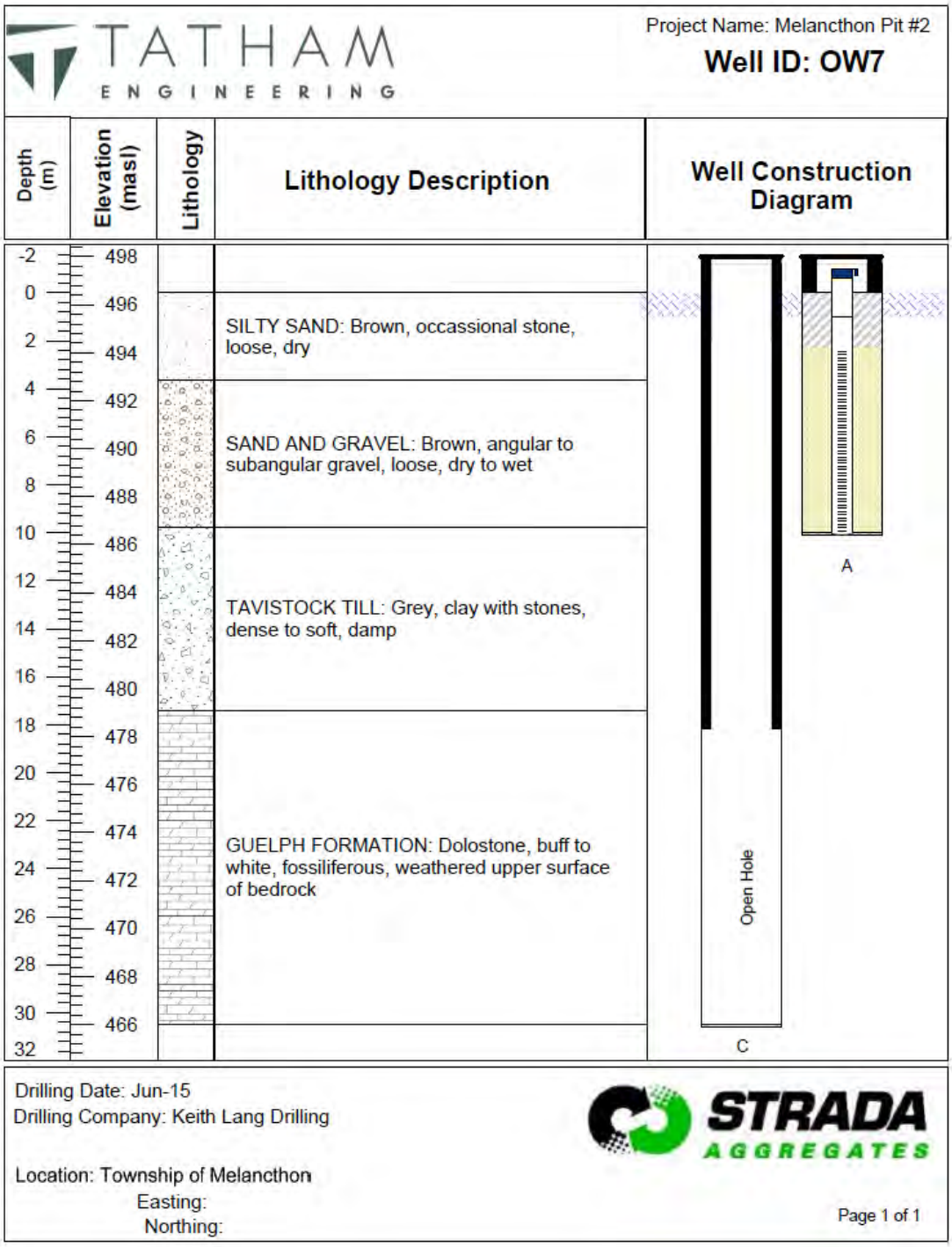


Figure A.34: Borehole log for Well OW7 A and C.

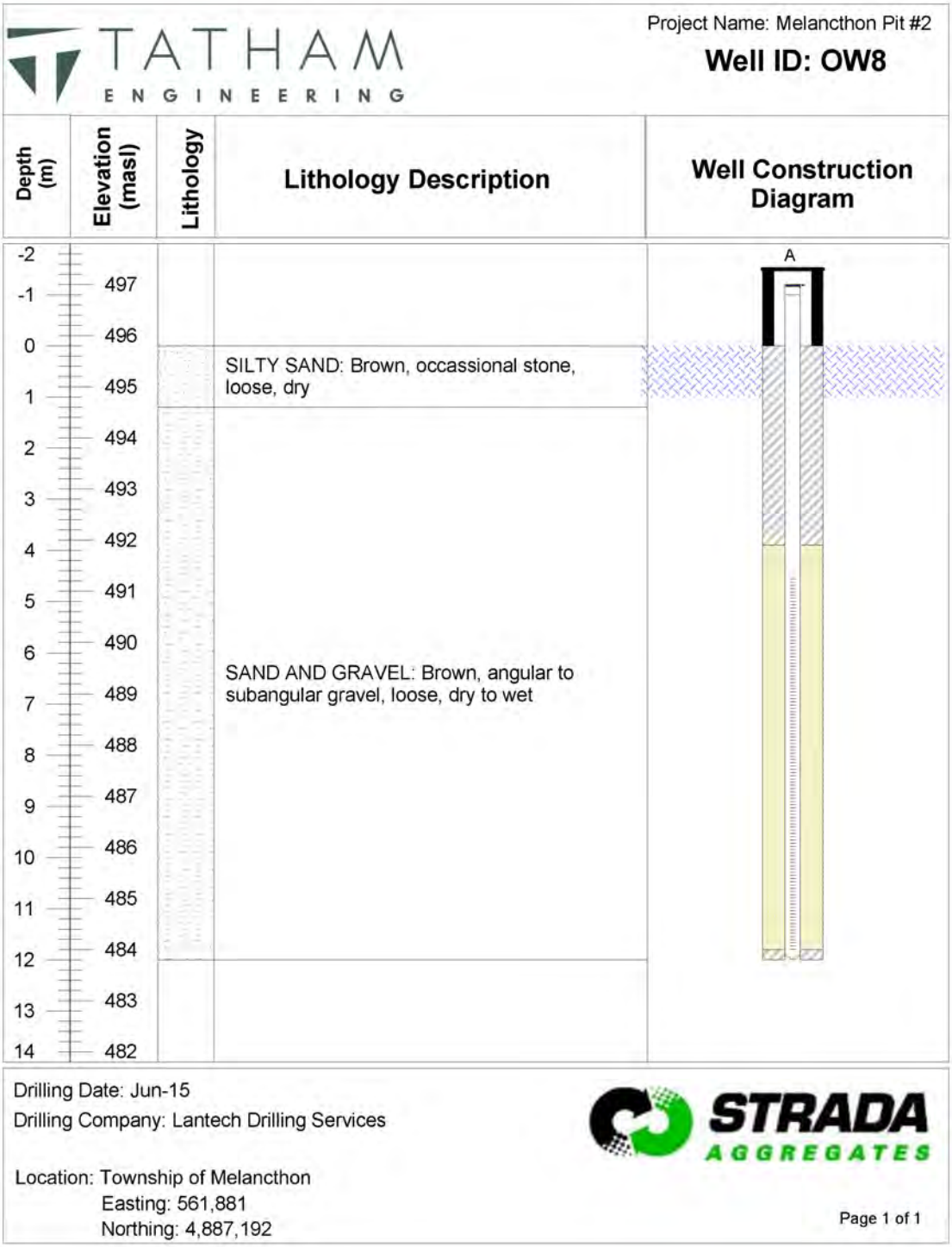


Figure A.35: Borehole log for Well OW8.

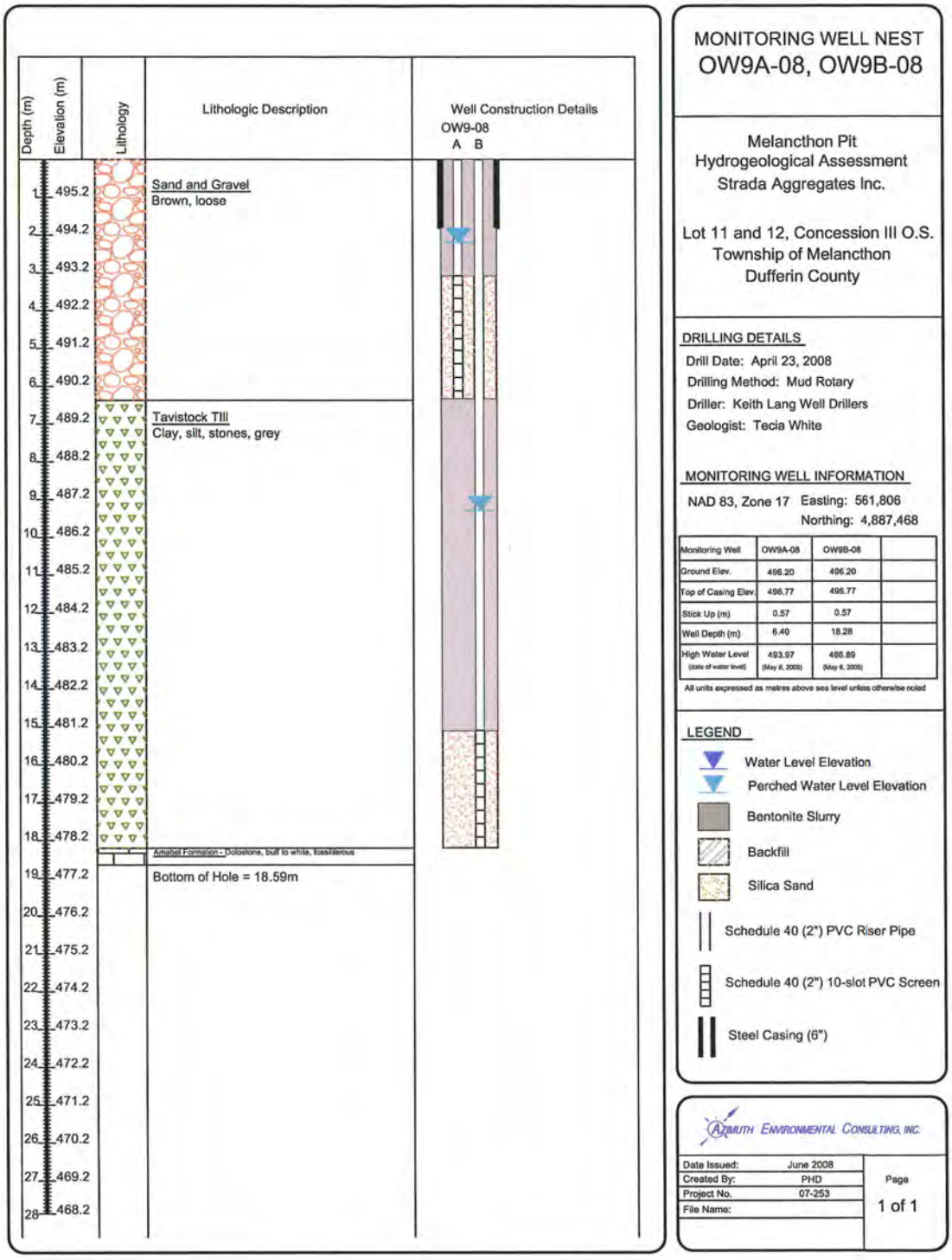


Figure A.36: Original Borehole Log for OW9 nest

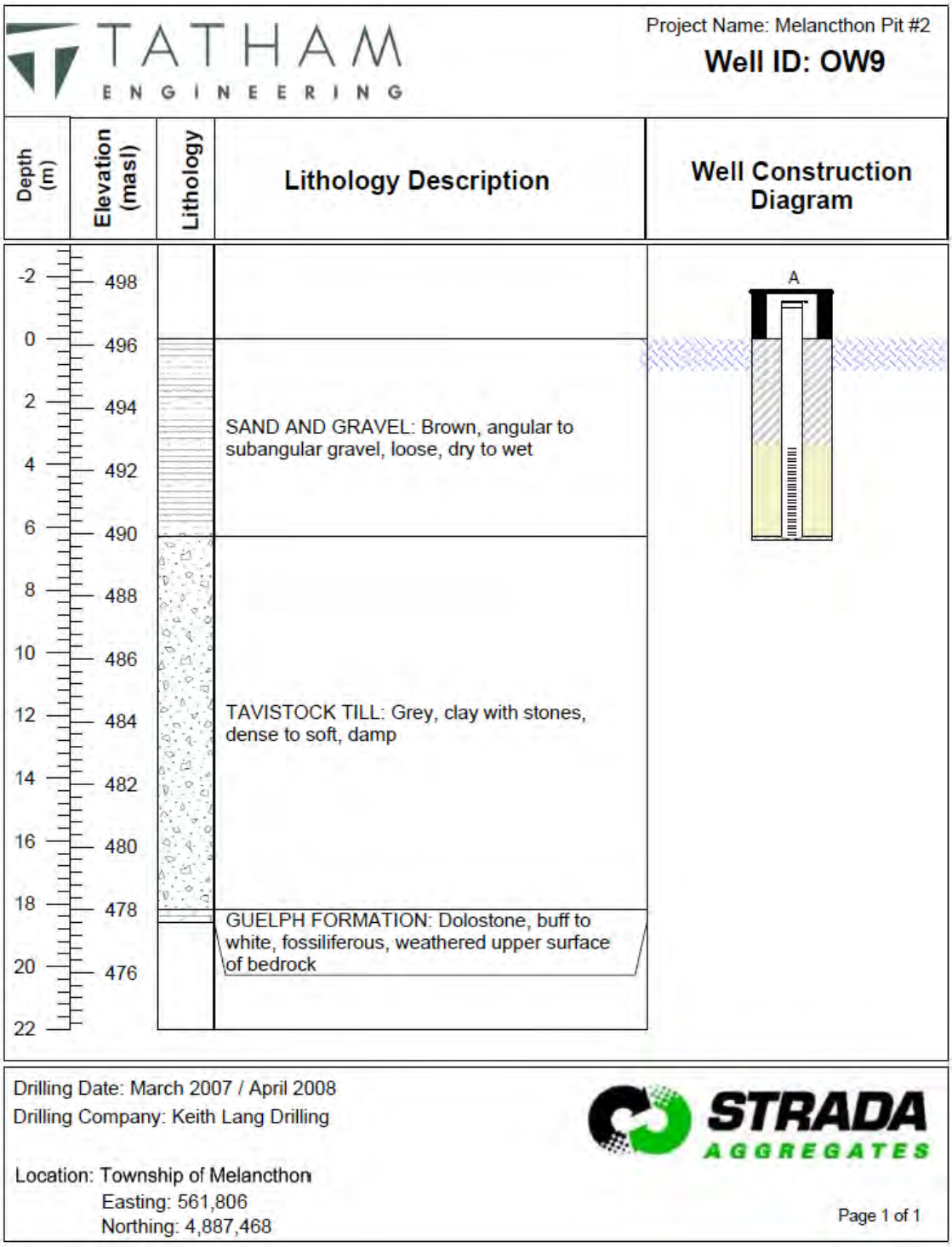


Figure A.37: New Borehole log for Well OW9-A.

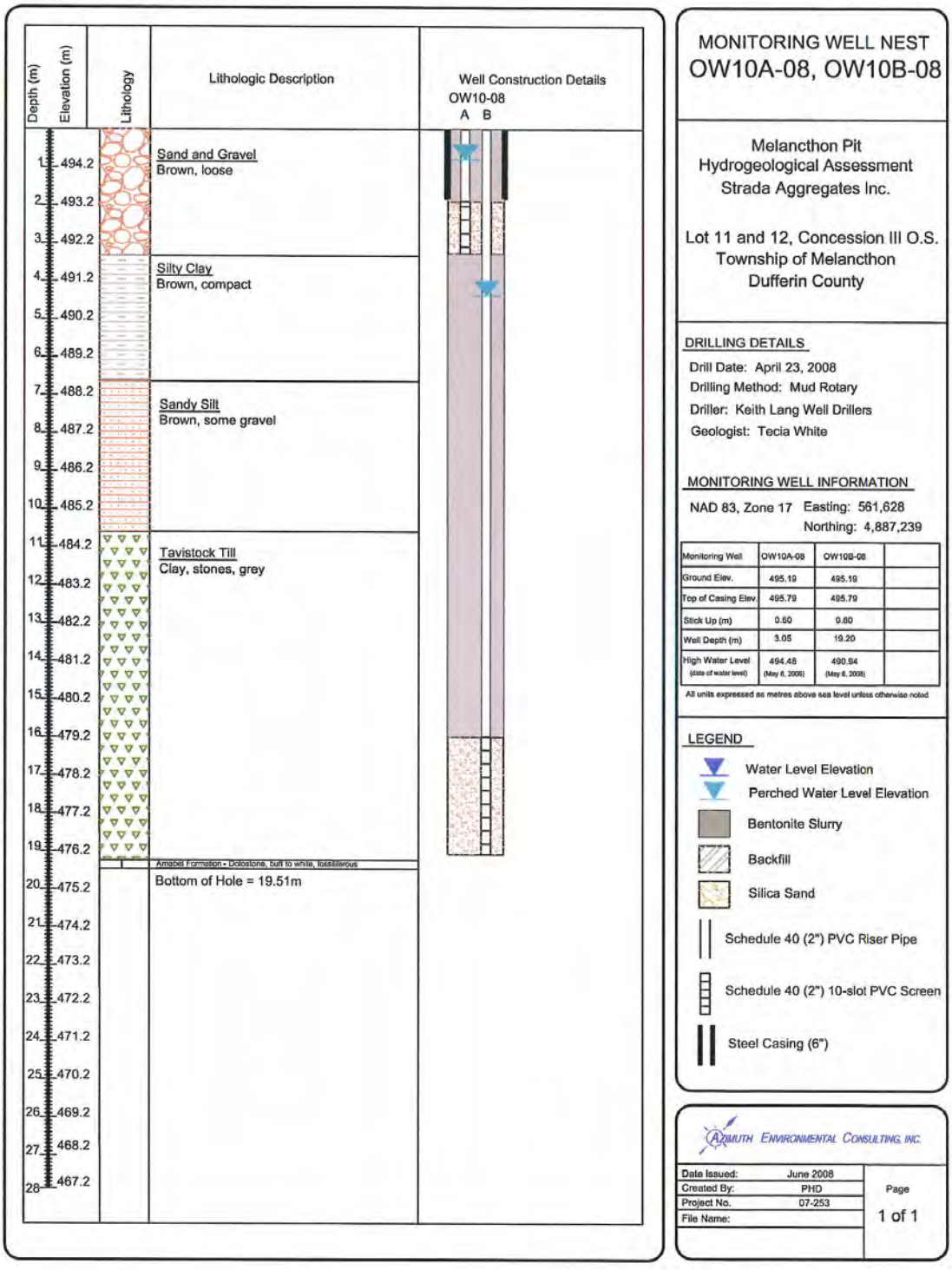


Figure A.38: Original Borehole Log for Nest OW10

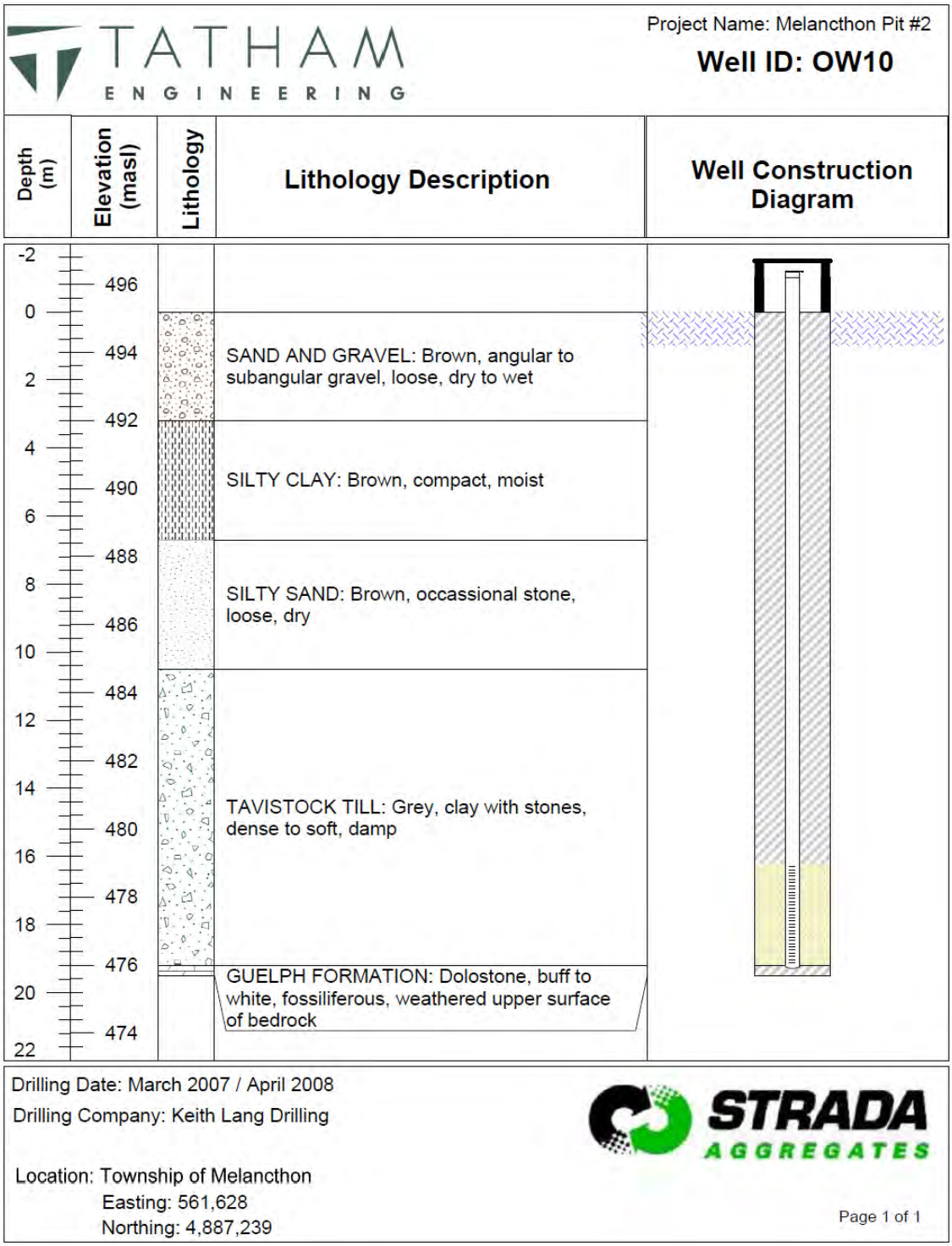


Figure A.39: New Borehole log for Well OW10.

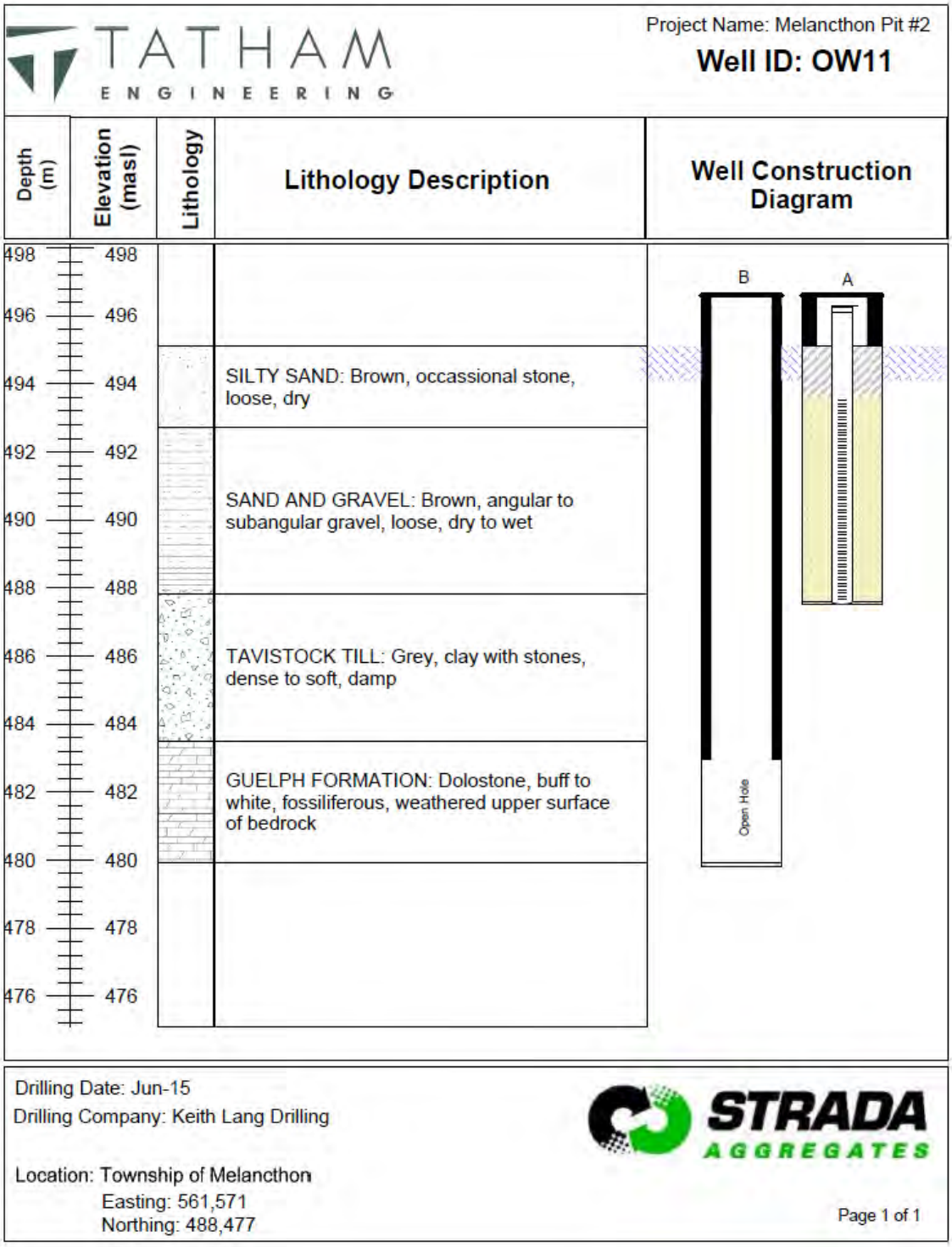


Figure A.40: Borehole log for Well OW11 A and C.

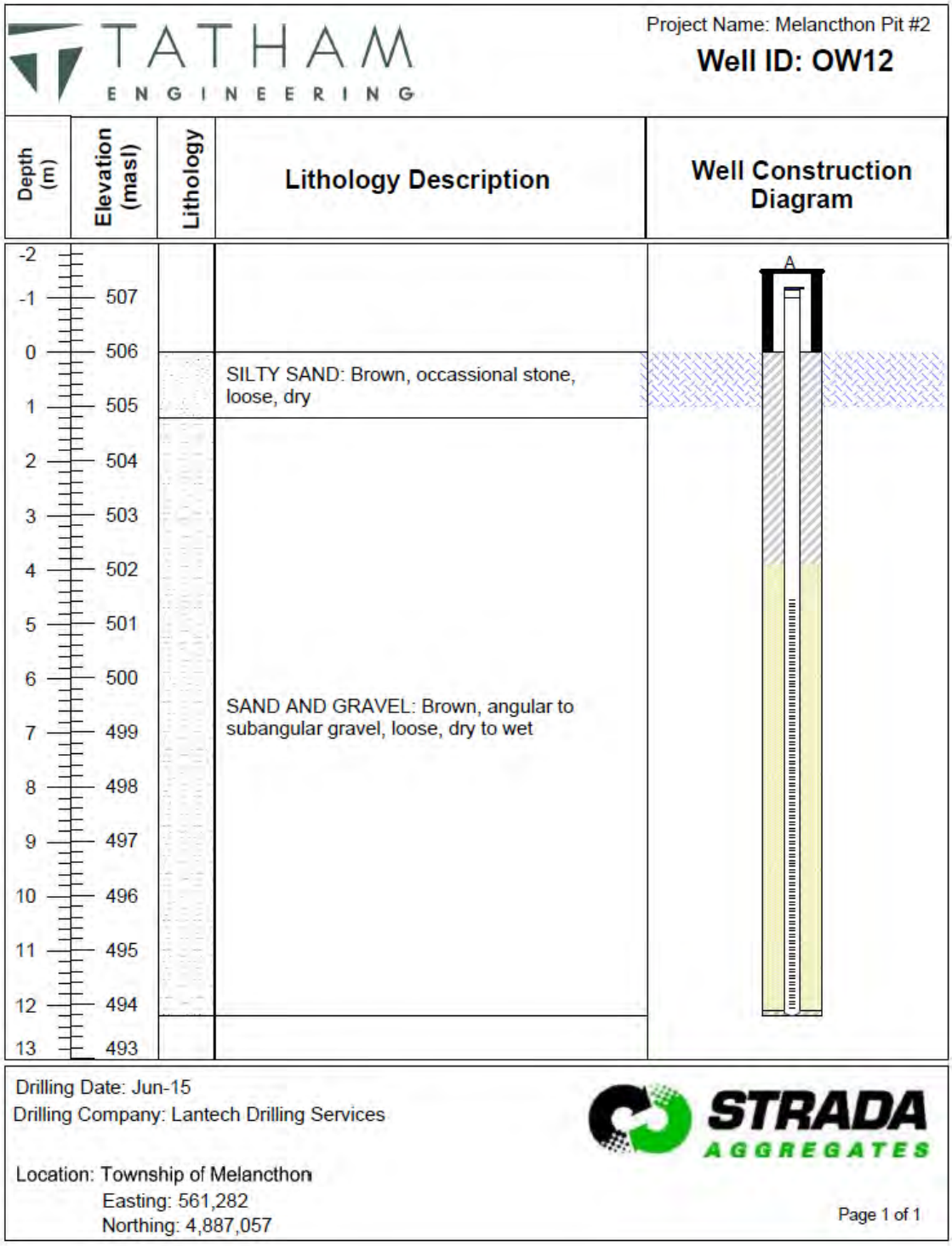


Figure A.41: Borehole log for Well OW12.

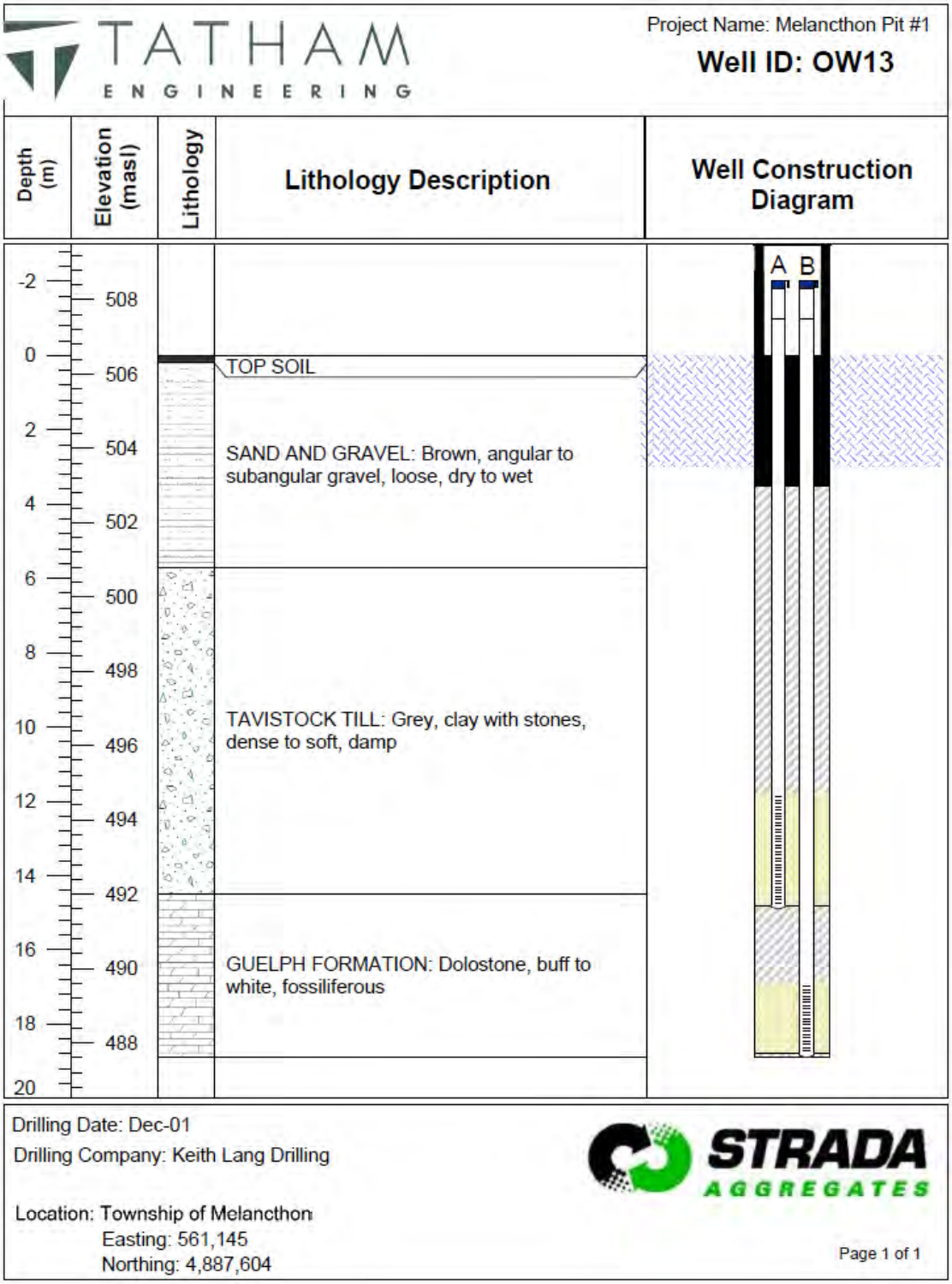


Figure A.42: Borehole log for Well OW13 A and B.

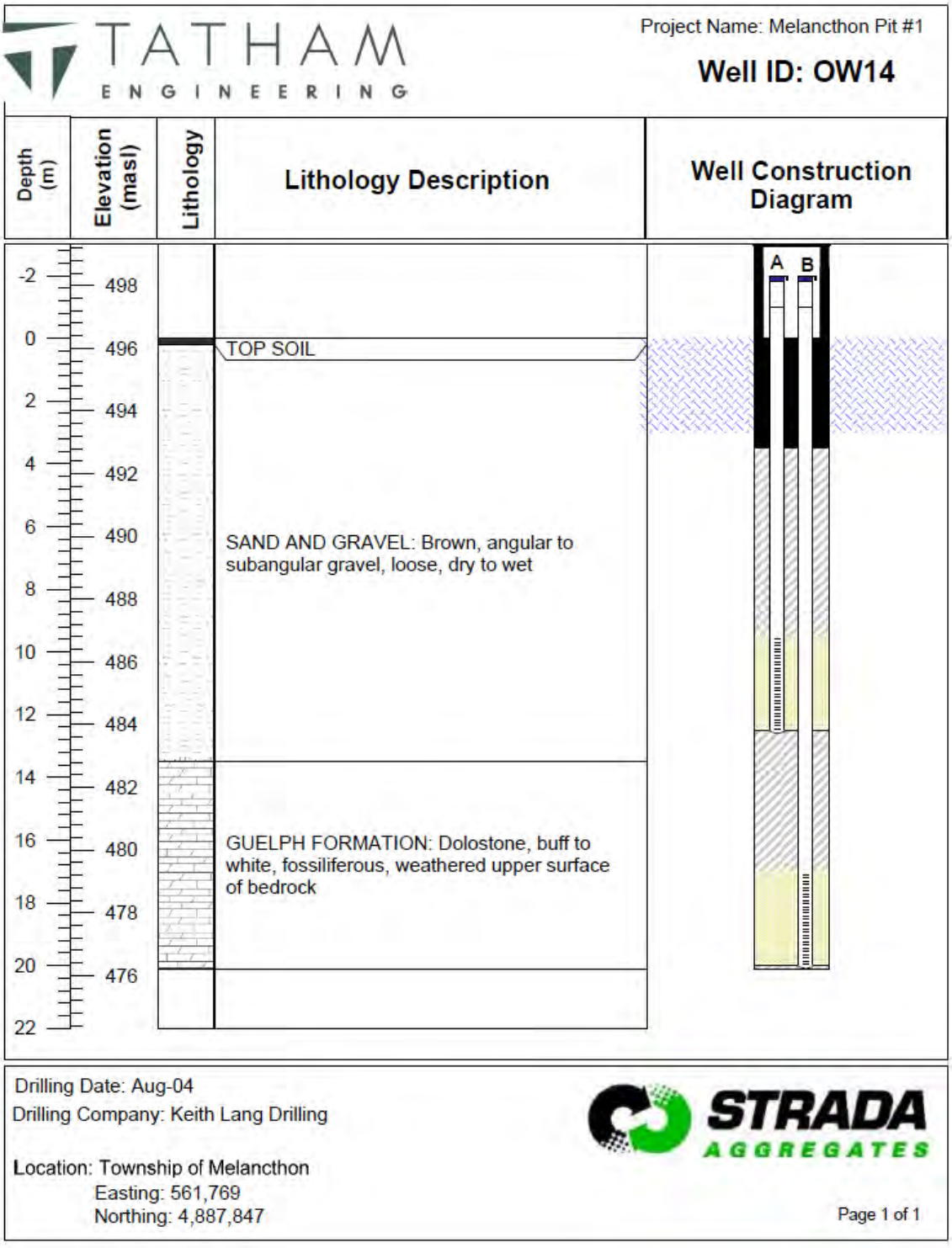


Figure A.43: Updated Borehole log for Well OW14 A and C.

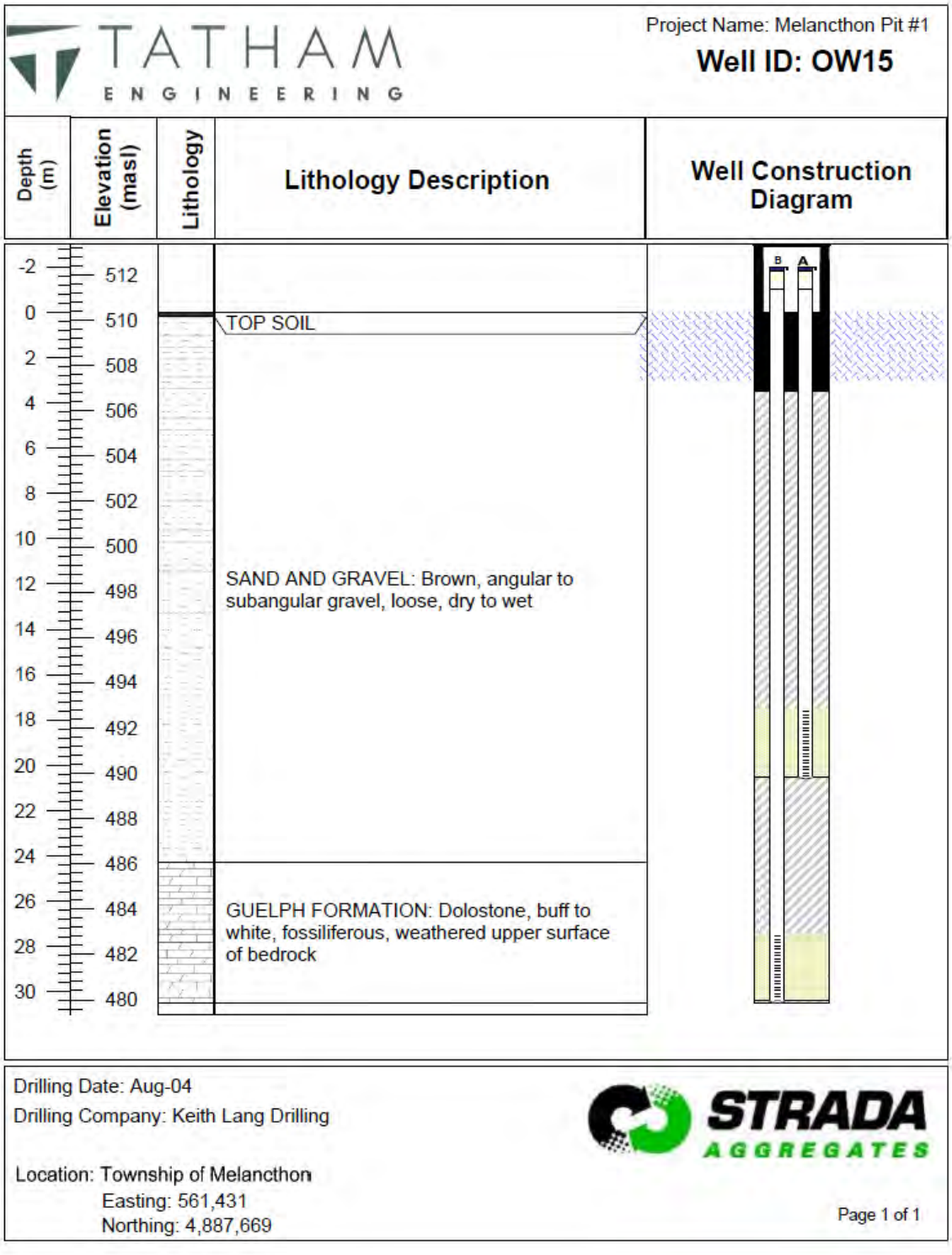


Figure A.44: Borehole log for Well OW15.

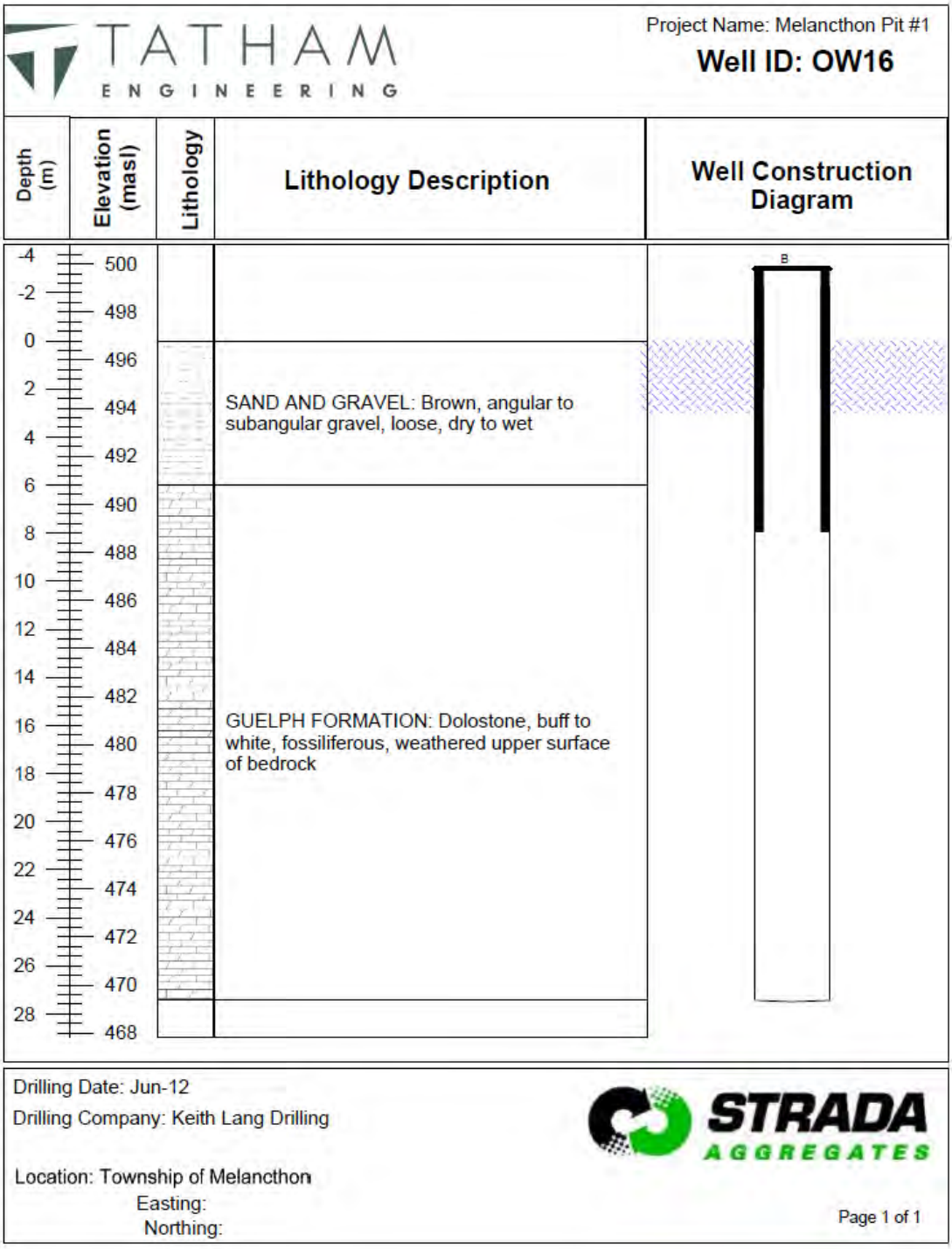


Figure A.45: Borehole log for Well OW16C.

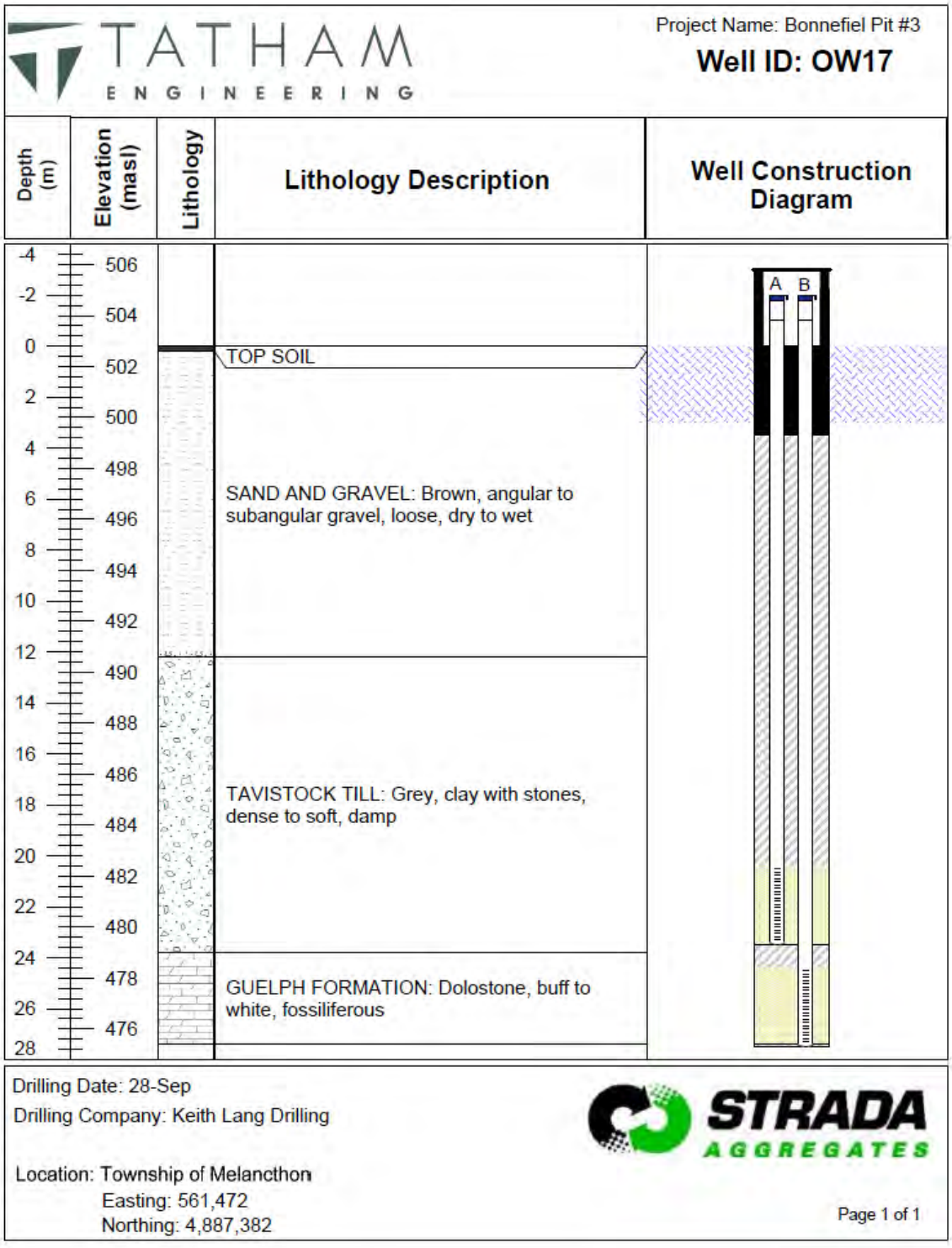


Figure A.46: Borehole log for Well OW17.

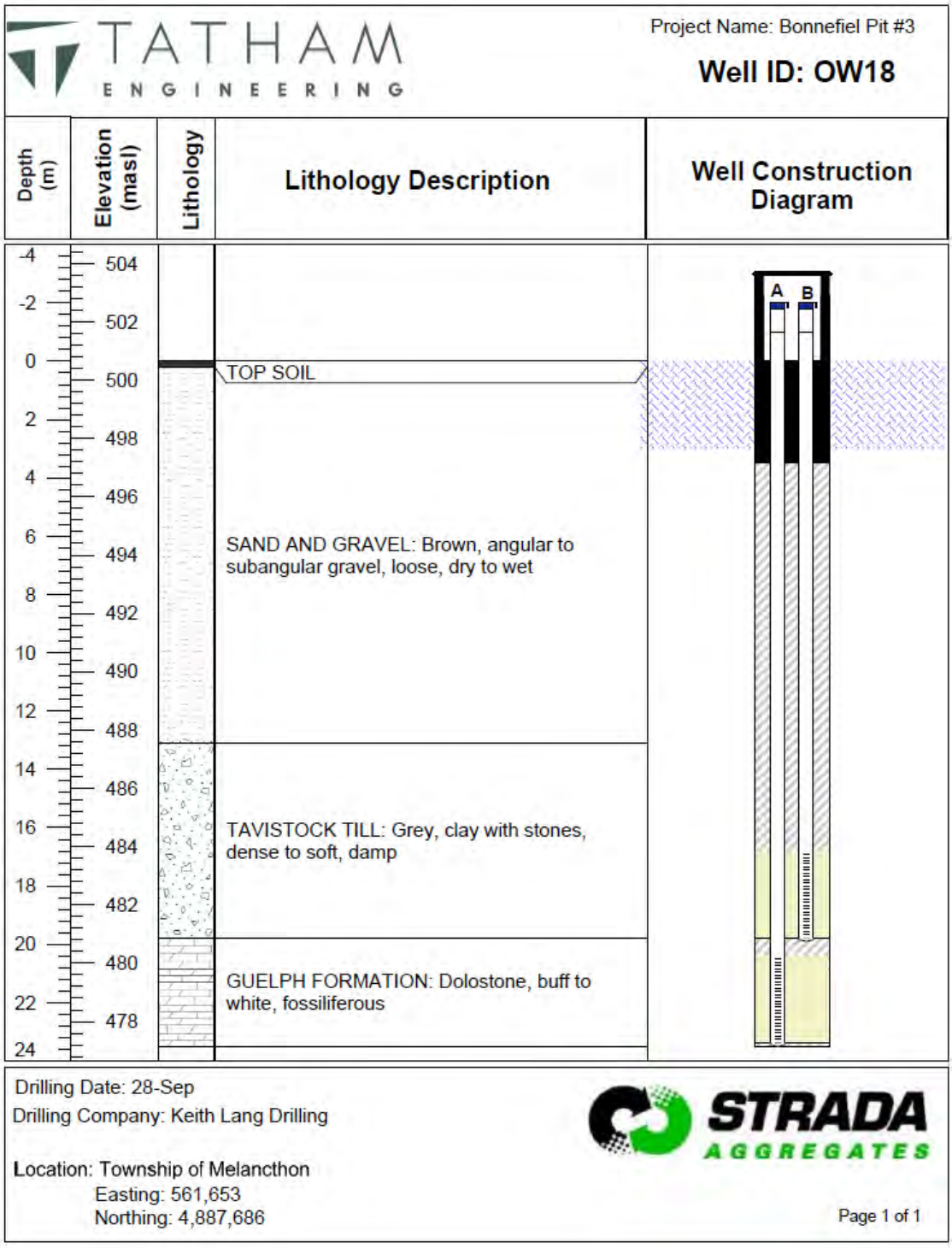


Figure A.47: Borehole log for Well OW18.

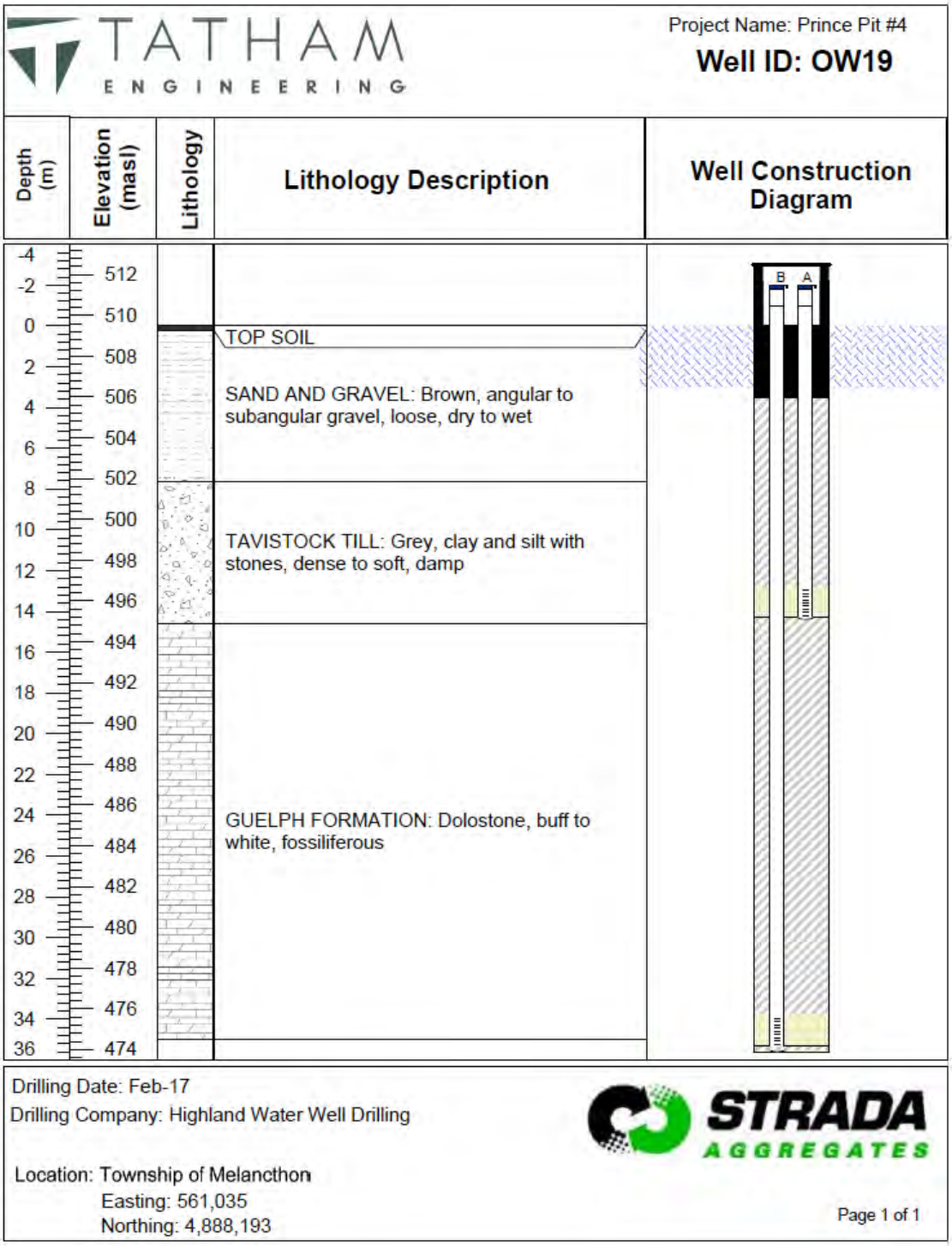


Figure A.48: Borehole log for Well OW19.

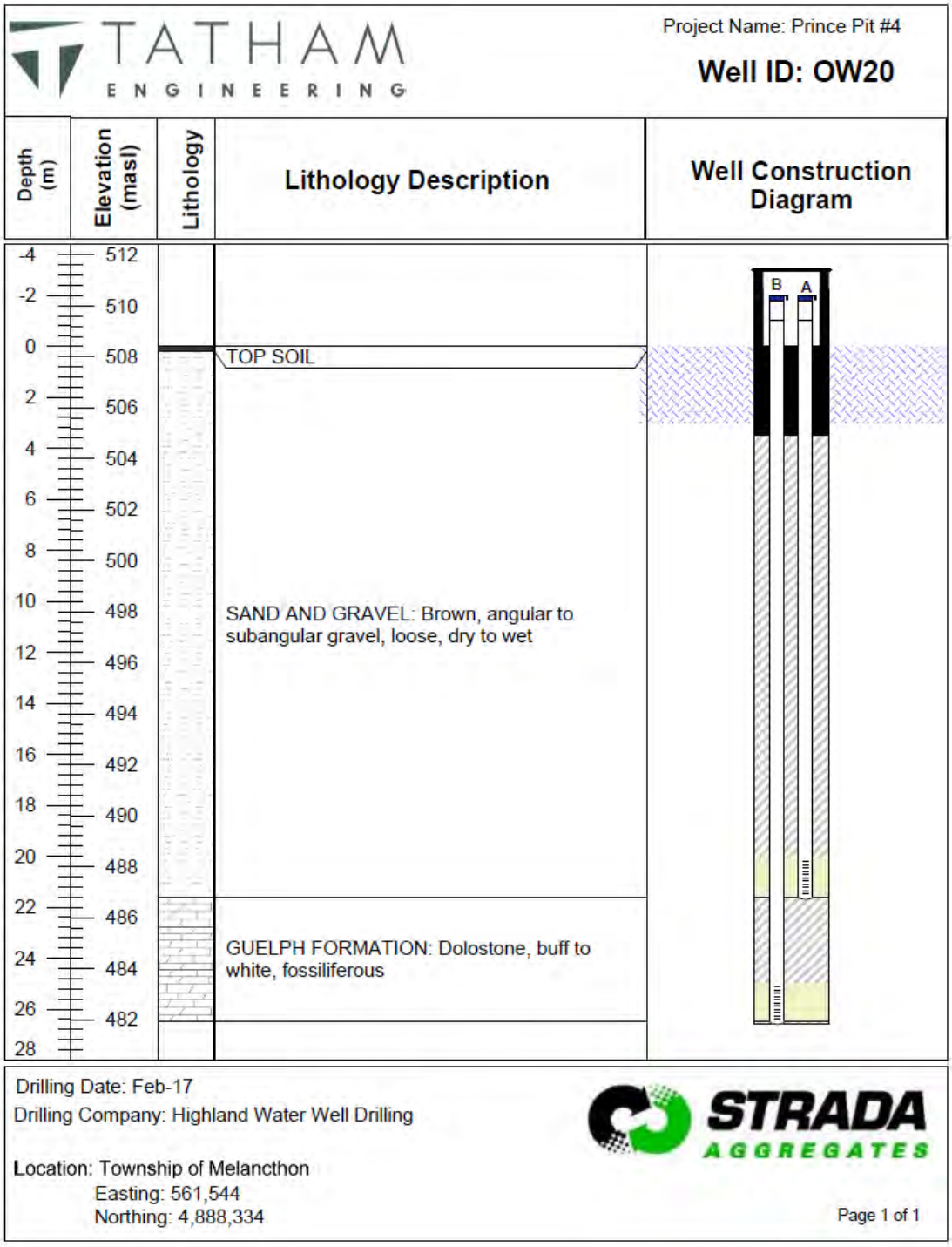


Figure A.49: Borehole log for Well OW20.

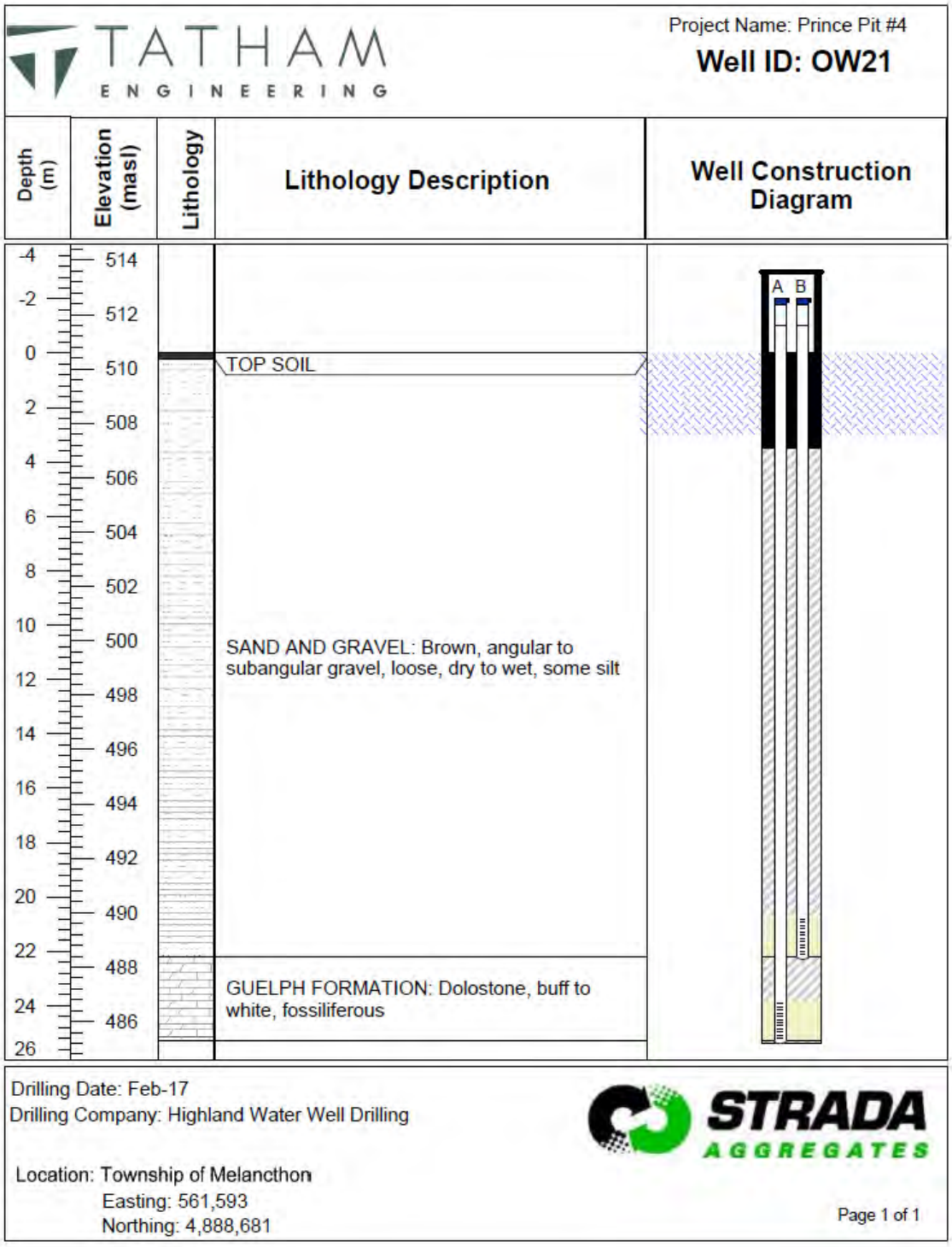


Figure A.50: Borehole log for Well OW21.

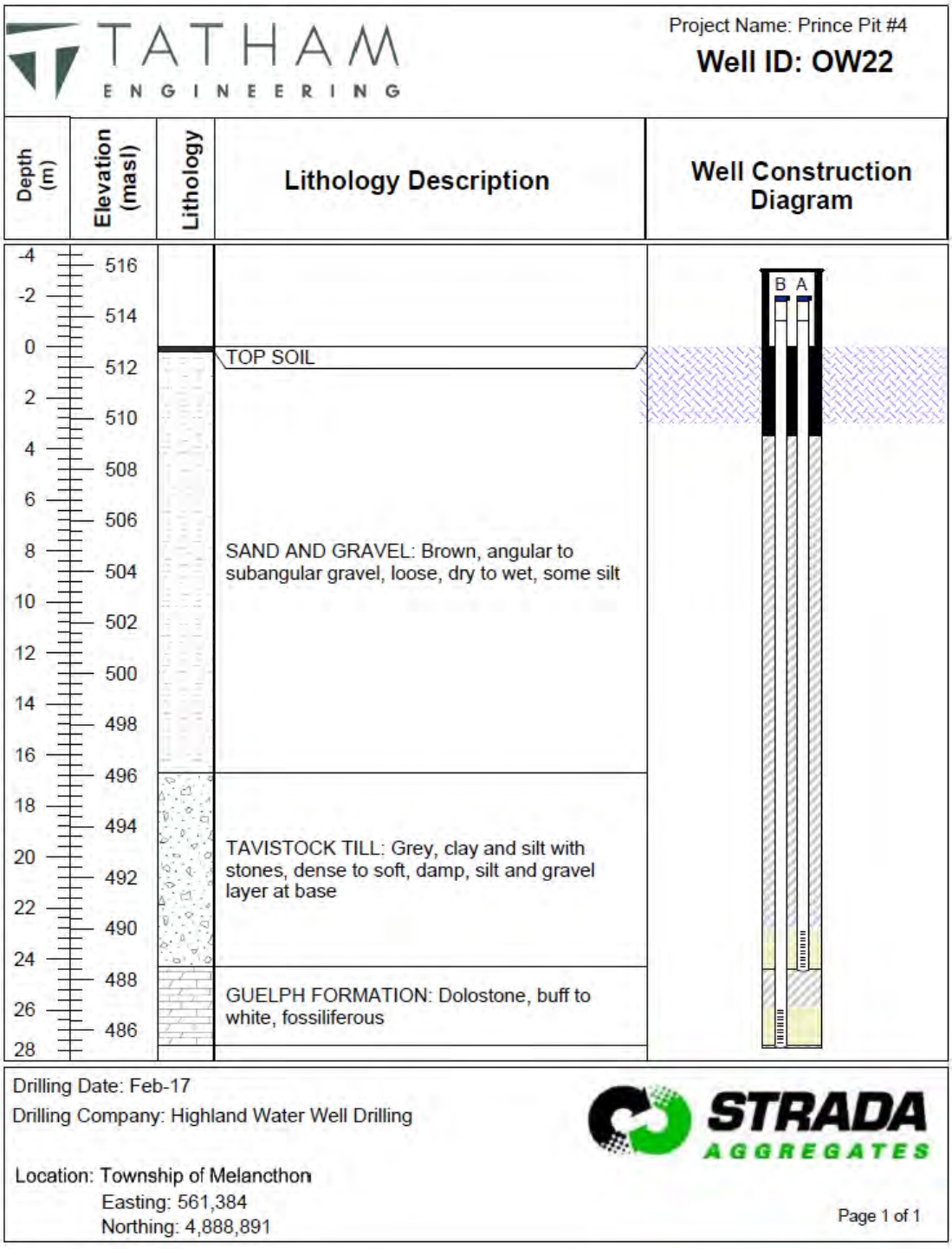


Figure A.51: Borehole log for Well OW22.

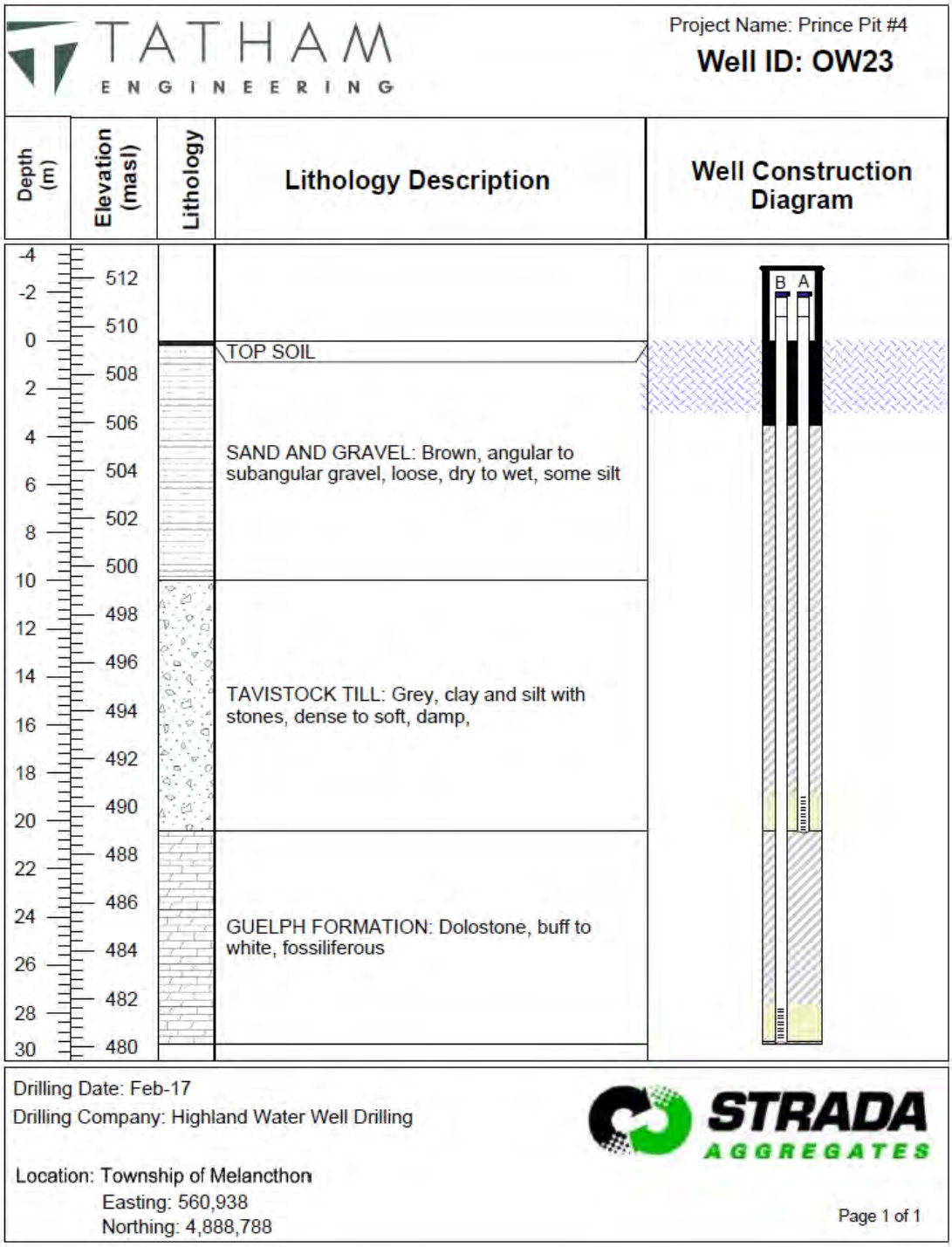


Figure A.52: Borehole log for Well OW23.

B. Field Program Data Assessment and Results

B.1 INTRODUCTION

The comprehensive multi-year field programs at the site have generated considerable information needed to assess site conditions and the potential effects of pit/quarry development. The purpose of this chapter is to present the field data and local site conditions. The integration of the site into the regional hydrogeologic and hydrologic setting is presented in more detail in the conceptual and numerical model development appendices.

B.2 STRATIGRAPHIC NOMENCLATURE

The objectives of the geological field program were to collect sufficient data to characterize the site conditions and rock properties, develop an extraction plan, and understand how the site fits into the regional stratigraphic and hydrostratigraphic setting.

The purpose of this section is to introduce the stratigraphic nomenclature and geologic framework used to describe the geologic units, and relate them to the core description at the site. This will be discussed in greater detail in Appendix C: Conceptual Model.

A schematic cross section showing the general stratigraphic nomenclature in the study area is shown in Figure B.1. The lower limit of the site investigations and interpretation is the Cabot Head Shale, a regionally extensive aquitard that isolates the site from the deeper groundwater flow system (Brunton and Brintnell, 2020, as illustrated in Figure B.2).

Brunton (2009) and Brunton and Brintnell (2020) have reconciled, refined, and updated the stratigraphic nomenclature of the units overlying the Cabot Head Formation (Cabot Head Shale). Prior to Brunton's work, different terminology was used in the southern (Niagara), central (Hamilton, Milton, Acton), and northern (Shelburne, Bruce Peninsula) sections of the Niagara Escarpment. A correlation of the various south and central nomenclature is shown in Figure B.3, while a correlation of the new nomenclature in the central and northern area is shown in Figure B.4. While the new nomenclature is an important integrated assessment and reconciliation of the stratigraphic framework, it is important to remember that there is considerable variability in the geologic conditions and rock properties across the 300+ km of the Niagara Escarpment. The interpretation also continues to evolve, for example, between 2012 and 2017, Brunton revised the geologic layering in the Shelburne area, removing the Eramosa Formation and revising geologic contact elevations by as much as 10 m (Earthfx, 2022).

Note that minor revisions to the spatial extents of the bedrock units were presented in the 2014 Aggregate Resources Inventory study (OGS/MHBC, 2014, and see map in Appendix C).

The quaternary geologic units are presented and discussed in Section B.4.

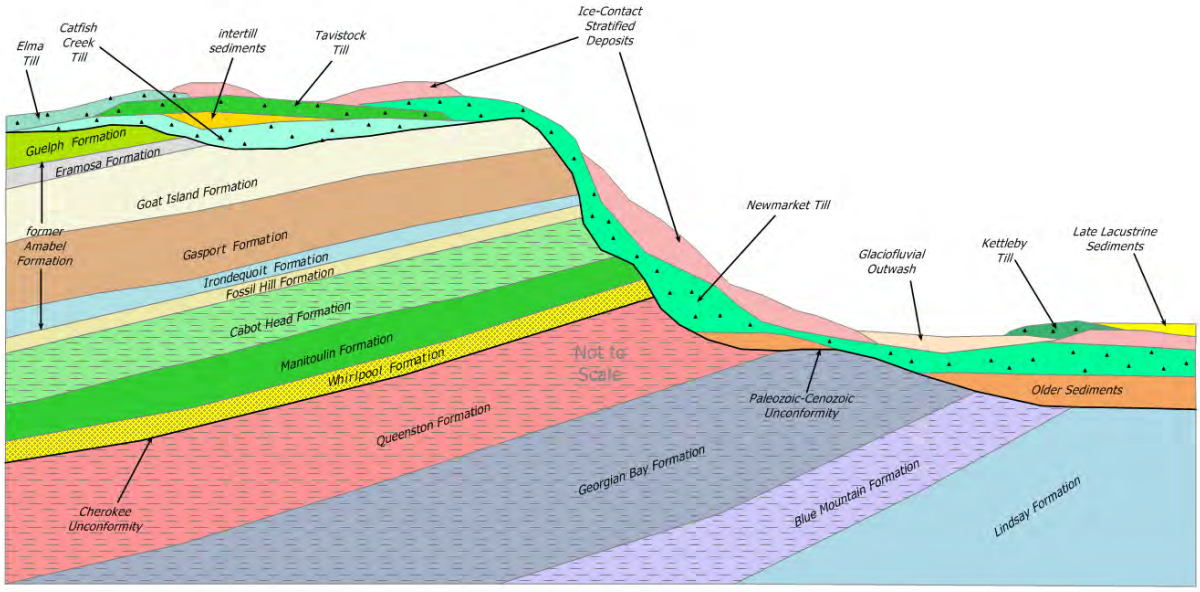


Figure B.1: Regional Stratigraphic Setting (After Earthfx, 2022).

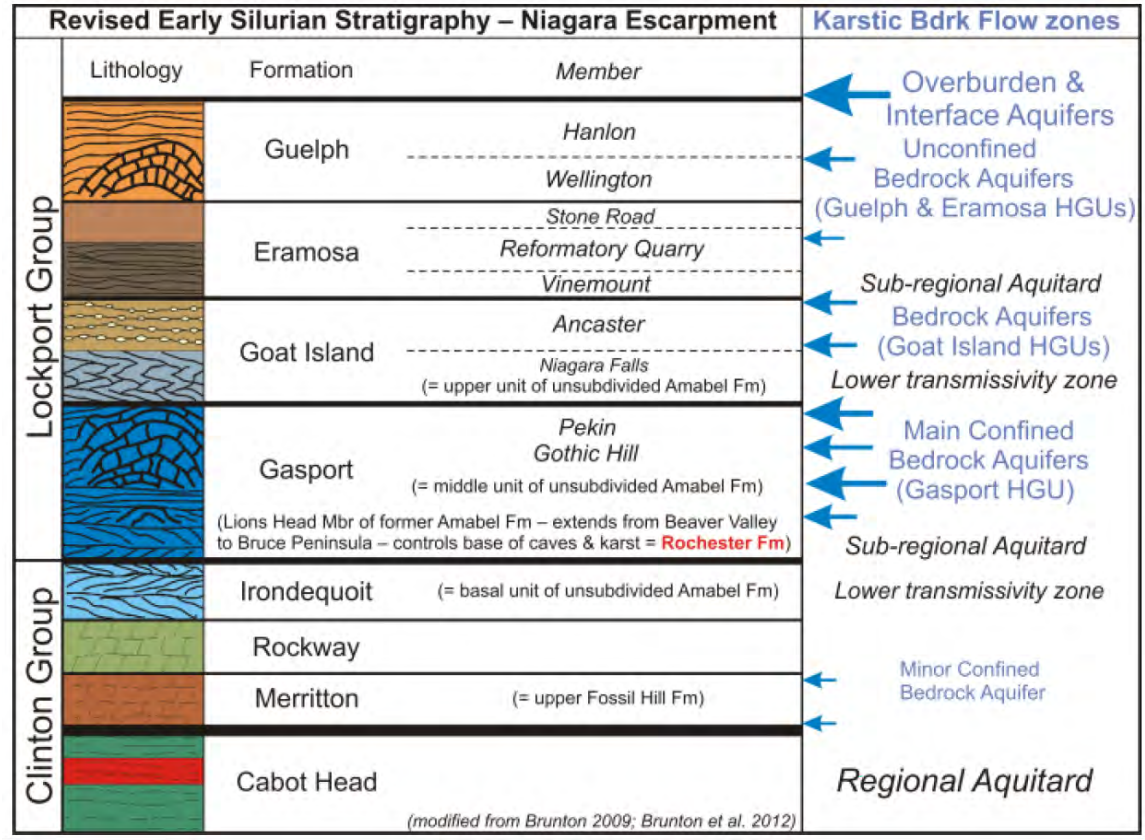


Figure B.2: Revised Early Silurian stratigraphy and hydrostratigraphy (Brunton and Brintnell, 2020).

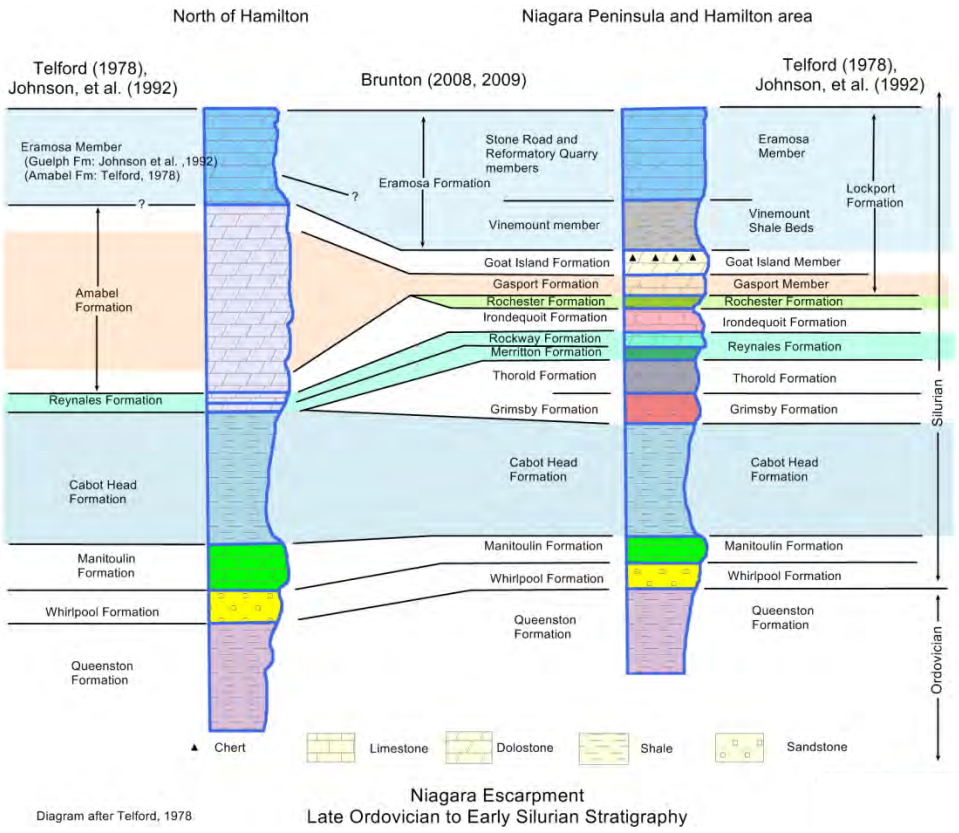


Figure B.3: Southern stratigraphic relationships and nomenclature.

Revised Conceptualization Formation / Member		Previous Conceptualization Formation / Member	
Overburden		Overburden	
Guelph Formation	Hanlon Member	Guelph Formation	
	Wellington Member		
Eramosa Formation	Stone Road Member	Amabel Formation	Eramosa Member
	Reformatory Quarry Member		
	Vinemount Member		
Goat Island Formation	Ancaster / Niagara Falls Members		Wiarton / Colpoy / Lions Head Members
Gasport Formation	Gothic Hill Member		
Rochester / Irondequoit / Rockway / Merritton Formations			
Fossil Hill Formation		Cabot Head / Reynales Formation	

Figure B.4: Updated bedrock nomenclature for the Bruce Peninsula area (after Brunton, 2009).

B.3 BEDROCK GEOLOGY

The bedrock geology at the site has been interpreted based on 7 high-quality cored boreholes. Core logs and photos were presented in Section A.10.1. The cores from these boreholes were logged in detail by Dirk Kassenaar (Earthfx) and Chris Rogers (Professor of Geological Engineering at Ryerson and former Manager of the Soils and Aggregates Section in the Materials Engineering and Research Office at the Ministry of Transportation). Logs and nomenclature were also reviewed and approved by Frank Brunton (Paleozoic Geologists at the Ontario Geological Survey).

A summary of the units found at the site is presented in Table B.1. The thickness and features presented in the table are generalized, and are discussed in more detail below. Representative sample images of the geologic units are presented in Figure B.5 and Figure B.6. These images can be compared to the core box images presented in Section A.10.1.

Table B.1: Site Summary – Bedrock Geology.

GEOLOGIC UNIT.	TOP OF UNIT (MASL)	BASE OF UNIT (MASL)	THICKNESS (M)	DESCRIPTION
Eramosa /Guelph Formation	489	474	15	White to brown/tan color
Goat Island Ancaster	474	466	8	Chert nodules
Goat Island – Niagara Falls	466	469	6	Blue-grey “pin-stripes”
Gasport Formation	460	443	17	Mottled blue-grey color
IRM Formation	443	437	6	Crystalline with stylolites
Cabot Head Shale	437	421	16	Grey to green to red-maroon, noncalcareous siliciclastic shales, with subordinate sandstone and carbonate interbeds



Figure B.5: Guelph Formation core photo (https://kocurekindustries.com/our-products/guelph-dolomite-cores).

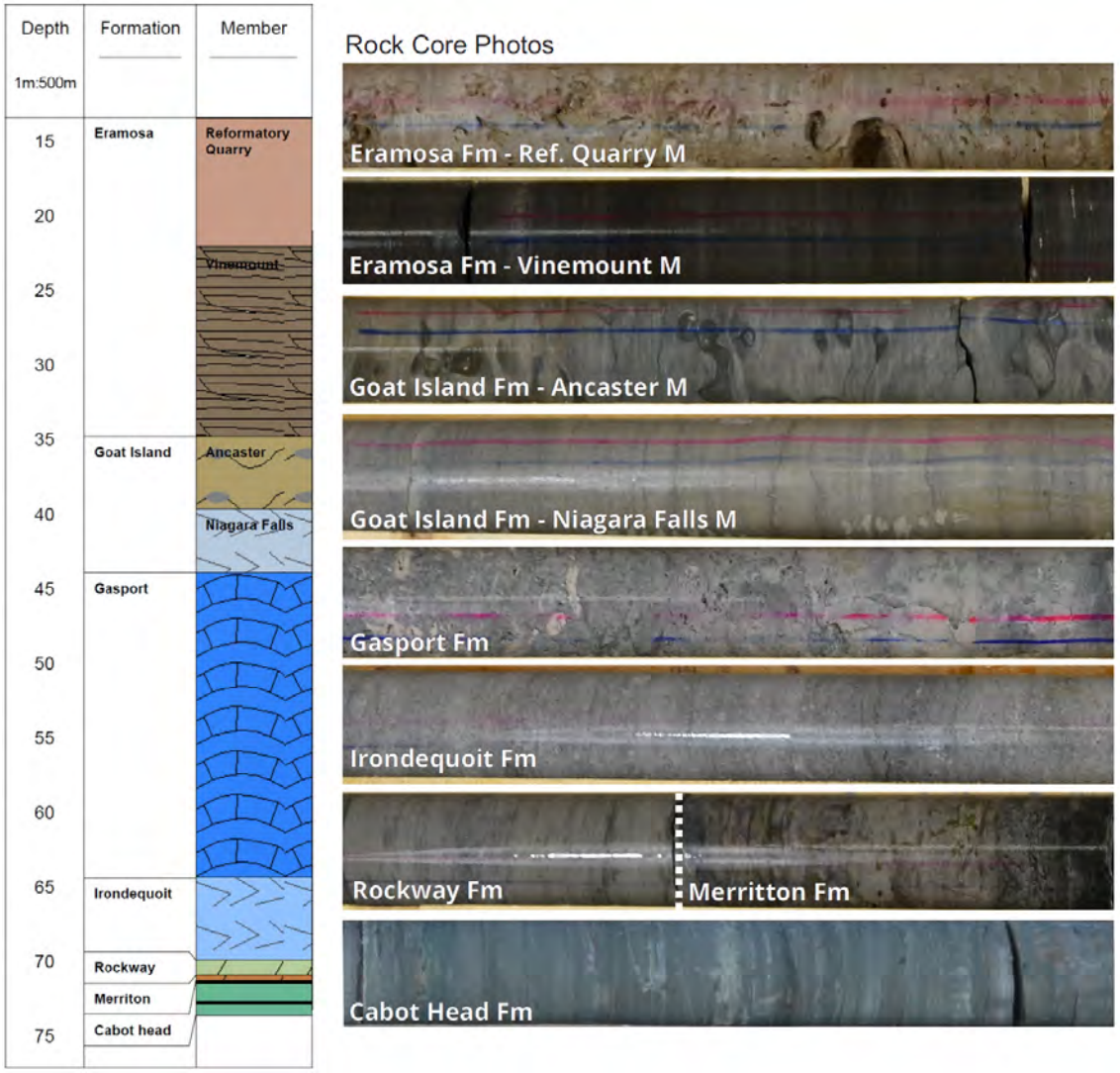


Figure B.6: Representative photos of each stratigraphic unit (After Munn, 2018 Figure 4.2.)

B.3.1 Cabot Head Formation

The rocks of the Cabot Head Formation are predominantly thinly laminated, grey and green, noncalcareous shales with minor interbeds of sandstone, limestone, and dolostone. It is the uppermost unit of the Cataract Group in the study area (Liberty, *et al.*, 1976a). A photo of the Cabot Head Shale from Core #3 is show in in Figure B.7. The Cabot Head Formation is continuous across the study area and was interpreted as the base of the flow system from the perspective of the proposed quarry impact analysis.



Figure B.7: Cabot Head Shale from Core #3.

B.3.2 Irondequoit, Rockway, and Merritton (IRM) Formations

The Merriton Formation (formerly known as the Reynales Formation) is at the base of the overlying Early Silurian Clinton Group. It unconformably overlies the Cabot Head Fm. and consists of cherty, dolomitic mudstone to wackestone (Brunton, 2009) and outcrops in the face of the Niagara Escarpment (Johnson *et al.*, 1992). The Rockway Formation conformably overlies the Merriton Formation and is described by Brunton (2008) as an argillaceous dolomicrite to wackestone with a distinctive, greenish-grey, finely crystalline matrix and thin shaly partings. Next in the sequence is the Irondequoit Formation, a porous, fine to medium crystalline limestone, with abundant fossils, particularly crinoid fragments. It is generally about two metres thick with one or two massive beds (Johnson *et al.*, 1992). The Irondequoit Formation was formerly thought to pinch out just west of Hamilton (Johnson *et al.*, 1992) along with the overlying Rochester Formation, but Brunton (2008, 2009) traced it in drill core as far north as the Bruce Peninsula and considers it to be the basal unit of the unsubdivided Amabel Formation (see Figure B.3 and discussion below). A photo of the IRM from Core #3 is show in in Figure B.8.



Figure B.8: IRM from Core #3.

B.3.3 Gasport Formation

The Gasport formation, also referred to as part of the unsubdivided Amabel Formation, is a regionally-important source of aggregate as well as groundwater. Light pinkish-grey, regionally transgressive, cross-bedded grainstone to packstone containing microbial–crinoidal reef mound lithofacies transitioning upward to rhynchonellid brachiopod–bryozoan–bivalve

coquinas. The site core exhibits the irregular elongate mottles that are commonly observed in the Colpoy Bay Member (now Gasport), as discussed in Dekeyser (2006, Figure 3.1).

In the Guelph area, Brunton (2008) found that the major aquifer in the former unsubdivided Amabel Formation is within what he called the "Gasport hydrogeologic unit" (this informal unit has also been referred to as the "Amabel Production Zone"). Brunton and Brintnell (2020) noted that the variable paleotopography of the Gasport Formation was the main control on the character and presence or absence of the overlying Goat Island and Eramosa Formations.



Figure B.9: Gasport Formation from Core #3.

B.3.4 Goat Island – Niagara Falls Formation

The Goat Island Formation is divided into two members. The Niagara Falls Member of the Goat Island Fm.is composed of finely-crystalline, crinoidal grainstones and is overlain by the chert-rich finely crystalline Ancaster Member (Brunton, 2009). (Note that the Goat Island and Gasport formations have been collectively referred to as the Amabel formation.) Brunton recently re-interpreted the geological data from the Town of Shelburne wellfield, and wellfield testing confirmed that the Niagara Falls member is an important regional aquitard that hydraulically isolates the deeper aquifer system from the shallower bedrock (Banks and Brunton, 2017). Therefore, the Niagara Falls Member of the Goat Island Fm. is interpreted as the key aquitard that confines the Gasport at the site. The Niagara Falls Member exhibits a characteristic "pin-stripe" pattern, and also characteristically exhibits a "sheen" reflection when wiped with a wet rag due to the fact that the moisture is not absorbed into the core (see Figure B.10).



Figure B.10: Niagara Falls member of the Goat Island Formation from Core #2.

B.3.5 Goat Island – Ancaster Formation

The Ancaster Member of the Goat Island Formation is also regionally significant, for it exhibits the characteristic and unique presence of chert nodules within the unit (Figure B.11). Regionally, the chert nodules have been used effectively to map the Ancaster unit in boreholes that were previously interpreted as unsubdivided Amabel Formation. The Ancaster is also interpreted as a regional aquitard unit.



Figure B.11: Chert nodules in the Ancaster member of the Goat Island formation from Core #2.

B.3.6 Eramosa and Guelph Formation

The Eramosa Formation typically overlies the Goat Island Fm. in southern Ontario. The presence of the Eramosa Formation in the study area has at times been difficult to confirm. The Eramosa was initially mapped in Shelburne well OGS10a by Golder (2013) but this unit was later removed in the logs presented in Banks and Brunton (2017) (Earthfx, 2022).

The lowest member of the Eramosa Fm. is a very shaley, fine-grained dolostones referred to as the Vinemount Member. The unit is characteristically very dark to black (see Figure B.6) and Brunton (2008) and others consider it a regional aquitard, where present. Some shale indicators are observed in the upper portion of the bedrock in the study area (Earthfx, 2022), and a bituminous smell is observed in Core #2, but no significant shale unit has been identified at this site.

The rock core collected above the Ancaster chert at the Strada site grades upwards from a tan buff-brown colour to a white/light grey color. The lower portion of this unit is inferred to be Eramosa formation, while the upper white portion of the core is softer and more porous (Figure B.12) and generally matches the characteristics of the Guelph Formation (Figure B.5).



Figure B.12: Upper portion of Core #2 – Guelph Formation.

The lower portion of this unit is a fine-grained buff-brown colour that is much less porous and somewhat massive in core recovery (Figure B.13). This unit is considered Eramosa, and may correspond to the Reformatory Quarry member of that unit, which is described as “light-brown to cream coloured thick bedded, coarsely crystalline and coral-stromatoporoid biostromal lithofacies”.

For the purposes of quarry assessment, the Guelph/Eramosa is considered one stratigraphic unit.



Figure B.13: Lower portion interpreted as the Eramosa unit.

B.4 QUATERNARY GEOLOGY

Overlying the Paleozoic bedrock is a suite of unlithified sediments (drift) of Quaternary age, deposited mainly in association with continental glaciation. A schematic representation of the overburden is shown in Figure B.1. Quaternary geology was mapped in the area by Gwyn (1975), Cowan (1976), and Burwasser (1974). These maps were incorporated into the Ontario Geological Survey digital compilation map of southern Ontario Quaternary Geology (OGS, 2010). Figure B.14 shows the surficial geology for the Strada site vicinity. As can be seen, the site lies within an area where the surface deposits have been mapped as ice-contact stratified deposits. There are till units surrounding and, most likely, underlying the ice contact deposits. The coarse-grained and till units are discussed further below.

B.4.1 Regional Till Units

Gwyn (1972) noted that exposures in the area were examined in which there were two or three tills in the profile. These could be Catfish Creek, Tavistock and Newmarket Till, as shown in Figure B.1. The oldest exposed Quaternary sediment in the area is probably the Catfish Creek Till, a very compact to hard, stony to bouldery glacial diamicton with a sandy silt matrix (Cowan, 1976). The unit outcrops in the northwestern part of the area (OGS, 2010) and is quite extensive in the subsurface. The Port Bruce-aged Tavistock Till consists of sandy silt to silt to clayey silt diamicton deposited mainly by southerly flowing glacial ice (Gwyn, 1975). It outcrops extensively in the southwestern part of the study area extending to the west of the Strada properties. A coarse-textured phase is present north of Shelburne and west of Mono Centre (OGS, 2010). The younger Newmarket Till outcrops east of the Strada property, and dominates below the Niagara Escarpment, where it was deposited by ice flowing to the southwest. It has a generally sandy silt to loam matrix with about 5 to 10% clasts (Gwyn, 1975). The youngest till in the area is the Kettleby Till, which outcrops below the escarpment along the Highway 89 corridor and Airport Rd west of Alliston (OGS, 2010). It is variable in texture, ranging from clay till to silt till with only 1 to 2% clasts (Gwyn, 1975).

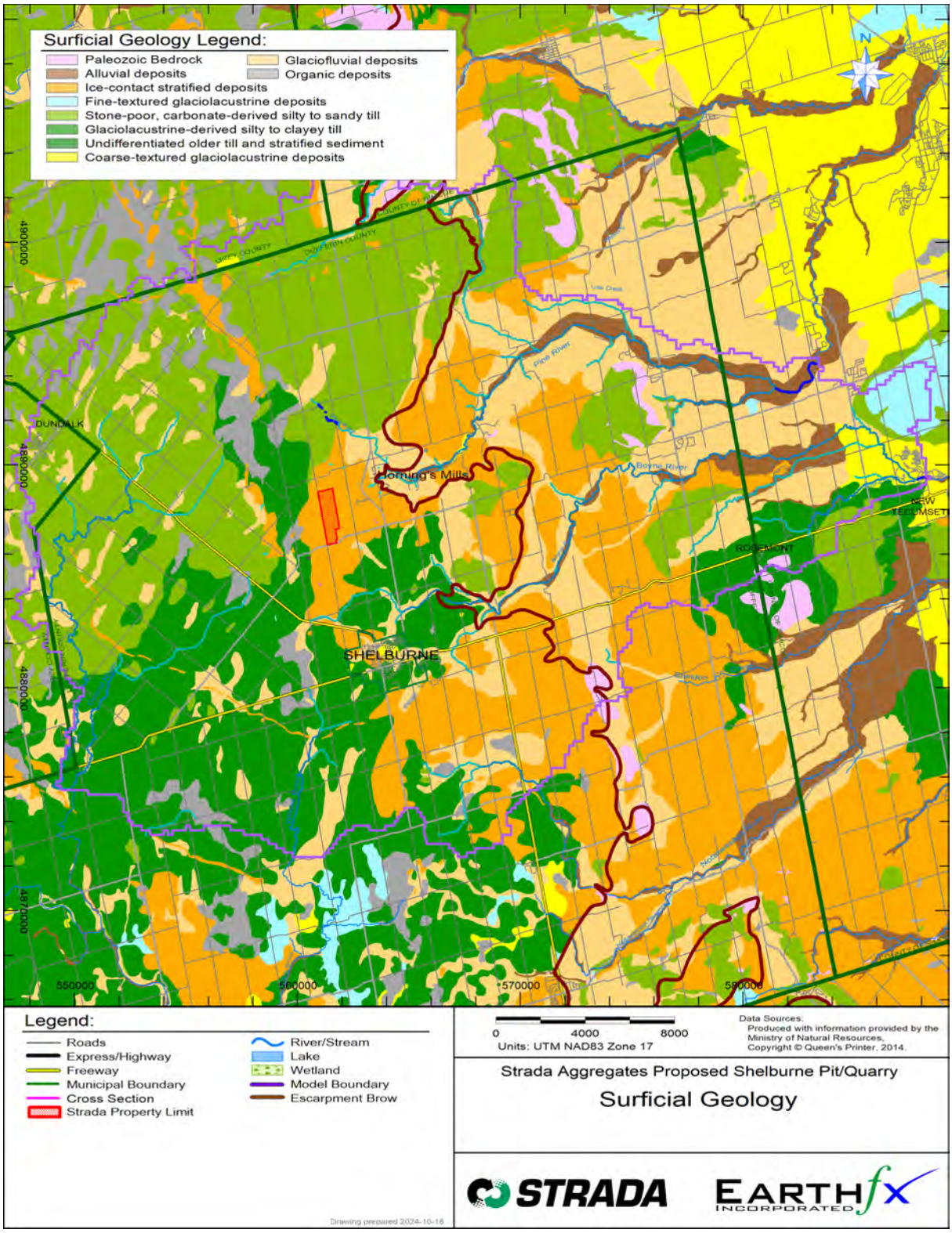


Figure B.14: Surficial geology in the site vicinity.

B.4.2 Coarse-Grained Deposits

Glaciofluvial deposits of sand, gravel, and minor silt are extensive in the vicinity of the Strada Property, particularly in the northern and eastern areas passing through the Escarpment (OGS, 2010). These bodies of granular material take the form of either ice-contact stratified deposits – eskers, kame moraines, and kame terraces – or outwash deposits formed in braided proglacial streams (Gwyn, 1975, Cowan, 1976). There are limited postglacial lacustrine deposits of fine sand, silt, and clay in the extreme eastern part of the area (OGS, 2010). Recent deposits include alluvial sediment of fine sand and silt along modern stream flood plains, as well as thin deposits of wind-blown fine and coarse silt (Gwyn, 1975).

B.4.3 On-site Deposits

At 13 drilling locations at the Strada site, a significant deposit of sand and gravel was found to overlie a dense silt till on bedrock (See Section A.10.2 for borehole logs). The till on bedrock is interpreted to be Tavistock Till, however the properties of the Catfish Creek are very similar . The other nests have only sand and gravel lying directly on bedrock. In one nest, OW10, located in the south-central portion of the site beside a shallow pond, a thin silty clay unit was identified. The geologic conditions at the site are discussed in more detailed below, while a more comprehensive discussion is presented in the conceptual model chapter.

B.5 HYDRAULIC TEST RESULTS

B.5.1 On-site Testing

As noted in Section A.6.1, two aquifer tests were completed at the site. The first was a 24-hour aquifer test conducted by Goffco Limited in November 2004 (Goffco, 2005). Pumping was continuous at a constant rate of 100 imperial gallons per minute (Igpm) or 454 L/min. The drawdown in the pumped well (PW1) after 24 hours was 16.37 m and the available drawdown was about 24.5 m. The aquifer transmissivity was inferred to be 60 m^2/d based on the specific capacity of 40 $m^3/d/m$. The pumping well was assigned a sustainable rate of 50 Igpm

The second aquifer test was conducted in May 2007 (Goffco, 2007). Pumping at well MW2-07 began at a rate of 16.3 Igpm (74 L/min) and continued for 15 minutes. The rate was decreased to 6.2 Igpm (28 L/min) for the rest of the 130 minute test. The static level at the start of pumping was 12.41 m below top of casing and the nearly-stable pumping level after 130 minutes was 52.54 m, indicating a drawdown of 40.13 m. No transmissivity estimate was provided by Goffco (2007) but using the same approach, the specific capacity of 1.0 $m^3/d/m$ would indicate a transmissivity of 1.5 m^2/d. The low yields resulted in a recommended sustainable pumping rate of 26 L/min.

These formal aquifer tests, together with the long-term pumping for wash water that occurred at the site, provide a valuable insight into the bedrock aquifer characteristics on site. Other nearby pumping tests, well operations and monitoring in the vicinity of site (e.g., Genivar (2011), Whitewater (2013) and the testing of Wells 7 and 8 for the Town of Shelburne (Earthfx, 2022)) provided additional regional-scale information on aquifer properties. All of these tests and observations are used for model development and calibration.

B.5.2 Lugeon Testing

Section A.6.3 described Lugeon testing conducted on-site to provide more detailed information on the hydraulic conductivity of the fractured bedrock system at the three cored boreholes. The results of testing are provided in a Figure B.15. All testing produced patterns consistent with dilatancy; that is, testing at higher pressures temporarily opened existing fractures, resulting in higher rates of flow. Accordingly, the smallest Lugeon value for each set of tests was taken as representative of the rock properties in the interval.

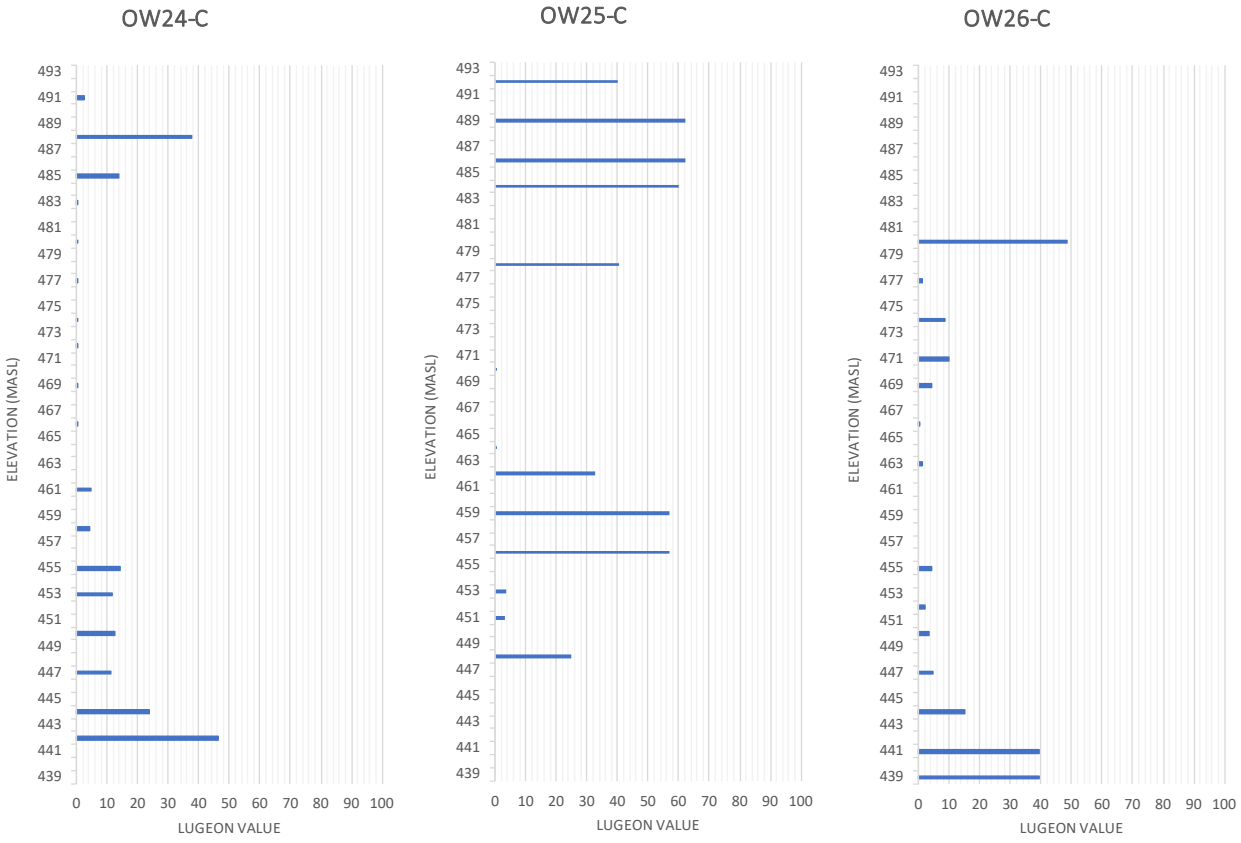


Figure B.15: Lugeon Results

B.6 GROUNDWATER LEVELS

B.6.1 Groundwater Monitoring

There are currently 22 groundwater well nests that monitor 30 discrete aquifer intervals in the overburden and bedrock aquifers at the site (Table A.1, and Figure A.5). As discussed in Section A.3 and A.4 and A.9.1, there is an extensive water level database developed from the existing wells in the groundwater monitoring program as well as historic data from wells that may have been destroyed or are no longer accessible. In this section, time-series of water levels at each well nest have been plotted for the various periods of record based on the data availability.

B.6.2 Groundwater Level Hydrographs

OW1 and PW1: In 2006, the MECP issued Strada a PTTW No.: 8277-6HYN9S, which permitted the taking of groundwater from PW1 (MECP Well ID 17-06267) for the purpose of filling a closed-lopped aggregate washing and settling system. As a

condition of this permit, Strada collected continuous water levels from PW1. OW1, located 31 m from PW1, was also equipped with a continuous datalogger. In May 2012 Strada cancelled the PTTW as well pumping was no longer required.

Water levels during the duration of the PTTW are presented on Figure B.16. Water levels show the wells response to both seasonal fluctuation as well as the effects of pumping. When PW1 was operating at a rate of 227 L/min, drawdown in the observation well OW1 was reported to be approximately 5.5 m. Drawdown in PW1 reported is approximately 0.5 m to 1.0 m greater than at OW1. The influence of pumping from PW1 on the water levels at other nearby bedrock wells on-site was minimal or not observed at all.

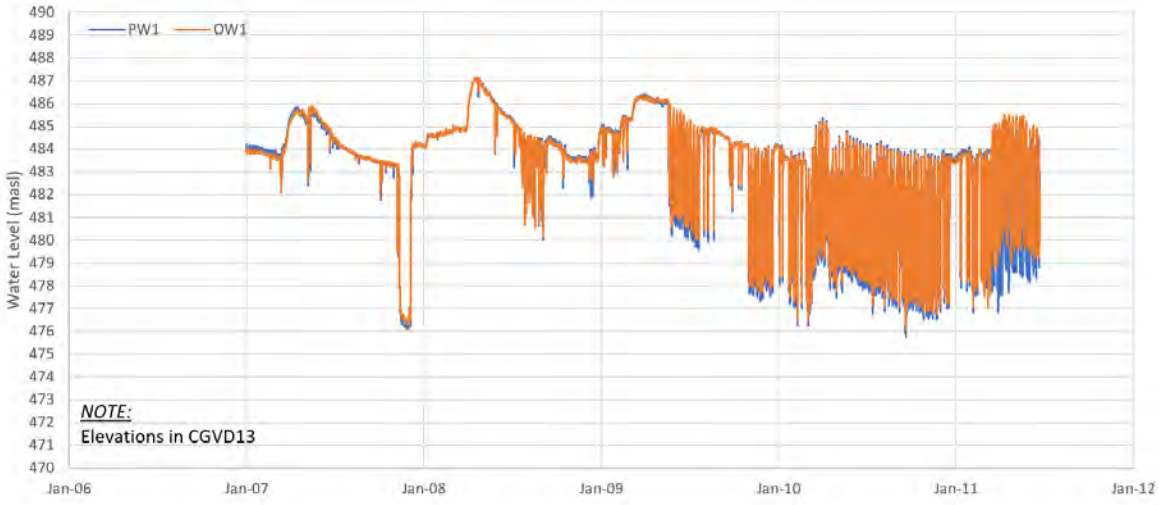


Figure B.16: Hydrograph of water levels at PW1 and OW1, in masl

OW2 Well Nest (destroyed in 2020): OW2 was located along the western property boundary (Figure A.5) and was destroyed in 2020 while berm work was being carried out. The water level record (Figure B.17) shows that the water levels in all three monitoring wells respond to seasonal conditions. Water levels measured in OW2A fluctuate between approximately 501.3 masl and lows of approximately 497 masl, which coincides with the base of the well screen indicating that the sand and gravel unit will dry up during drought conditions. The water level in the till unit (OW2B) fluctuates between a high of approximately 500.5 masl to a low of 494 masl. The water level in the bedrock unit fluctuates between a high of approximately 498 masl to a low of approximately 492.5 masl. Water levels are above the bedrock contact, which is found at an elevation of approximately 480 masl (Figure B.17). The vertical gradient is downwards across the A and B monitors and is upward from the C to B monitors.

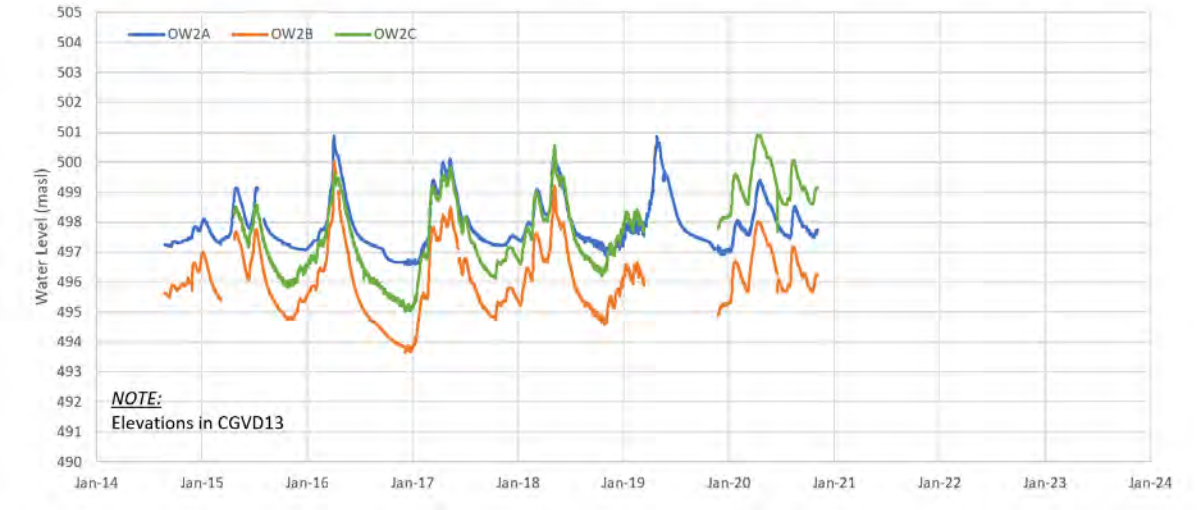


Figure B.17: Hydrograph of water levels at Well Nest OW2, in masl.

OW3 Well Nest: OW3 is also located along the western property line (Figure A.5). Bedrock water levels (OW3C) and overburden water levels (OW3B) have been plotted on Figure B.18. The sand and gravel unit is dry at this location (OW3A). Water levels in the bedrock mirror the water levels in the overlying till unit and fluctuate between a high of approximately 495.6 masl and a low of 490.73 masl. Water levels measured at OW3B drop below the base of the well screen and into the bedrock during dry conditions.

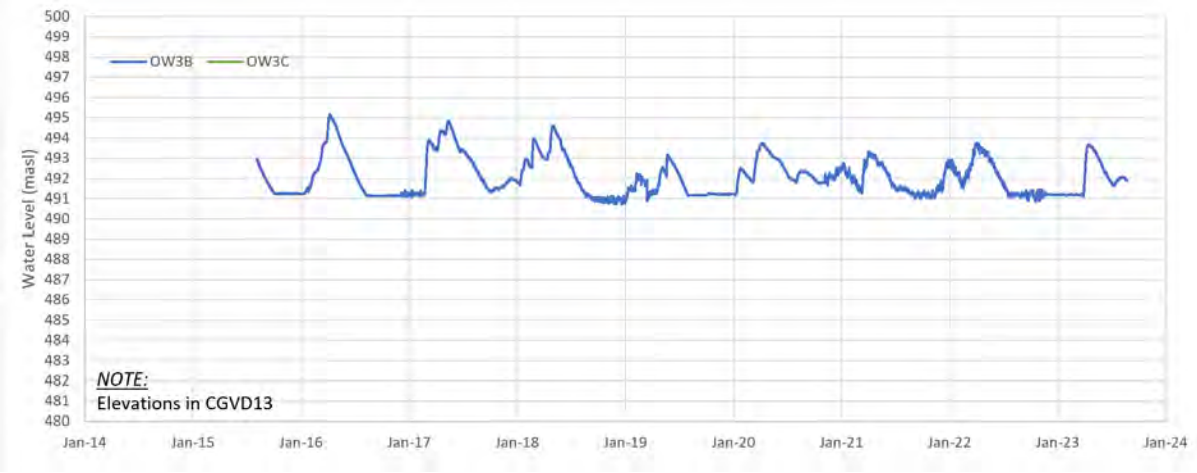


Figure B.18: Hydrograph of water levels at Well Nest OW3, in masl, 2008 to 2009.

OW4 Well Nest: OW4 is in the southwestern corner of the site (Figure A.5). Bedrock water levels (OW4C) have been plotted on Figure B.19 and have been compared to water levels reported in the overburden (OW4A and OW4B). Water levels in the in the bedrock are found between 494.5 masl and 490.2 masl (range of 4.3 m). OW4A, OW4B, and OW4C show seasonal

responses to spring freshet and large storm events, and surprisingly, the responses in the bedrock are more significant, possibly due to increase inflow where the till is thin.

OW29C was installed in the spring of 2023 in the vicinity of OW4 to better understand the vertical hydraulic between the shallow bedrock unit and the deep Gasport bedrock unit. Figure B.20 illustrates a downward hydraulic gradient between the OW4 monitors and the deep bedrock OW29C monitor.

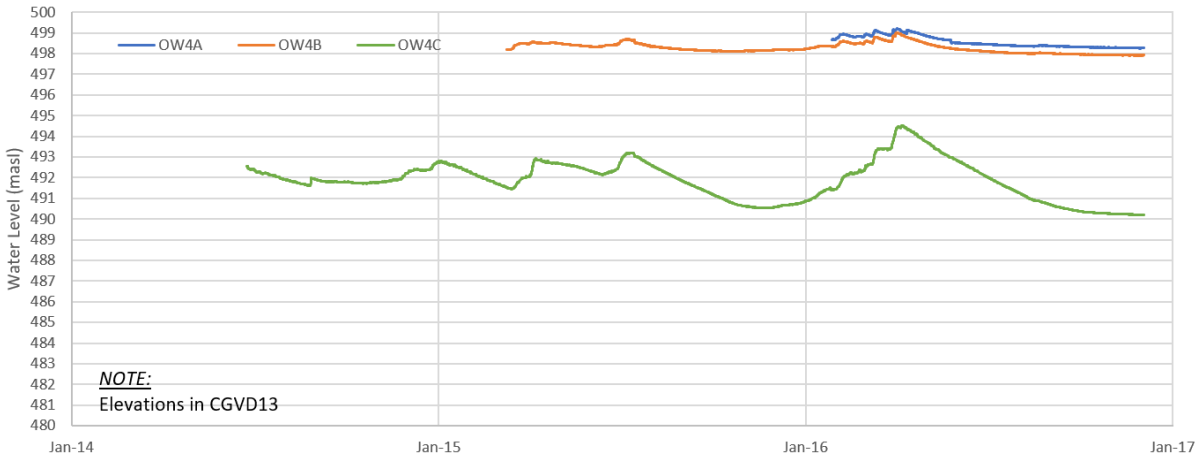


Figure B.19: Hydrograph of water levels at Well Nest OW4, in masl., 2014 to 2016

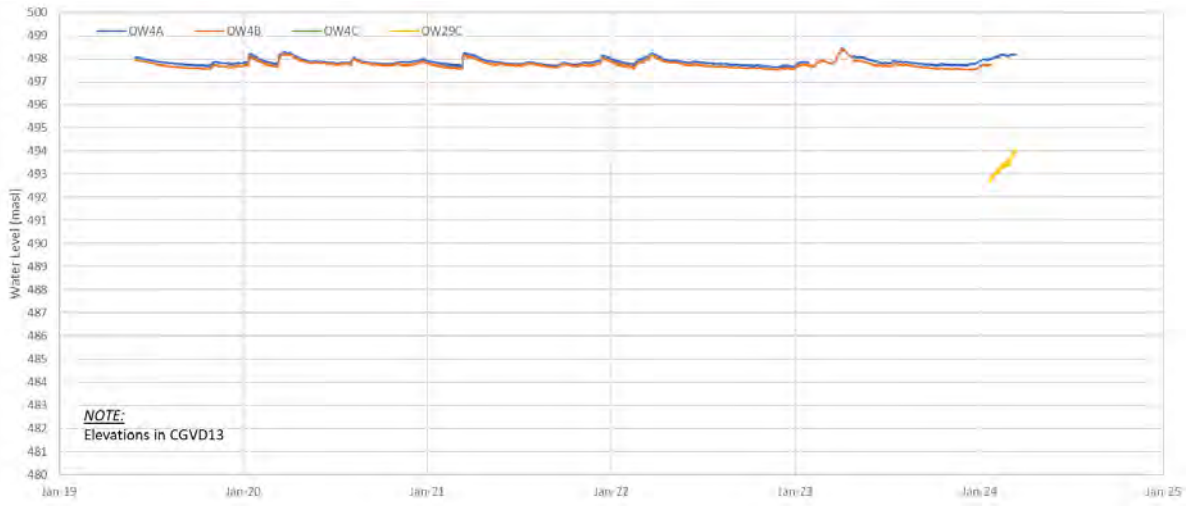


Figure B.20: Hydrograph of water levels at Well Nest OW4 and OW29C, in masl.

OW5 Well Nest: The OW5 well nest is in the southeast corner of the site. The water levels at this location differ in that there is an upward gradient between the sand and gravel aquifer and the lower till unit and bedrock aquifer. Water levels in the till unit and bedrock aquifer are nearly identical (OW5A water levels are masked by the water levels from OW5C in Figure B.21).

Water levels in the sand and gravel aquifer range between a high of approximately 492.7 masl and 488.2 masl (range of 3.8 m). In the till unit and bedrock aquifer, water levels range from approximately 494.3 masl to a low of 489 masl (range of 5.3 m). The vertical gradient is upwards from both the C and B monitors to the A monitor.

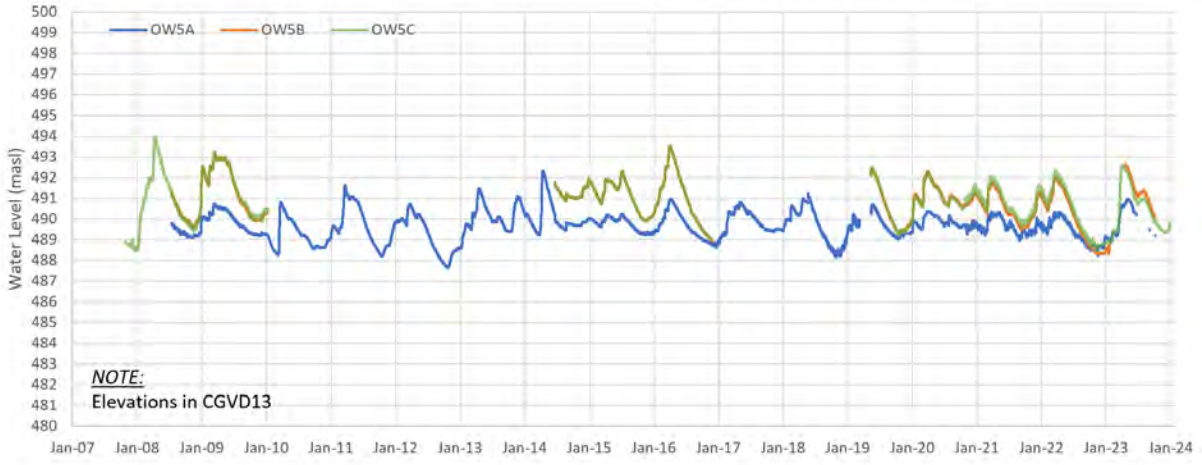


Figure B.21: Hydrograph of water levels at Well Nest OW5, in masl.

OW6: Monitoring at OW6 is only conducted in the shallow sand and gravel aquifer. This well is located on the eastern edge of the existing aggregate operation and immediately adjacent to the aggregate washing operation. Water levels (Figure B.22) range between a high of approximately 493.5 masl and a low of 490.6 masl (range of 2.9 m).

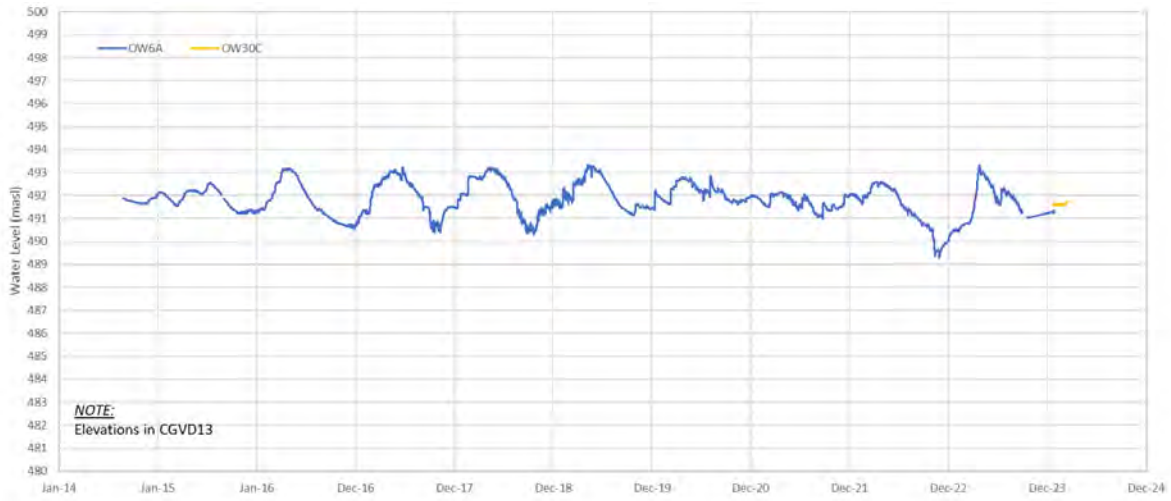


Figure B.22: Hydrograph of water levels at OW6A, in masl, 2014 to 2024.

OW7 Well Nest: OW7 Well nest consists of separate monitoring wells in the sand and gravel and bedrock aquifers. Water levels in the sand and gravel aquifer (OW7A) range from a high of approximately 492.7 masl to a low of 489.9 masl. Water levels in the bedrock aquifer (OW7C) range from a high of approximately 493.3 masl to a low of 488.8 masl. Both aquifer systems respond to seasonal conditions. It is noted that like water levels collected at the OW5 well nest, the amplitude of the seasonal fluctuation tends to decrease between 2020 and 2023. During wet periods, there is an upward gradient that typically lasts between March and May. Water levels then decrease at a relatively faster rate than the sand and gravel aquifer unit, until downward gradients dominate the remainder of the year.

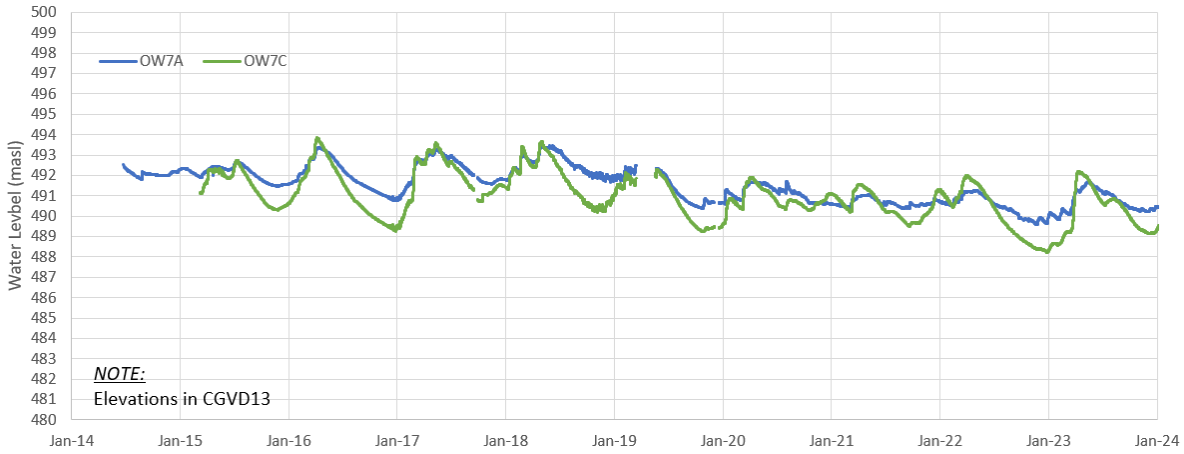


Figure B.23: Hydrograph of water levels at Well Nest OW7, in masl.

OW8: OW8A is a single well that monitors the overburden in the vicinity of the scale house. This well was installed to monitor groundwater quality and to ensure no hydrocarbons from the fuel tank have entered the underlying groundwater. Water

levels are relatively consistent between 497 and 498 masl, which may be attributed to over 12 m of overburden cover and presence of a silty layer. The water levels only seem to respond to the peak of the freshet in some years.

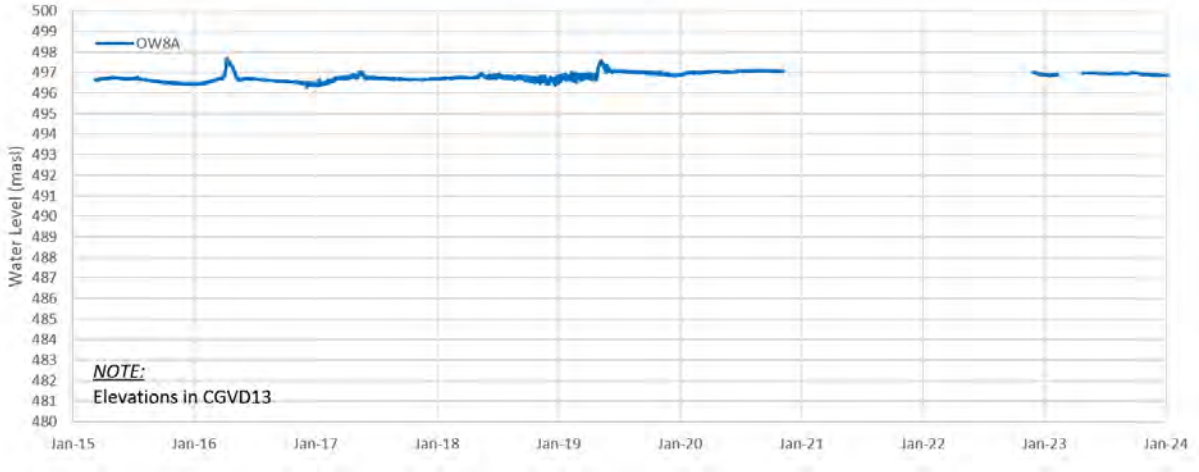


Figure B.24: Hydrograph of water levels at OW8A, in masl.

OW9 Well Nest: OW9A monitors the groundwater within the sand and gravel aquifer. Water levels show a seasonal response and range between a high of approximately 494 masl and low of 491.3 masl. OW9B monitored water levels in the till unit for a short period of time in 2015. This monitoring was discontinued to focus on the shallow aquifer system. The limited data show that there is a downward gradient between the units of approximately 6m. Water levels in OW9B are consistent with the longer period of record at OW18C, and the general lower site levels towards OW14C.

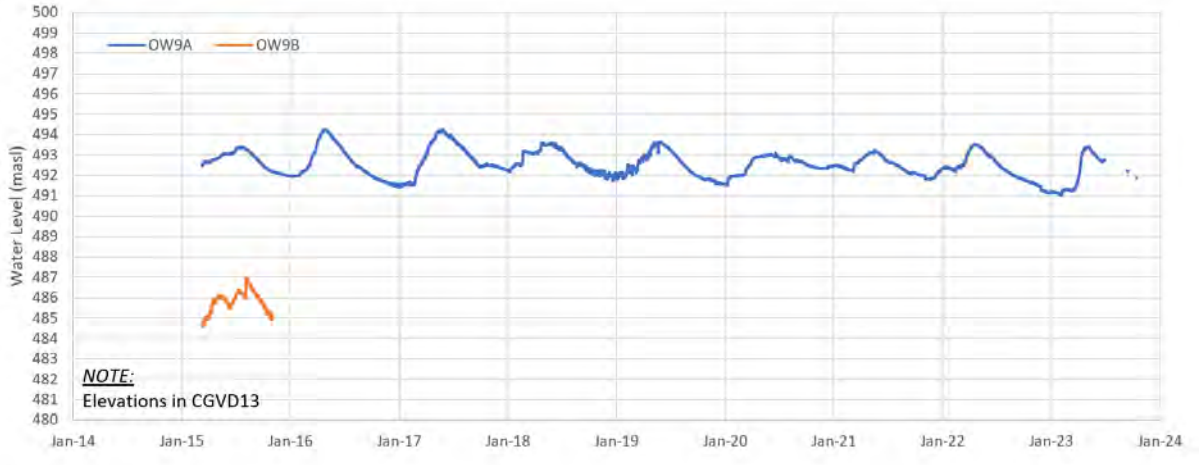


Figure B.25: Hydrograph of water levels at Well Nest OW9, in masl.

OW10 Well Nest: OW10A, which monitors the sand and gravel aquifer unit was discontinued in 2016 as the aquifer would dry up during the summer months following the infiltration of the spring freshet. OW10A is completed above a shallow clayey

silt layer that is 7.5 m above the Tavistock till, and therefore reflects local perched conditions. Water levels in OW10A respond like the water levels in the North Pond, which typically holds water until early summer. OW10B monitors the water levels in the lower till unit, which ranged between a high of approximately 490 masl and a low of 487 masl. Figure B.26 shows the downward gradient at the well nest location of approximately 3.7m.

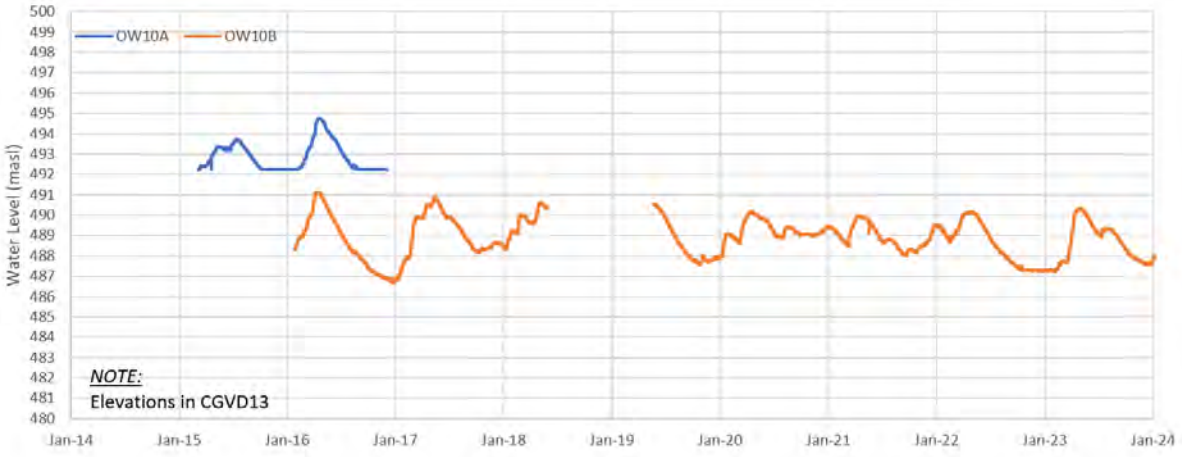


Figure B.26: Hydrograph of water levels at Well Nest OW10, in masl.

OW11 Well Nest (Destroyed): This nest has monitors in the top sand and gravel unit (OW11A) and in the bedrock unit (OW11C). Water levels at this location (Figure B.27) exhibit periods of upward gradients (similar to OW7). These occur at the peak of the freshet and, in some instances, during the recession curve (for example, in year 2017). Unlike OW7, the water levels after the peak of the freshet follow a similar slope suggesting a high connectivity through the approximately 5 m thickness of the till. Snowmelt events preceding the freshet are clearly recorded in both units.

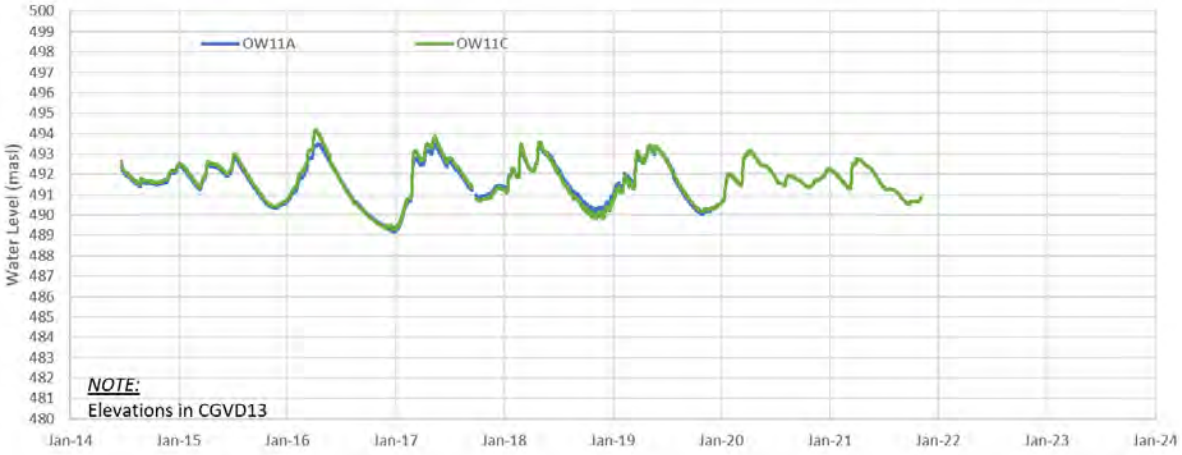


Figure B.27: Hydrograph of water levels at Well Nest OW11, in masl.

OW12: OW12A monitors the overburden aquifer along the western property boundary. Water levels show the seasonal response with a muted response to precipitation events likely due to the filtering effect of the silty sand overlaying the sand and gravel unit. Water levels range between a high of approximately 493 masl to a low of approximately 491.2 masl.

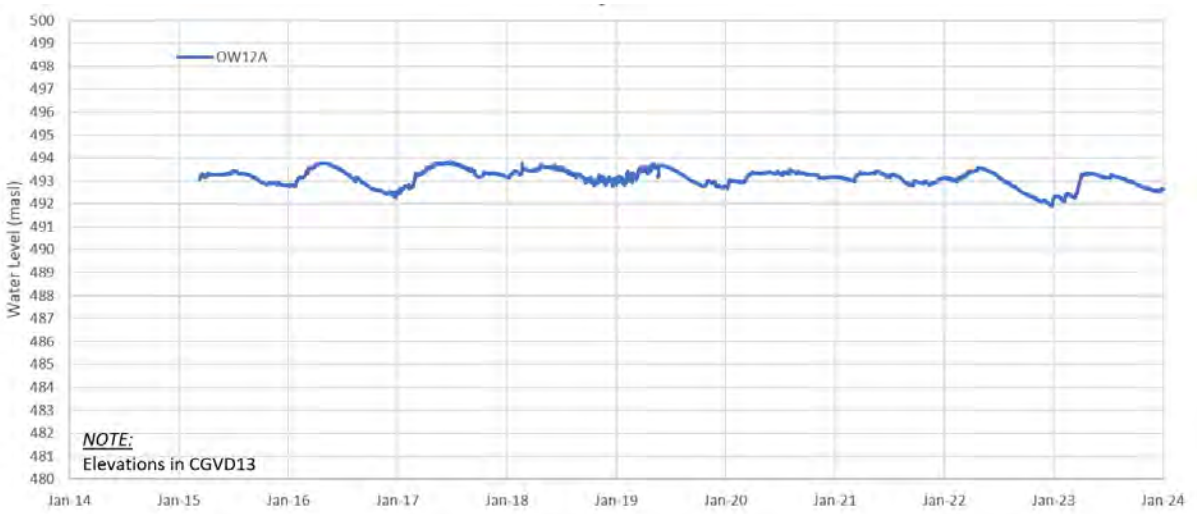


Figure B.28: Hydrograph of water levels at Well OW12A, in masl.

OW13 Well Nest: At OW13 well nest, the water level response is somewhat unique due to the change reported over the monitoring period: The overburden aquifer frequently dries out during the summer months and the water level drops into the bedrock aquifer from reported spring highs of 499.2 masl. The OW13C datalogger cannot reach the base of the well and therefore sits above the well screen, limiting the ability to capture low water levels. However, the recession water levels of the 2020 spring freshet were captured fully by both monitors, and they also recorded the response to some summer rainfall events of the same year. The downward gradient during the wet periods reaches values up to approximately 3 m and it is reduced to 0.2 m during dry periods, but no upward gradient is identifiable.

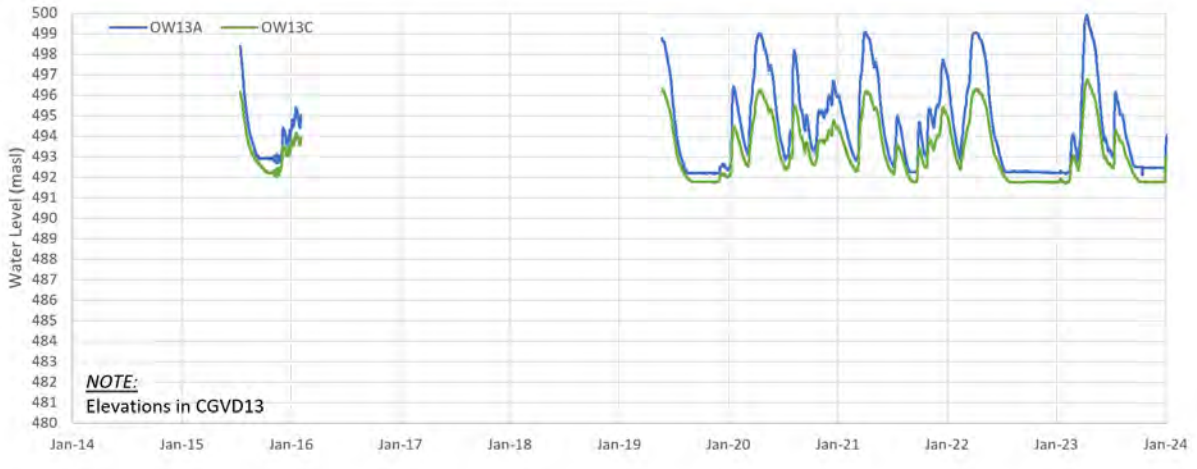


Figure B.29: Hydrograph of water levels at Well Nest OW13, in masl.

OW14: OW14 has been constructed as a well nest with a shallow overburden monitoring well. OW14A has been dry since installation. OW14C is completed 6.4 m into the bedrock and reports water levels that range between a high of approximately 483.3 masl and a low of 479.4 masl (Figure B.30). The water levels are found within the upper 3 m of the weather bedrock system. The possible geologic reasons for the lower water levels in the east-central portion of the site (i.e. possible shallow karst or Pine River re-entrant valley features) are discussed in more detail in Appendix C and D.

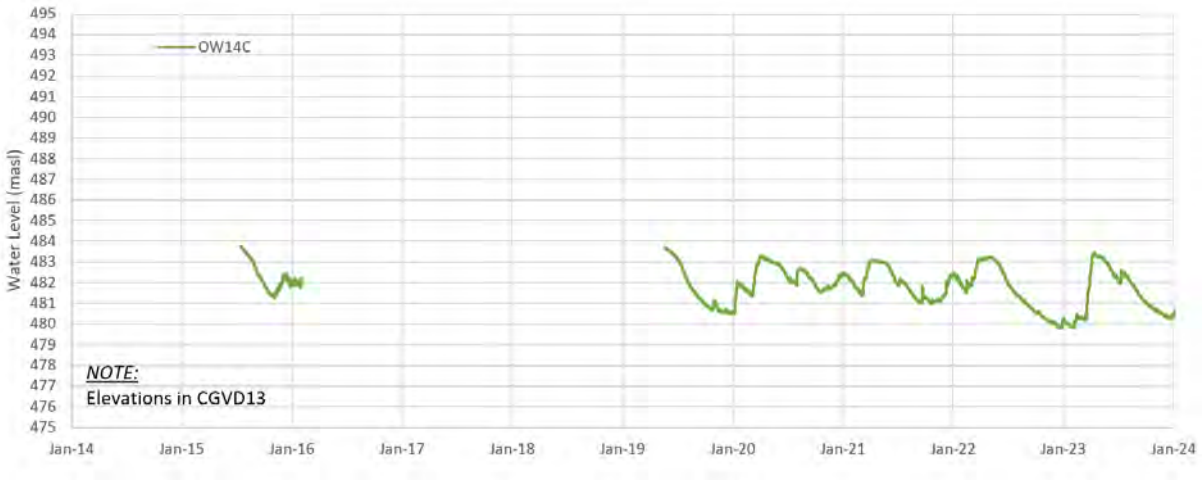


Figure B.30: Hydrograph of water levels at Well OW14C, in masl.

OW15 Well Nest (Destroyed): There is insufficient information to accurately plot water levels from this location due to damage to the well and changing measuring elevations.

OW16: OW16C was constructed as an open-hole bedrock monitoring well. Water levels fluctuate between a high of approximately 481.6 masl and a low of 477.9 masl (Figure B.31). The bedrock contact is reported to be at an elevation of 490.8 masl, leaving over 10 m of unsaturated dolostone above the high-water level. Seasonal variability of water levels has been recorded at this monitoring location for several years, exhibiting the driest months in December 2015, December 2019, and December 2022. The range in water levels among the driest and wettest periods is greater for the drier periods, in the collected data. Low levels in OW16C are consistent with OW14C and, as noted above, the possible geologic reasons for lower water levels in the east-central portion of the site (i.e. shallow karst or Pine River re-entrant valley features), are discussed in Appendix C and D. Upward gradients from the deeper Gasport aquifer to the shallow bedrock observed in monitor nest OW25 are discussed below (Figure B.40).

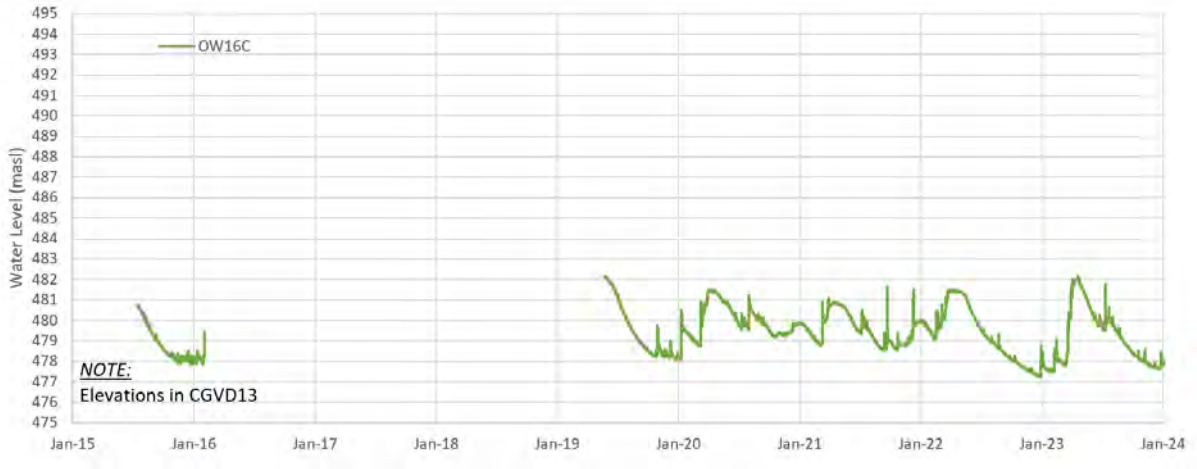


Figure B.31: Hydrograph of water levels at Well OW16C, in masl.

OW17 Well Nest (Destroyed): The OW17 well nest monitors the water levels in the overburden and bedrock units. Based on the water well record, there is only 1 m of annular seal separating the shallow (OW17B) and deep (OW17C) well screens, which may be causing the similarities in the reported water levels (compromised well seal). The water level in both wells range from a high of approximately 488.7 masl to a low of 485.5 masl (Figure B.32). The water levels are within the overburden unit over the duration of the monitoring period. Recharge-induced events are clearly recorded in both monitors, in spite of being located underneath 11.5m of till.

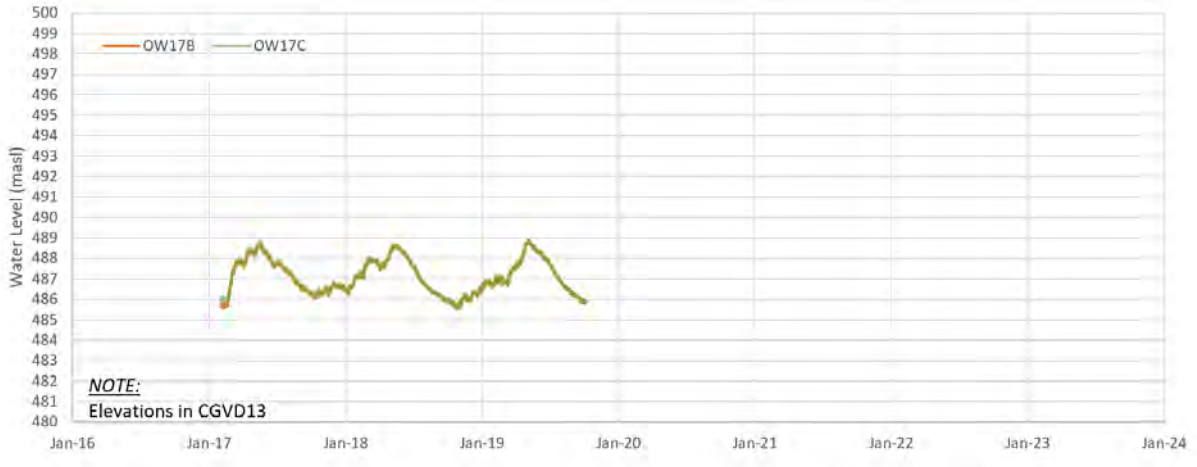


Figure B.32: Hydrograph of water levels at Well Nest OW17, in masl.

OW18 Well Nest: OW18 is located along the western property boundary and monitors the water levels in both the overburden and bedrock units. The overburden well shows that water levels range between a high of approximately 489.1 masl and a low of 486.1 masl (Figure B.33). Seasonal response to climatic conditions is evident between 2017 and 2019. After

2019 the water level responses become more variable in time but less variable in magnitude, possibly as a result of soil stripping just north of the monitoring well.

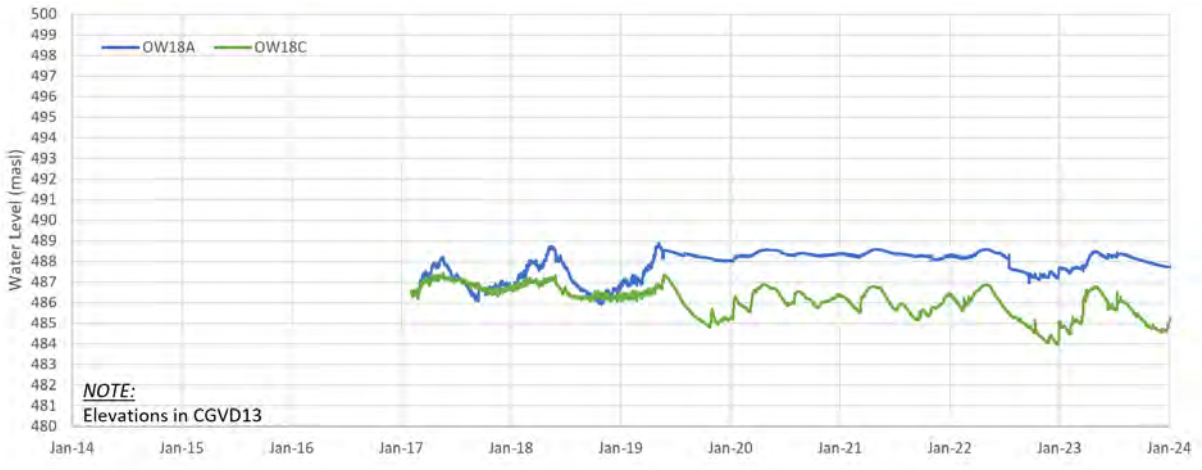


Figure B.33: Hydrograph of water levels at Well Nest OW18, in masl.

OW19 to OW23 Well Nests: Well Nests OW19 to OW23 were all constructed in the northern portion of the proposed Strada Quarry. OW19A and OW20A are dry and OW21A is plugged. OW22A and OW23A have similar water levels as OW22B and OW23B, possibly due to problems with well construction. Like OW17, there is only 1 m of annular seal separating the shallow and deep well screens.

Figure B.34 shows the data from the OW19, OW20, OW21, OW22, and OW23 monitors with data.

OW19C (Figure B.35) and OW20C (Figure B.36) are located in the central part of the site, which appears to have lower water levels, as discussed with OW16, above. OW19C is screened 19 m into the bedrock (and possibly in the Ancaster formation) on the west side of the proposed quarry, while OW20C is screened in the shallow weathered bedrock, on the east side of the quarry in the same zone as OW16 and OW25.

OW21 has been illustrated with the monitoring data from OW28A and C (Figure B.37) which were installed in 2023. The water levels measured in OW21C and the OW28A monitor show similar groundwater elevations, a slight downward gradient between the OW28A monitor and the OW28C monitor is observed. Similarly, the OW23C and OW27C monitors show similar groundwater elevations (Figure B.38).

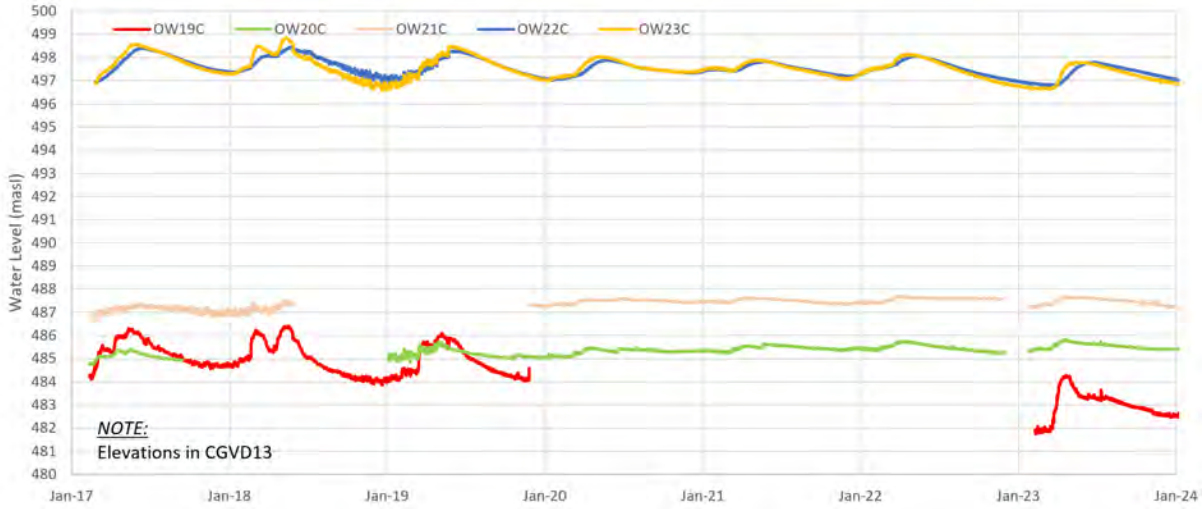


Figure B.34: Hydrograph of water levels at Well Nests OW19, OW20, OW21, OW22, and OW23.

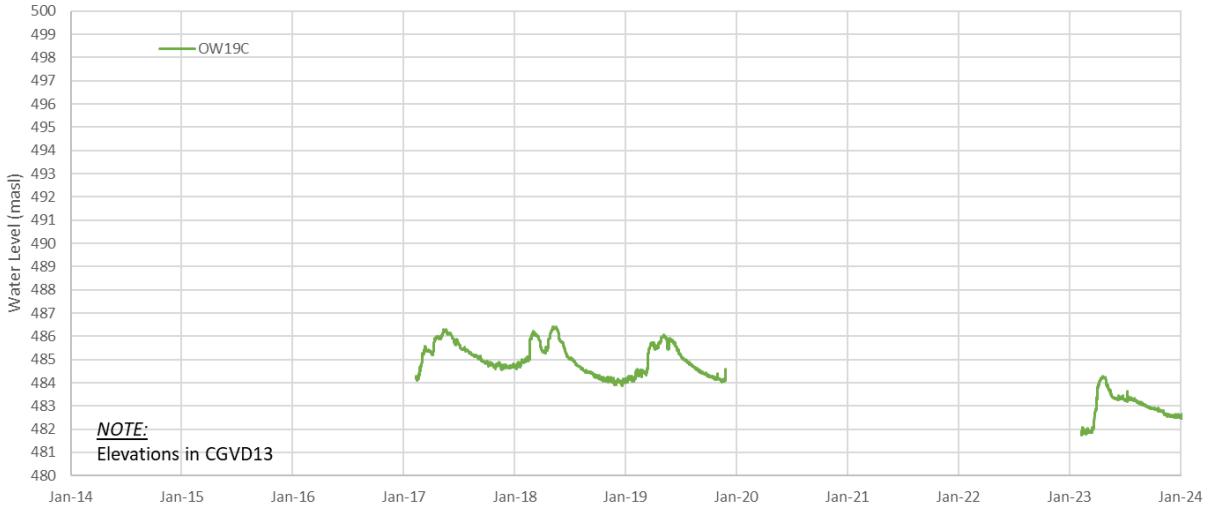


Figure B.35: Hydrograph of water levels at Well Nest OW19C, in masl



Figure B.36: Hydrograph of water levels at Well Nest OW20C, in masl.

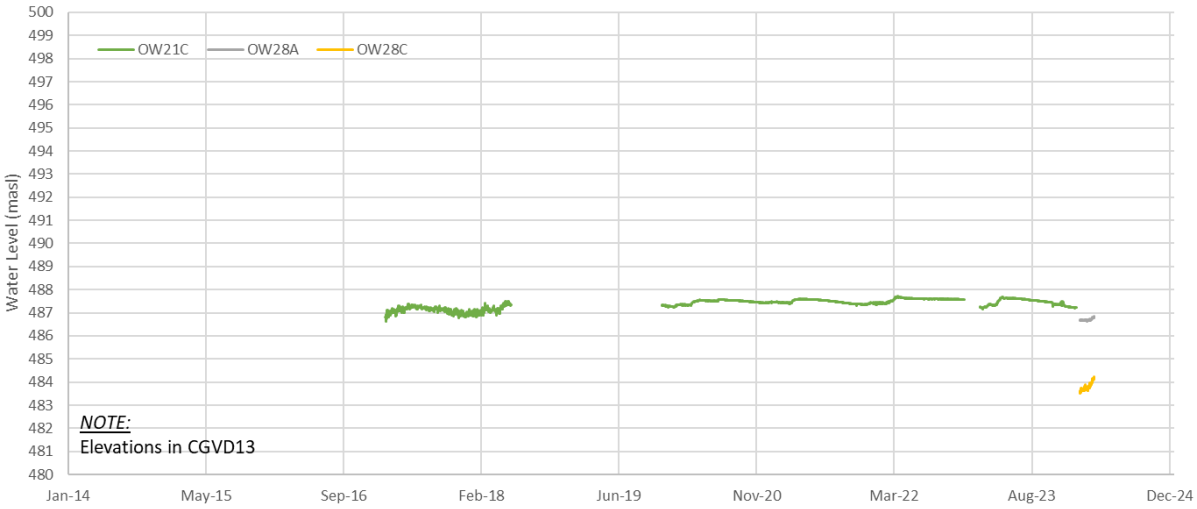


Figure B.37: Hydrograph of water levels at Well Nests OW21 and OW28, in masl.

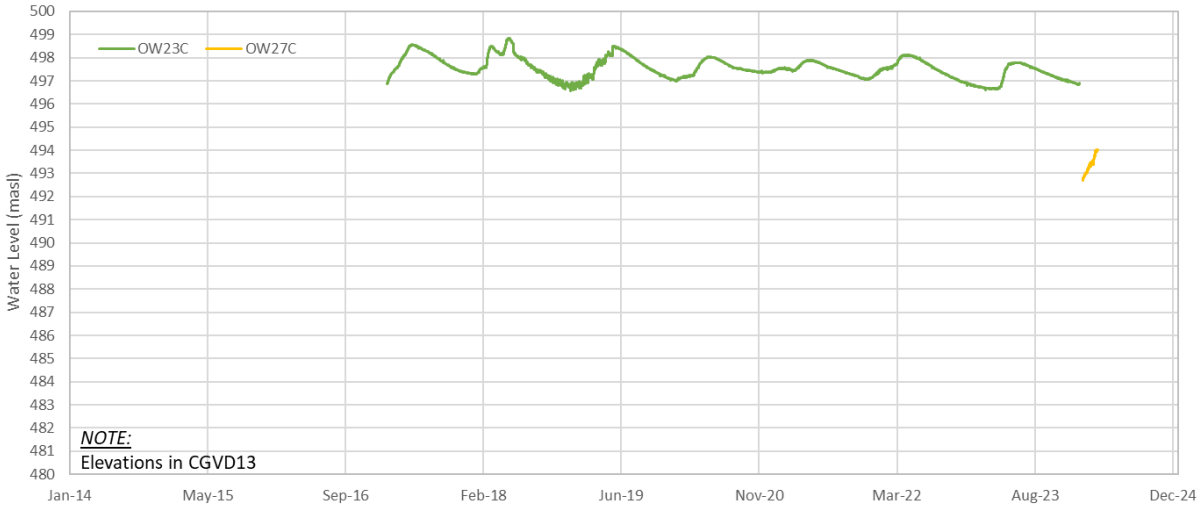


Figure B.38: Hydrograph of water levels at Well Nests OW23 and OW27, in masl.

OW24 to OW26 Well Nests: Well Nests OW24 to OW26 were originally installed as open core holes and later completed as nested monitoring wells in late 2023 (Figure B.39, Figure B.40, Figure B.41). Note that the "H" monitor data at each location refers to the "historic" data recorded as a long open hole, prior to the installation of the discrete shallow and deep monitors. A downward gradient between the A monitor and the C monitor was observed in OW24 and OW26; however, an upward gradient between the C monitor and the A monitor is observed in OW25. The upward gradient at OW25 is consistent with there being a more permeable zone in the shallow bedrock (as discussed in OW16, above, and Appendix C and D). the head change from the C to A monitors confirms the presence of an intermediate aquitard.

OW27 to OW30 were installed in 2023; OW27 and OW30 were constructed as deep monitors (C monitor only), and OW28 and OW29 were equipped as nested monitoring wells (A and C monitors) (Figure B.42, Figure B.43, Figure B.44, and Figure B.45). A downward gradient between the A monitor and the C monitor was observed at OW28, and the vertical gradient at OW29 appears to change seasonally; however, the fluctuations may be a result of groundwater levels stabilizing following installation and development.

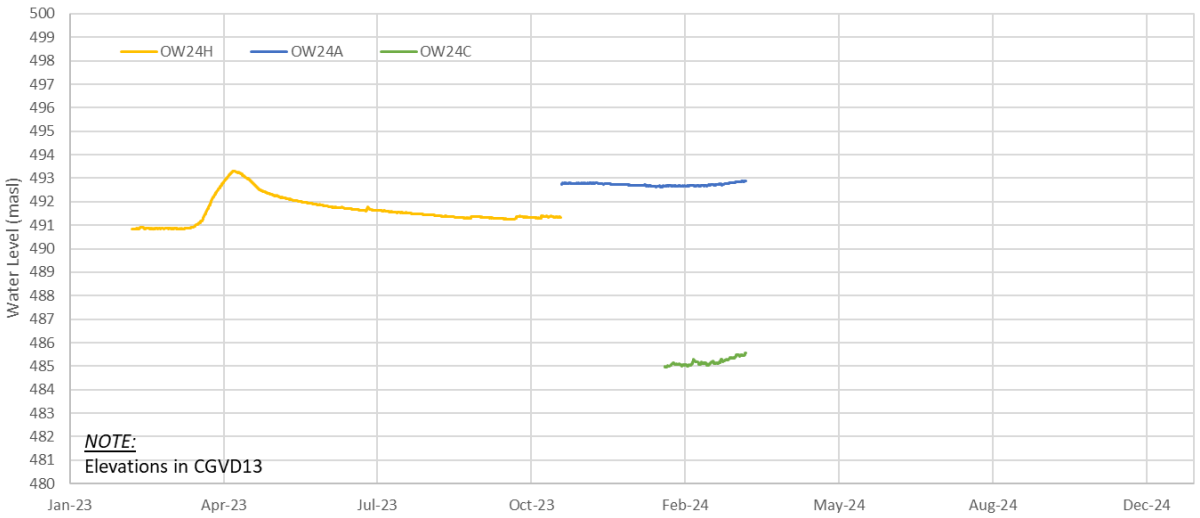


Figure B.39: Hydrograph of water levels at Well Nest OW24, in masl.

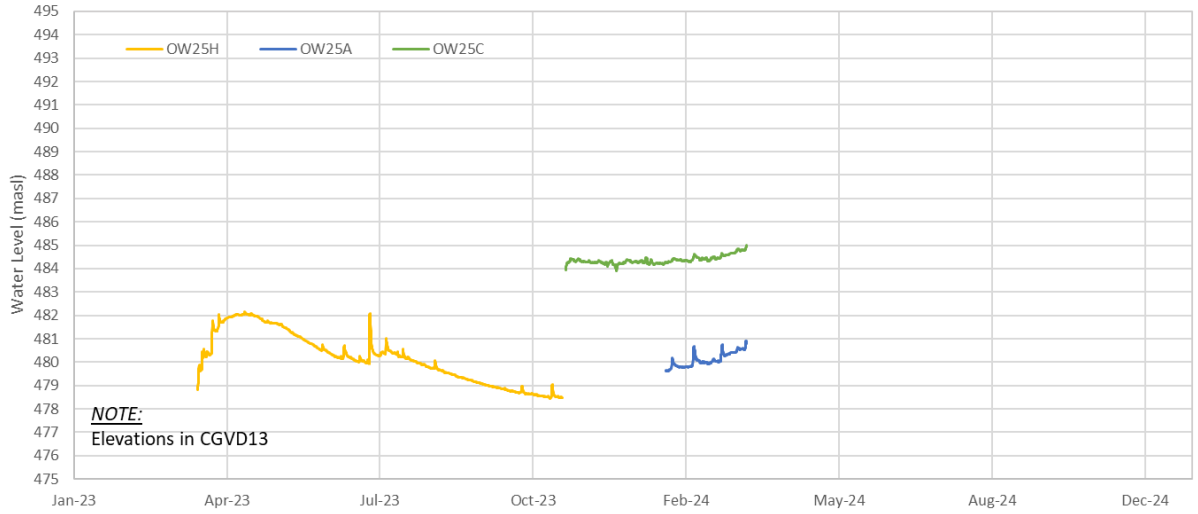


Figure B.40: Hydrograph of water levels at Well Nest OW25, in masl.

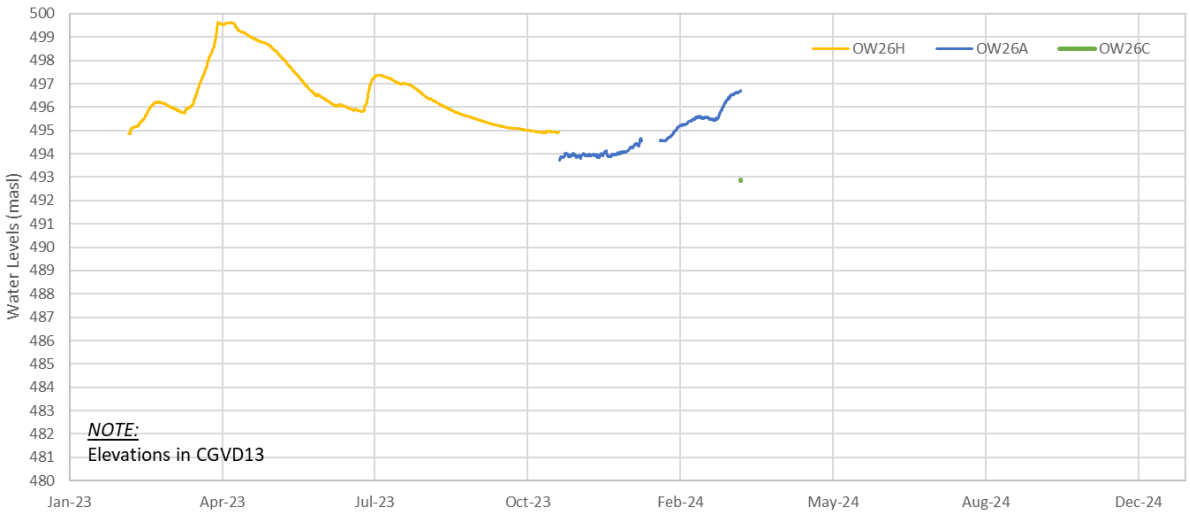


Figure B.41: Hydrograph of water levels at Well Nest OW26, in masl.

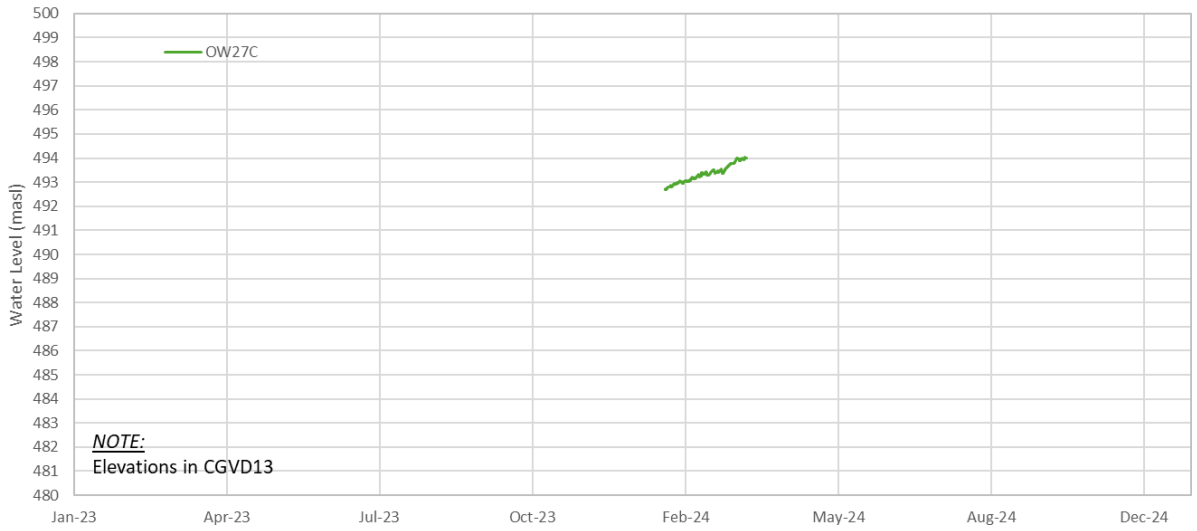


Figure B.42: Hydrograph of water levels at Well Nest OW27, in masl.

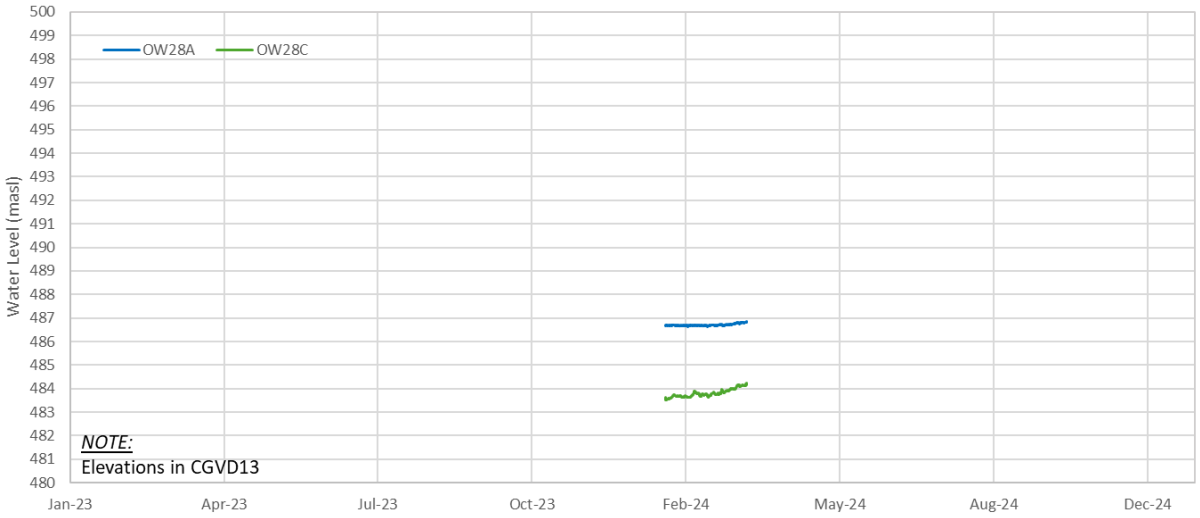


Figure B.43: Hydrograph of water levels at Well Nest OW28, in masl.

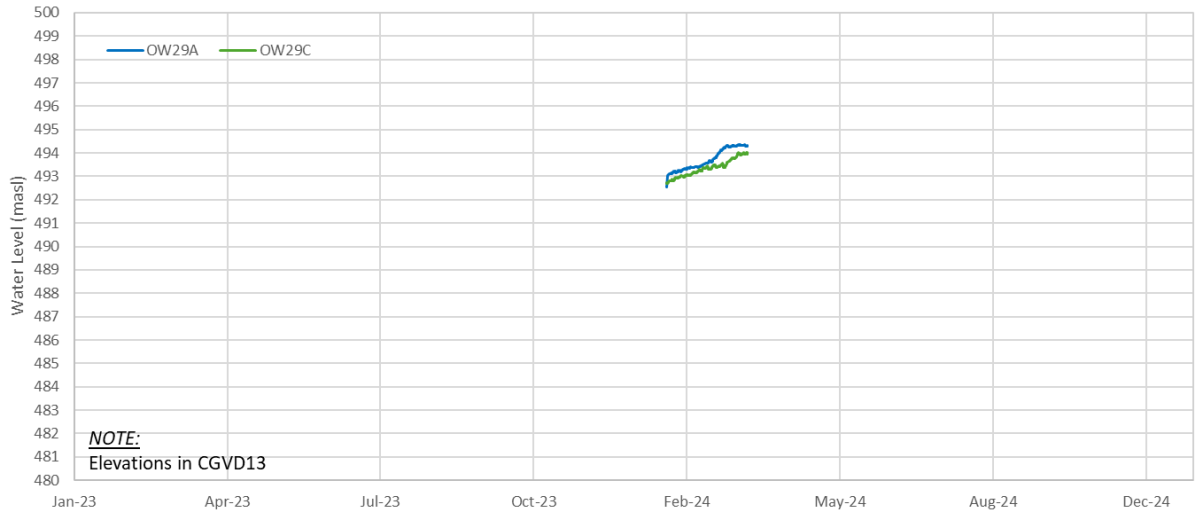


Figure B.44: Hydrograph of water levels at Well Nest OW29, in masl.

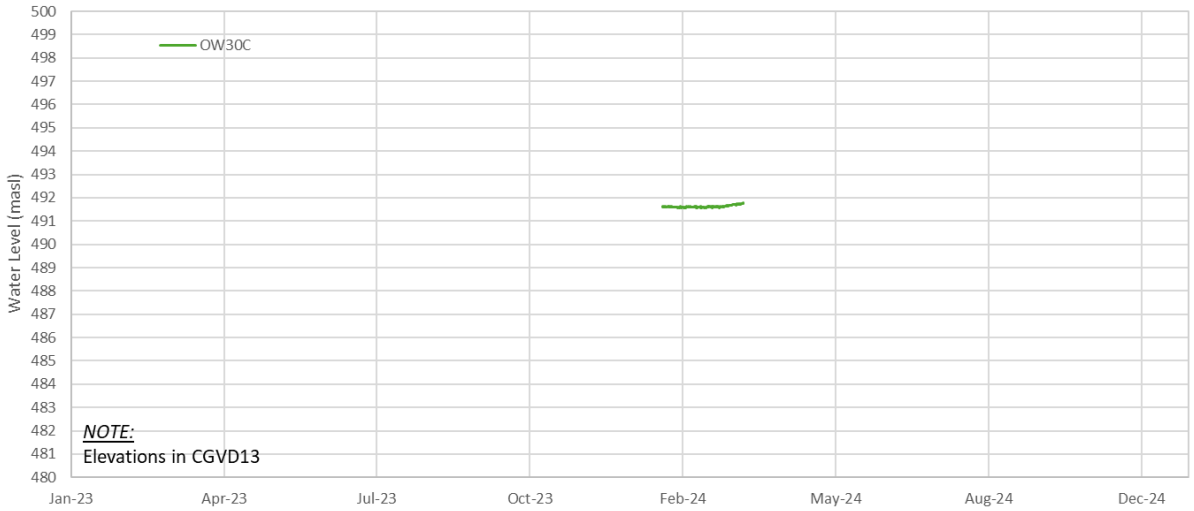


Figure B.45: Hydrograph of water levels at Well Nest OW30, in masl.

B.6.3 Domestic Monitoring Wells

Water level monitoring in five domestic water wells initiated in 2022 and the monitoring data measured to date is show in Figure B.46 through Figure B.50. The logger at DW2 has been removed several times during the course of the monitoring, additional measures are being reviewed to ensure future loggers are not removed.

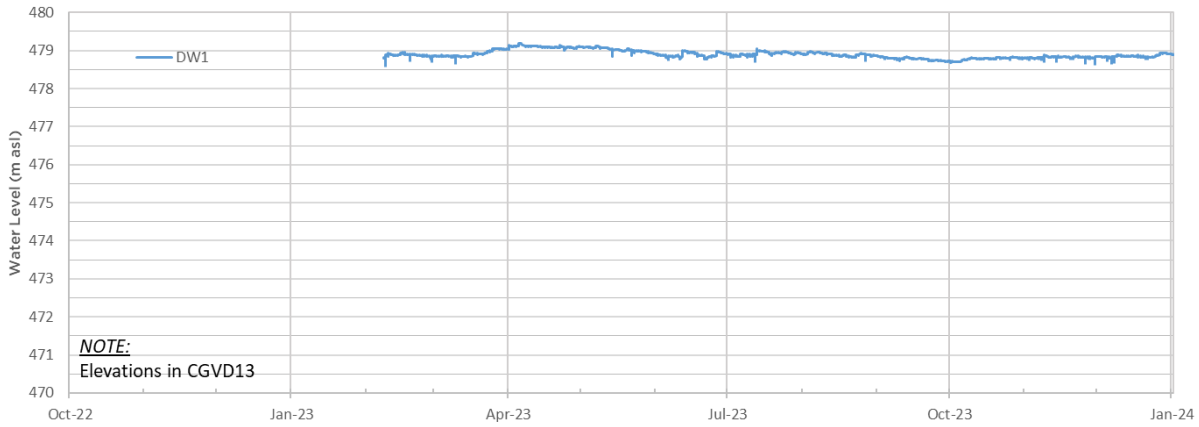


Figure B.46: Hydrograph of water levels at Domestic Well DW1, masl.

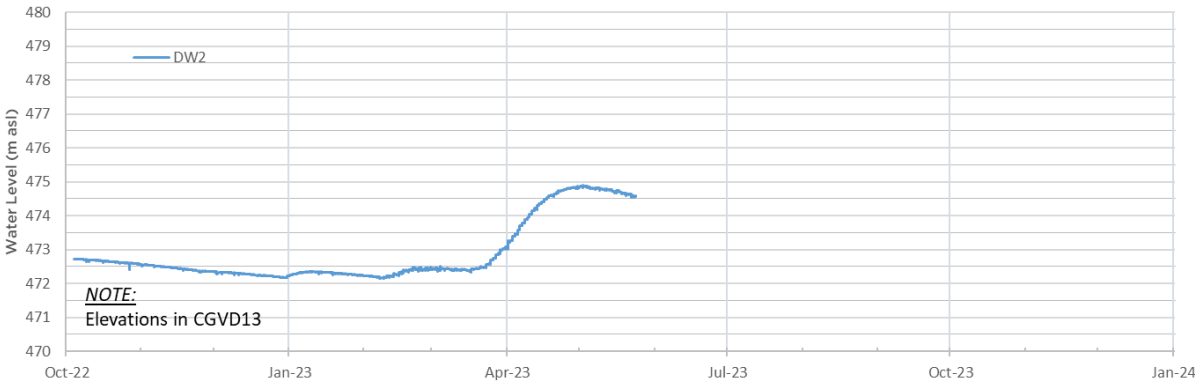


Figure B.47: Hydrograph of water levels at Domestic Well DW2, masl.

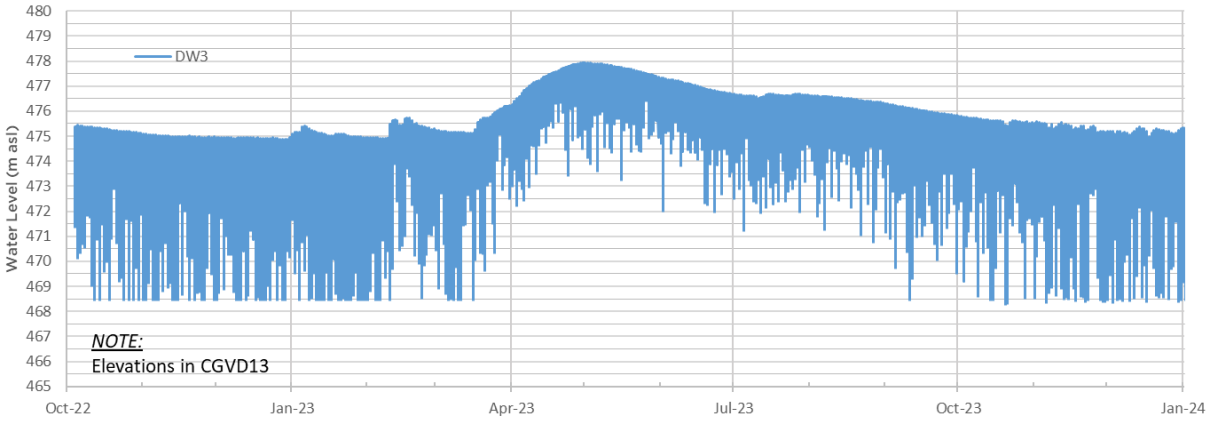


Figure B.48: Hydrograph of water levels at Domestic Well DW3, masl.

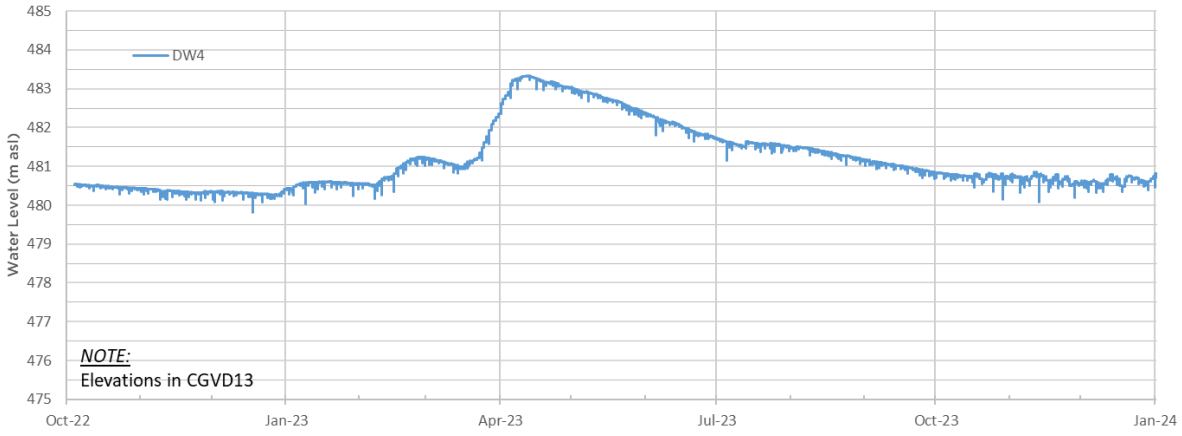


Figure B.49: Hydrograph of water levels at Domestic Well DW4, masl.

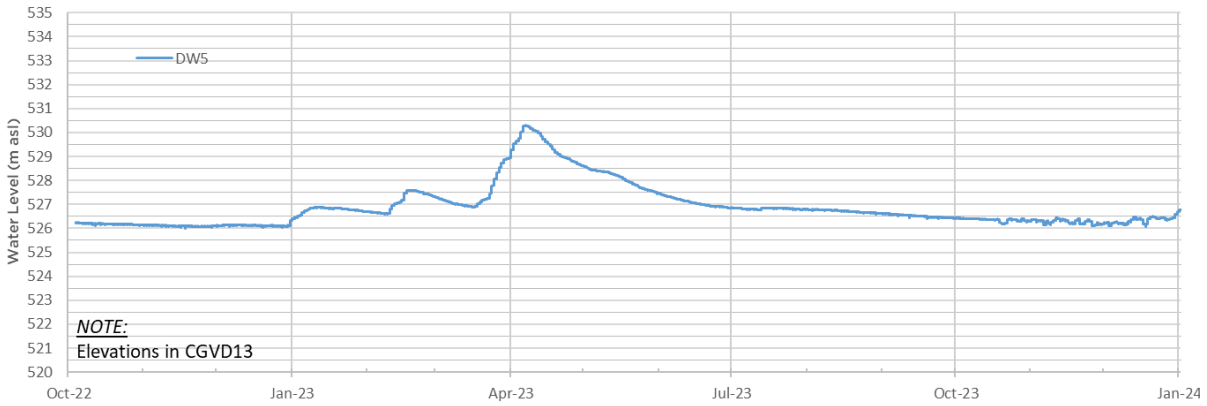


Figure B.50: Hydrograph of water levels at Domestic Well DW5, masl.

B.6.4 Groundwater Flow Conditions

Figure B.51 presents a composite hydrograph of observed groundwater levels across the Strada site. Most monitors show a strong degree of seasonal response but several show a very muted response. The response is likely affected by changes in storage properties (i.e. specific yield) when the water table is mainly within the overlying till (as it is on the western boundary), within the weathered bedrock (center of the site), or deeper within the bedrock (eastern boundary). Water levels and the local response to recharge events are also affected to some extent by soil stripping and gravel extraction operations.

Figure B.51 also presents the results from the seven deeper monitoring wells installed in 2023 (OW24C to OW30C).

Corresponding composite hydrographs for the B and A series monitors are included in Figure B.52 and Figure B.53.

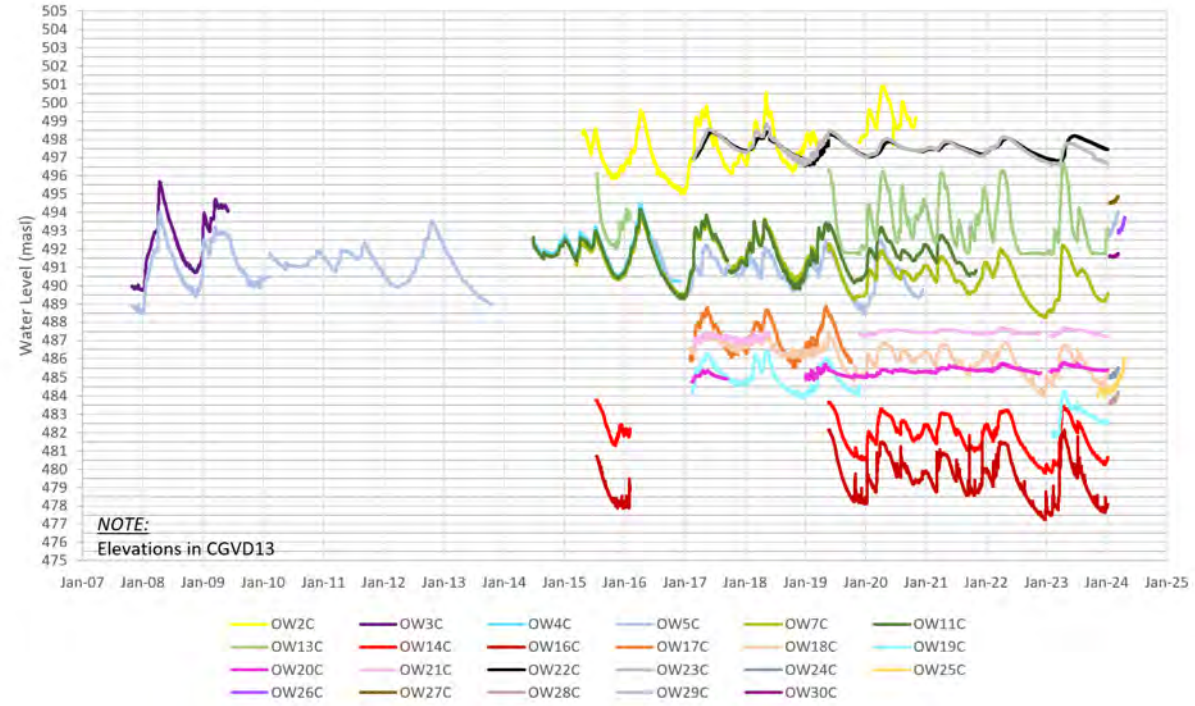


Figure B.51: Hydrograph of bedrock water levels (C Series) across the site.

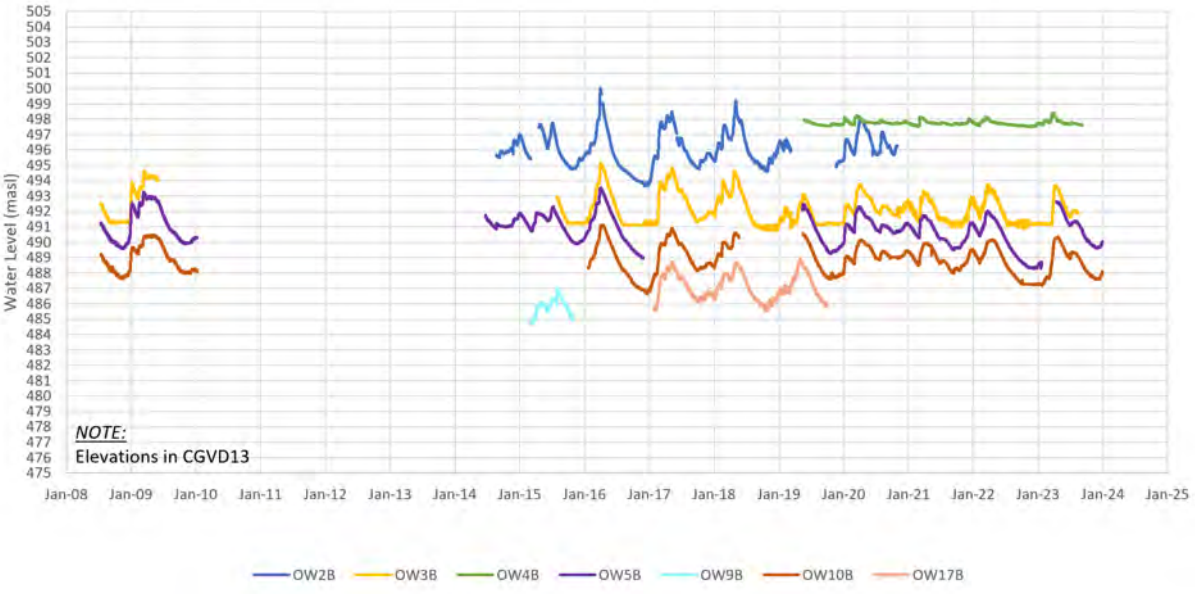


Figure B.52: Hydrograph of intermediate series "B" wells across the site.

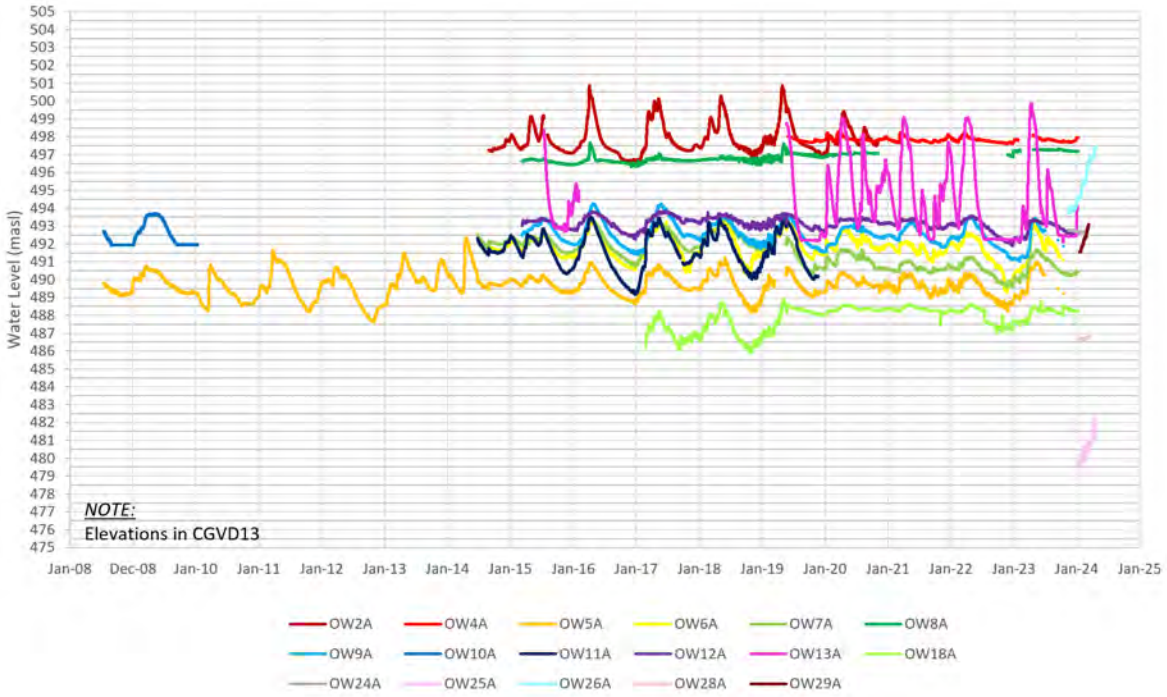
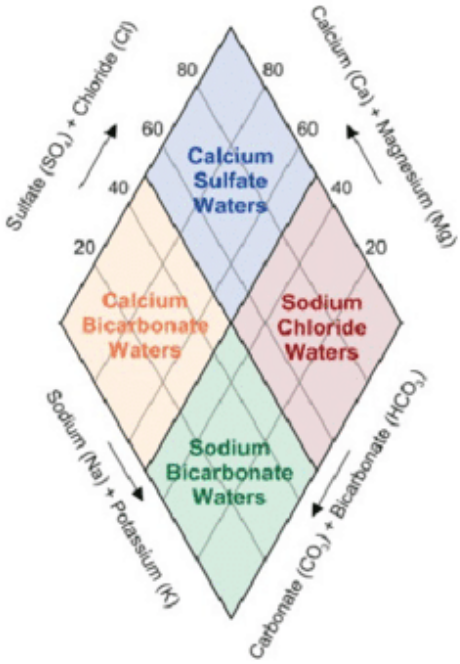


Figure B.53: Hydrograph of intermediate series "A" wells across the site.

B.7 GROUNDWATER HYDROCHEMISTRY



Hydrochemical properties of groundwater depend on lithology, the regional flow pattern of water, and residence time (Domenico 1972). All groundwater can be divided into three main categories: bicarbonate, sulfate, and chloride types (Chebotarev 1955). The chemical signature of water begins to change as if flows from areas of groundwater recharge to areas of groundwater discharge. The groundwater composition changes progressively along the flow path towards the composition of seawater (Chebotarev Sequence: bicarbonate → sulphate → chloride). The dominant ion in the groundwater correlates with distance along the flow path and residence time or age of the groundwater. A Piper diagram (1944) can be used to help identify the type of water: bicarbonate (HCO^{-3}) plus carbonate (CO_3^{-2}), sulfate (SO_4^{-2}), or chloride (Cl^-).

A Piper diagram (Piper, 1944) was used to characterize the local groundwater signatures of the average water quality collected from the groundwater monitoring network utilizing groundwater quality monitoring results from 2019 to 2024 (Figure B.54 through Figure B.57). The Piper Diagrams shows that groundwaters in all three units monitored (sand and gravel, till, and bedrock) are generally characterized as calcium bicarbonate waters, except for the groundwater found at OW28C. Calcium bicarbonate water is typical of natural (uncontaminated) shallow overburden and dolomitic limestone aquifers in southern Ontario. The groundwater found at OW28C is characterized as sodium bicarbonate waters.

Water quality samples have historically been compared to the Ontario Drinking Water Standards (ODWS) for comparison purposes, but it should be noted that the majority of the water quality samples have been obtained from monitoring wells rather than potable water supply wells. Water samples are obtained utilizing industry standard water quality sampling procedures; however, the total suspended solids in each water sample is typically higher than what would be expected from a sampled potable water supply well due to well construction and monitoring well sampling procedures. Due to the elevated total suspended solids in each sample the concentration of dissolved analytes is expected to be elevated in comparison to a water sample obtained from a potable water well where some level of filtration would be applied reducing the total suspended solids in the water and ultimately reducing the total dissolved analyte concentrations.

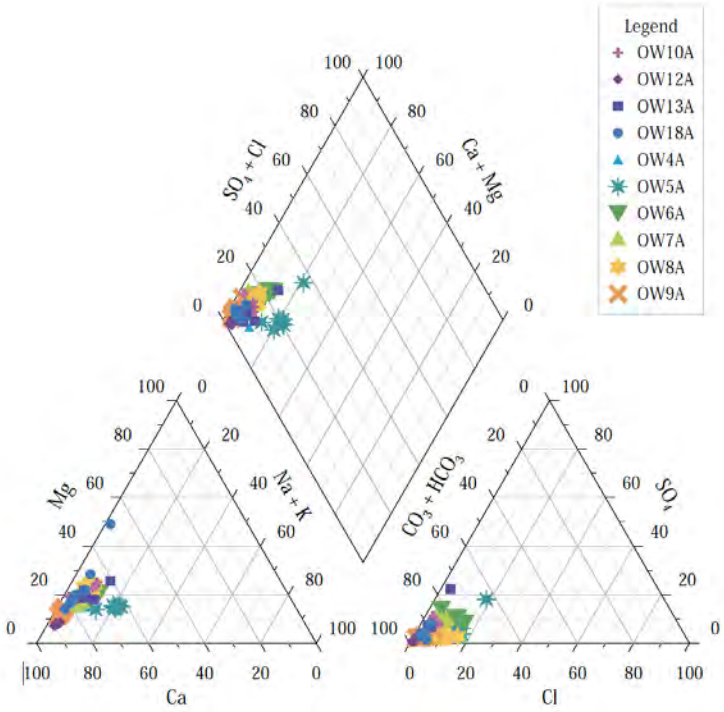


Figure B.54: Piper Diagram of sand and gravel water quality samples

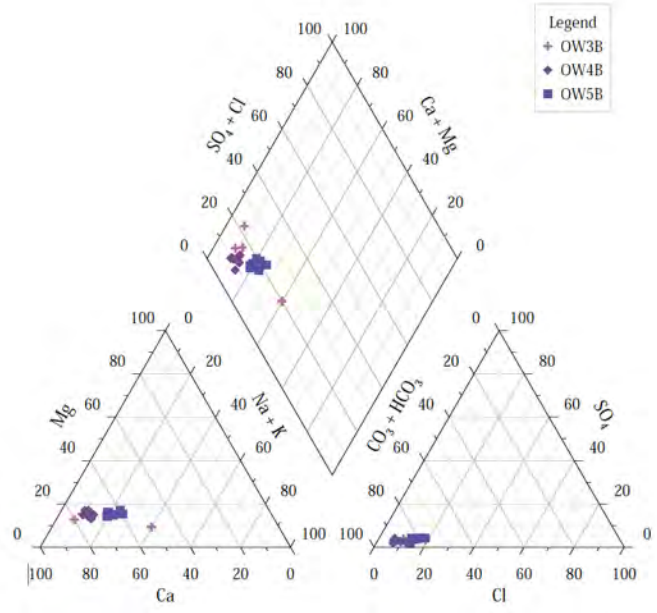


Figure B.55: Piper Diagram of till water quality samples

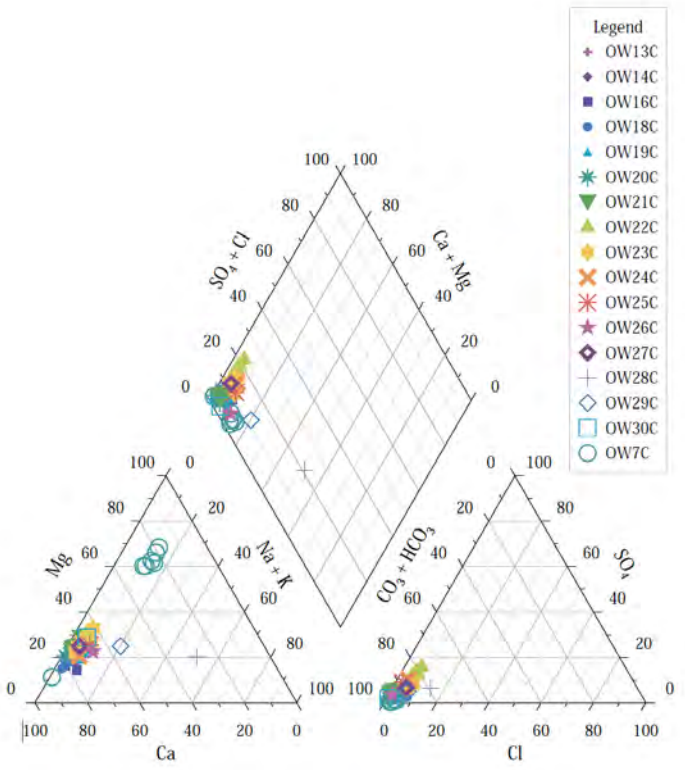


Figure B.56: Piper Diagram of bedrock water quality samples

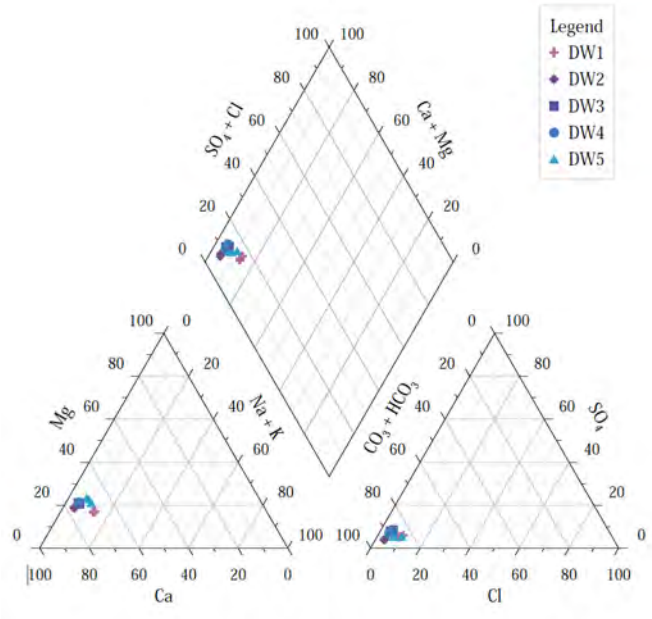


Figure B.57: Piper Diagram of Domestic Well water quality samples

Regardless historically elevated concentrations of nitrate exceeding the ODWS of 10 mg/L have been noted within the sand and gravel and till units at OW4A/B, OW8A and OW9B, and recently slightly elevated nitrate concentrations were noted in OW24C and OW27C (6.5 and 4.1 mg/L, respectively). The elevated nitrate concentrations are considered to be a result of the legacy farming activities in the area as the elevated concentrations remain localized to the upper overburden units and are downgradient of historical farming operations.

Further historically elevated concentrations of sodium exceeding the health related ODWS of 20 mg/L have been noted in the sand and gravel and till units at OW5A/B and OW4B, and in 2024 in OW28C; however, the ODWS aesthetic limit of 200 mg/L has not been exceeded. The ODWS health related limited is not a Maximum Allowable Concentration but rather a trigger limit to ensure that the local health department is aware of drinking water that may impact persons on salt restrictive diets. As the predominant potable drinking water source is the deeper bedrock aquifer this health related ODWS is not considered applicable for water samples obtained from monitoring wells rather than potable drinking water wells. However, the elevated sodium concentrations are considered to be a result of the on-going road salt application as the two locations where observed increased sodium concentrations are noted are immediately adjacent to County Road 17.

Regardless, the geochemical signatures of the uncontaminated waters are not likely to vary greatly over time which is observed in the historical groundwater quality sampling completed on-site.

B.8 SURFACE WATER MONITORING

B.8.1 Stream Flow Monitoring

In 2024 an off-site stream flow monitoring program was initiated where 23 surface water stations were visited twice and stream flow measurements were recorded. The stream flow monitoring is summarized in Table B.2.

Table B.2: Streamflow Monitoring Network

Monitoring Location	Location	May 30, 2024		August 15, 2024	
		Stream Flow Rate (L/s)	Temperature	Stream Flow Rate (L/s)	Temperature
SW3	17T 4890372N, 563730E	241.1	7.6	45.3	10.6
SW4	17T 4890176N, 563023E	65.5	12.3	61.7	16.0
SW5	17T 4889273N, 563588E	177.1	14.5	139.7	17.1
SW6	17T 4888803N, 563662E	54.5	7.5	38	13.3
SW7	17T 4887588N, 565205E	Dry		Dry	
SW8	17T 4889224N, 560167E	<1	17.9	Dry	

Monitoring Location	Location	May 30, 2024		August 15, 2024	
		Stream Flow Rate (L/s)	Temperature	Stream Flow Rate (L/s)	Temperature
SW9	17T 4886586N, 559909E	Dry		Dry	
SW10	17T 4886286N, 560921E	<1	13.8	Dry	
SW11	17T 4885828N, 561440E	Dry		Dry	
SW12	17T 4886643N, 561981E	3.3	15.5	Dry	
SW13	17T 4885308N, 564308E	99.6	16.5	28.2	20.5
SW14	17T 4889540N, 565402E	--		449.5	16.1
SW15	17T 4890444N, 563986E	62.2	7.5	5.3	9.2
SW16	17T 4891192N, 563232E	--		36.9	9.3
SW17	17T 4889841N, 562098E	--		38.9	15.7
SW18	17T 4889066N, 562888E	--		Dry	
SW19	17T 4886317N, 562739E	--		8	16.4
SW20	17T 4885622N, 562859E	--		10.9	18.2
SW21	17T 4885241N, 559850E	--		<1	14.7
SW22	17T 4885052N, 560178E	--		1.1	18.6
SW23	17T 4884000N, 560368E	--		<1	15.6
SW24	17T 4889416N, 563777E	--		211.4	16.5
SW25	17T4889920N, 566202E	883.4	10.9	332.5	16.1

B.9 CONCLUSIONS

An extensive program of drilling, coring, aquifer and aquitard property testing and monitoring has been developed at the Strada property. This extensive data set provides significant insight into the site conditions, and as indicated in Figure A.7, there is considerable additional high-quality data in the local area to support the development of a comprehensive conceptual and numerical model of the proposed application.

This site data and the available surrounding information is developed into a conceptual model in Appendix C. The quantitative numerical analysis of the data is presented in Appendix D.

B.10 REFERENCES

Chebotarev, I.I., 1955, Metamorphism of natural waters in the crust of weathering. Geochim. Cosmochim. Acta, 8: 22-48, 137-170, 198 212.

Dekeyser, L., 2006, The Silurian Amabel and Guelph formations of the Bruce Peninsula: insights into stratigraphy and diagenesis from petrography and ground-penetrating radar. M.Sc. Thesis, University of Waterloo.

Domenico, P.A., 1972, Concepts and Models in Groundwater Hydrology

Banks, W.D. and Brunton F.R., 2017, Collaboration between Ontario Geological Survey, Consultants and Municipal staff results in discovery and development of a safe and sustainable bedrock groundwater supply for the Town of Shelburne, Southern Ontario, Canada, Presented at GeoOttawa, 2017

Brintnell, C., 2012, Architecture and stratigraphy of the Lower Silurian Guelph Formation, Lockport Group, Southern Ontario and Michigan: unpublished MSc. thesis, University of Western Ontario, 243p.

Brunton, F.R., 2009, Update of Revisions to the Early Silurian Stratigraphy of the Niagara Escarpment: Integration of Sequence Stratigraphy, Sedimentology and Hydrogeology to Delineate Hydrogeologic Units, in Summary of Field Work and Other Activities 2009, Ontario Geological Survey, Open File Report 6240, p.25-1 to 25-20.

Brunton, F.R. and Brintnell, C. 2020, Early Silurian Sequence Stratigraphy and Geological Controls on Karstic Bedrock Groundwater-Flow Zones, Niagara Escarpment Region and the Subsurface of Southwestern Ontario, Ontario Geological Survey, Groundwater Resource Study 13.

Burwasser, G.J., 1974, Quaternary geology, Collingwood-Nottawasaga area, southern Ontario; Ontario Division of Mines, Preliminary map P0919, scale 1:50 000.

Cowan, W.R., 1976, Quaternary Geology of the Orangeville area, southern Ontario; Ontario Division of Mines, Geoscience Report 141, 98p.

Earthfx, 2022, Updated Wellhead Protection Area Delineation and Vulnerability Scoring for the Town of Shelburne, Ontario, Prepared for the Town of Shelburne.

Genivar, 2011, Proposed Melancthon Quarry Hydrogeologic and Hydrologic Assessment. Prepared for: The Highland Companies 477476 Third Line, R.R. #2 Shelburne, Ontario. Genivar Project No. 082032.05

Goffco Limited, 2005, Hydrogeology Report in Support of an Application for a Permit To Take Water From a Well and Pond For Aggregate Washing Purposes, West Half Of Lot 13, Concession 3 Township Of Melancthon, Dufferjn County, prepared For Strada Aggregates Inc.

Goffco Limited, 2007, Report on a Preliminary Pumping Test for Monitoring Well MW2-07 Near the Shelburne Pit Lot 12, Concession 3, Melancthon Township

Golder Associates and Banks Groundwater Engineering, 2013, Long Term Well for Additional Water Supply Project, Environmental Assessment/Environmental Impact Statement: prepared for the Town of Shelburne, September 2013.

Gwyn, Q.H.J. 1972. Quaternary Geology of the Dundalk area Southern Ontario. Ontario Department of Mines and Northern Affairs. Preliminary Map P.727 Geological Series Scale 1:50,000

Gwyn, Q.H.J., 1975, Quaternary geology of the Dundalk area, southern Ontario: Ontario Division of Mines, Open File Report 5132, 138p.

Houlsby, A. (1976), Routine Interpretation of the Lugeon Water-Test. Q. J. Eng. Geol. Vol. 9, pp. 303-313.

Johnson, M.D., Russell, D.J., and Telford, P.G., 1983, Oil shale assessment project, volume 2 drillholes for regional correlation 1981/82, Ontario Geological Survey, open file report 5459, 32 p.

Johnson, M.D., D.K. Armstrong, B.V. Sanford, P.G. Telford, and M.A. Rutka, 1992, Paleozoic and Mesozoic geology of Ontario; in Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 2, p. 907-1008.

Lugeon, M., 1933, Barrage et Géologie. Dunod. Paris

Munn, J.D., 2018, Measuring groundwater flow system variability in a fractured carbonate aquifer using fibre optic distributed temperature sensing. PhD Thesis, University of Guelph

Ontario Geological Survey, 2010, Surficial geology of southern Ontario: Ontario Geological Survey, Miscellaneous Release – Data 128 revised, digital compilation of southern Ontario surficial geological mapping.

Ontario Geological Survey Aggregate Resources Inventory Paper 163—Revision 2, 2014. Aggregate Resources Inventory of Dufferin County Southern Ontario. Prepared by MacNaughton Hermsen Britton Clarkson Planning Limited, White Land Science, Robinson Consultants, D.J. Rowell and F.R. Brunton

Piper, A. M., 1944, A graphic procedure in the geochemical interpretation of water analyses, Trans. Amer. Geophys. Union, vol. 25, pp. 914-923.

Quiñones-Rozo, C. , 2010, Lugeon test interpretation, revisited. Senior Civil/Geotechnical Engineer, URS Corporation, 1333 Broadway Suite 800, Oakland, CA 94612, camilo_quinones-rozo@urscorp.com

Whitewater Hydrogeology, 2013, Category 3 PTTW Application: 3191574 Nova Scotia (Downey Farms). Prepared for the Ministry of the Environment, Environmental Assessment and Approvals Branch, 2 St. Claire Avenue West, Floor 12A Toronto ON

Appendix C:
Conceptual Model Report

Strada Aggregates Proposed Strada Pit/Quarry

Appendix C
Conceptual Model Report

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October, 2024

Proposed Strada Aggregates
Shelburne Pit/Quarry

Appendix C
Conceptual Model Report

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Proposed Strada Aggregates Shelburne Pit/Quarry Conceptual Model Report

1 Introduction

1.1 *Background*

Strada Aggregates is seeking a license to operate a pit/quarry at the site of their Shelburne pit, located at 437159 4th Line, Shelburne, Ontario (Figure 1.1).

To assess the potential impacts of pit/quarry development on groundwater and surface water resources, an understanding of groundwater flow through the underlying overburden and fractured rock environment is required. This is developed through the collection of field data and the development of a site conceptual model. Once a sufficient level of understanding has been developed, the conceptual representation of the fractured bedrock is translated into a mathematical model for the purpose of impact assessment.

1.2 *Objectives*

The purpose of this investigation is to meet the requirements of the Ontario Ministry of Natural Resources (MNR) Level 1/Level 2 Hydrogeological Investigation. This includes:

- Field characterization of the current hydrogeologic conditions at the proposed pit/quarry site;
  - Appendix A and B: Field Program Methodology and Results

- Evaluation of the current hydrogeologic and hydrologic conditions through data interpretation, conceptual interpretation and the development of a groundwater/surface water model of the site; See:
    - Appendix C: Conceptual Model Report (this report)
    - Appendix D: Model Development and Calibration (Earthfx Inc., 2024a)
    - Appendix E: Impact Assessment (Earthfx Inc., 2024b)

The purpose of this “Appendix C: Conceptual Model Report” is to present a description of the physical setting, including local geology, hydrogeology, climate and surface water features in and around the site. More detailed analysis of the data is presented in Appendix D: Model Development and Calibration (Earthfx Inc., 2024a).

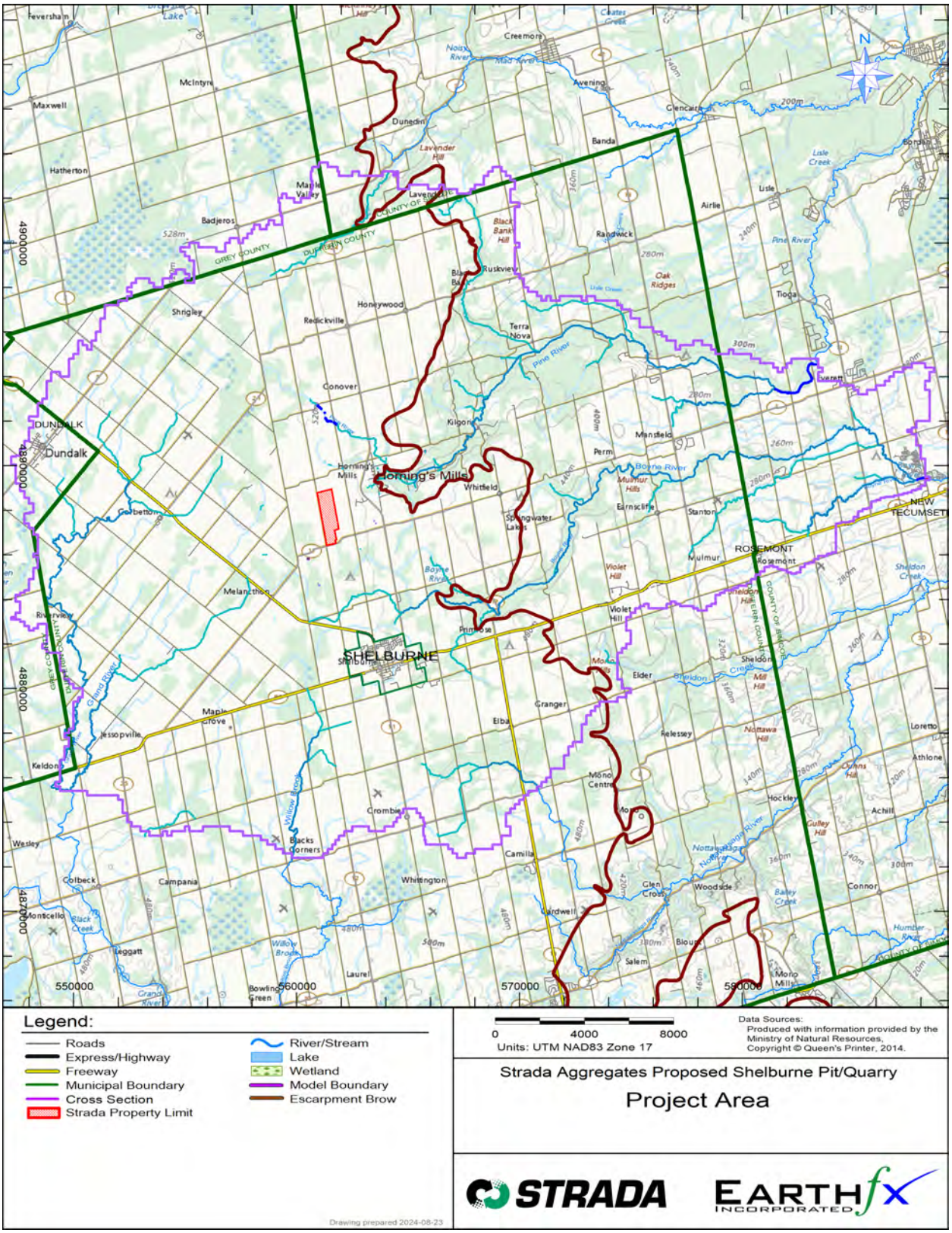


Figure 1.1: Location of the the proposed Strada Pit/Quarry and the surrounding study area.

2 Physical Setting

2.1 *Physiography and Topography*

The study area contains parts of five physiographic regions as defined by Chapman and Putnam (1984, 2007). These regions, shown in Figure 2.1, include the Dundalk drumlinized till plain (western half of the study area), the Horseshoe till moraine, the Niagara Escarpment (most of the eastern half of the study area), the Simcoe lowlands (sand plains), and the Peterborough drumlin field in the east. The Dundalk till plain is gently rolling with generally low local relief and hosts spillway and esker deposits as well as a till plain (Gwyn, 1975). It is also characterized by poorly drained depressions, making the presence of swamps and bogs very common. A more detailed map showing the physiographic features within the region is shown in Figure 2.2. Soils are typically loams or silt loams, likely due to deposition of loess materials, which favor the early cultivation of the land in the spring. Soils around the Town of Honeywood (i.e., Honeywood loam) are more easily drained.

The Niagara Escarpment is a roughly north-south trending, east-facing cuesta, capped by Silurian carbonate rocks, that is largely mantled with Quaternary-age sediments. Although buried across much of the study area, the escarpment represents a significant topographic feature, as evidenced by the map of ground surface elevations in Figure 2.3 (based on the Ontario Ministry of Natural Resources and Forestry (MNRF) digital elevation model). Above the escarpment, topography ranges from highs of over 528 metres above sea level (masl) northwest of the study area, to approximately 405 masl along the edge of the Niagara Escarpment, in closest vicinity of the Strada property. Moving east from the edge of the escarpment, topography drops to below 216 masl at the eastern edge of the study area, defining a relief of approximately 200 m.

The broad moraine ridges of the Horseshoe moraines system are present both above and below the Niagara Escarpment and generally trend north-south with moderate local relief (Figure 2.2) (Gwyn, 1975; Chapman and Putnam, 1984, 2007). There are meltwater spillways in between and east of the moraines (Figure 2.2). There are low relief sand and till plains in the extreme eastern part of the study area (Chapman and Putnam, 1984, 2007).

A kame moraine feature underlies the Strada property, which is itself surrounded by the most predominant feature above the escarpment -- the Dundalk till plain. The kame moraines refer to sand and gravel deposits that are the result of meltwater stream deposits and are likely an extension of the Horseshoe moraines. An elongated shape of a spillway associated with the moraines is present along 5th Line, west of the site.

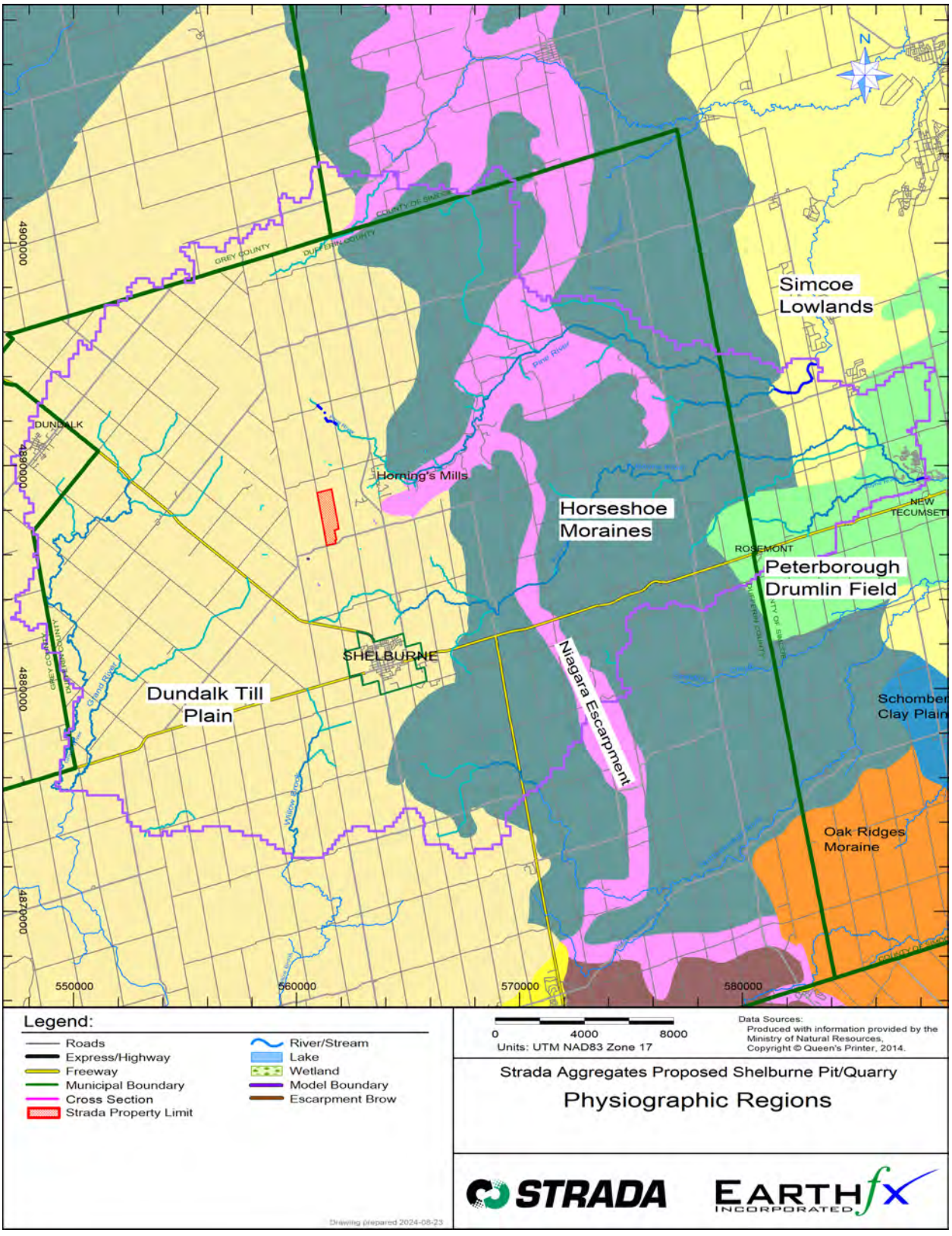


Figure 2.1: Physiographic regions (after Chapman and Putnam, 1984).

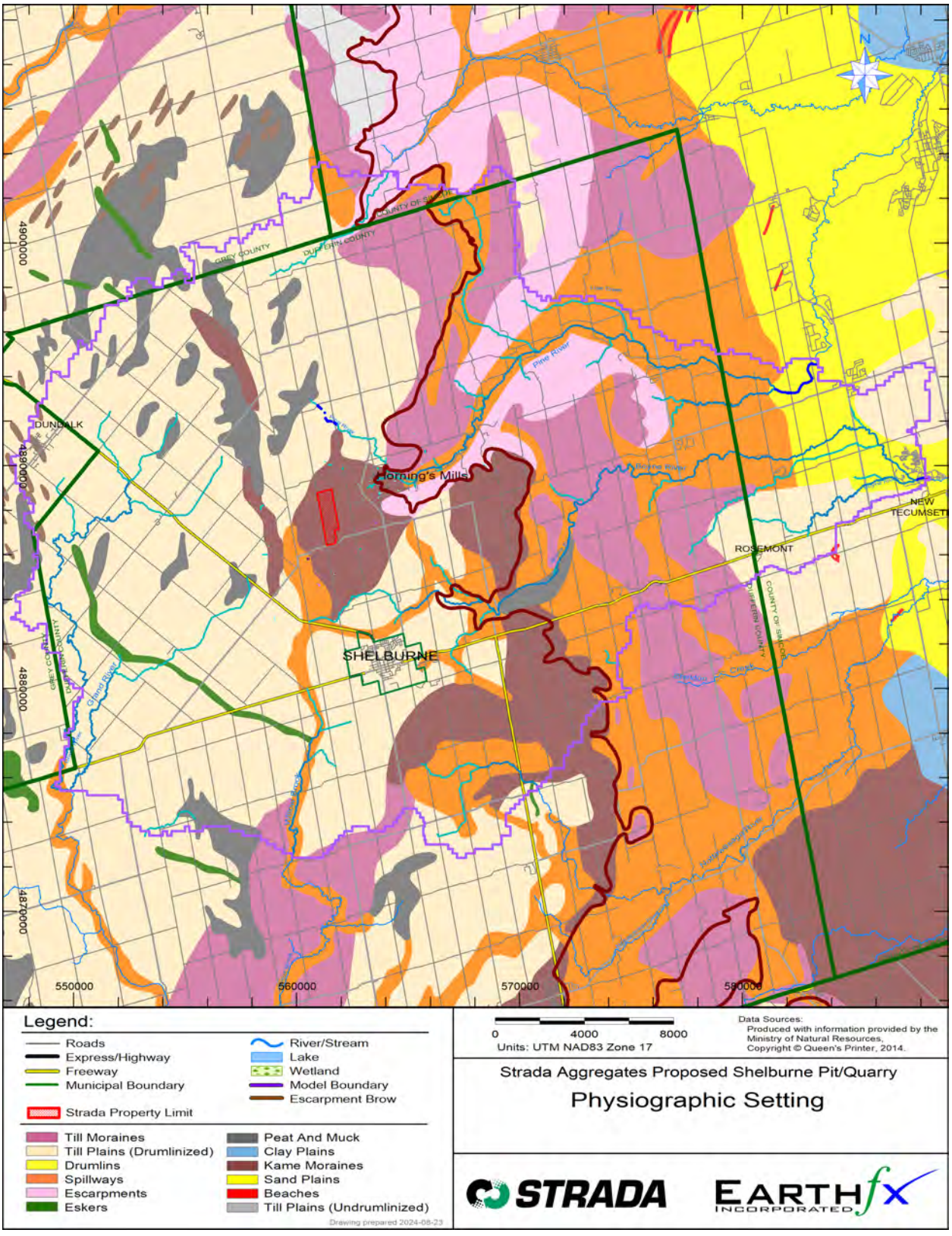


Figure 2.2: Physiographic setting (after Chapman and Putnam, 1984).

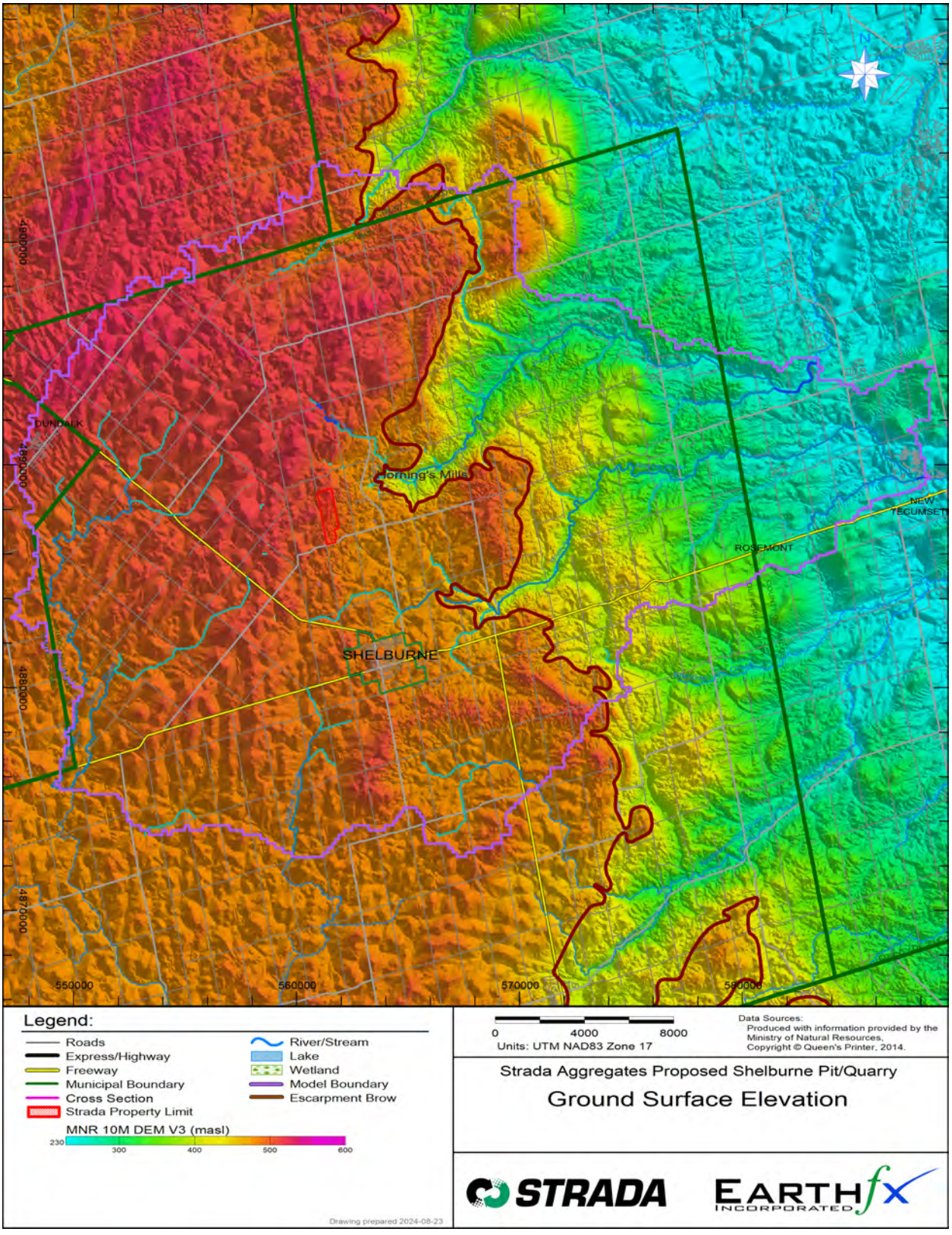


Figure 2.3: Ground surface elevation (based on the 10-m MNRF digital elevation model).

2.2 *Bedrock Geology*

The area surrounding the proposed Strada Shelburne pit/quarry is underlain by clastic and carbonate sedimentary rocks of Late Ordovician to Early Silurian age, which make up parts of three major depositional sequences (Johnson *et al*., 1992), with outcropping rocks becoming younger from east to west (Figure 2.4). The strata dip gently to the southwest, as shown in the conceptual diagram in Figure 2.8. The area was mapped by Liberty *et al.* (1976a and 1976b) and Telford (1976) and was included in the OGS digital compilation map of Armstrong and Dodge (2007).

This section presents an overview of the conceptual model of the study area. This overview is important for a few reasons, particularly as (1) new drilling in the area have explored deeper formations and (2) the conceptual model and nomenclature have evolved over the last 15 years based on research and mapping by the Ontario Geological Survey (OGS). It is important to note that local OGS interpretation of the layering has changed in the study area since 2015. The Eramosa formation, previously mapped by the OGS and interpreted as the confining unit separating the upper and lower aquifers in the nearby Town of Shelburne wellfield, has been removed from the interpretation (Banks and Brunton, 2017), and the Goat Island members (Ancaster/Niagara Falls units) are now considered to contain the aquitard that separates the shallow and deep aquifers.

The oldest bedrock unit outcropping in the area close to the Strada property and below the Niagara Escarpment (Figure 2.4), is the Late Ordovician age Queenston Formation. The Queenston Formation is predominantly dark red, fissile, hematitic, calcareous shale with green-coloured reduction zones that are either parallel or discordant to bedding (Johnson *et al.*, 1992). It is unconformably overlain by the Early Silurian age Cataract Group. The Whirlpool Formation, the lowest unit in this group, is composed mainly of fine-grained quartz sandstone with thin shale interbeds (Liberty, *et al.*, 1976a). This unit can be up to five metres (m) thick in outcrop. Thicknesses up to 9.5 m have been reported in petroleum wells. It is succeeded by the thin- to medium-bedded fossiliferous dolostone of the Manitoulin Formation, which may be up to 4 m thick in outcrop and ranges from less than one metre to more than 15 m thick in boreholes. The contact with the overlying Cabot Head Formation is gradational. The rocks of the Cabot Head Formation are predominantly thinly laminated, grey and green, noncalcareous shales with minor interbeds of sandstone, limestone, and dolostone. It is the uppermost unit of the Cataract Group in the study area (Liberty, *et al.*, 1976a).

Brunton (2008, 2009, 2012, 2017 and 2020) has recently reconciled the stratigraphic nomenclature of the units overlying the Cabot Head Formation. Prior to his work, different terminology was used in the southern (Niagara) central (Hamilton, Milton, Acton) and northern (Shelburne, Bruce Peninsula) sections of the Niagara Escarpment. Figure 2.5 presents the new nomenclature of Brunton for the units above the Cabot Head Formation. Figure 2.6 correlates the Brunton nomenclature with that used in the Hamilton and Niagara regions, while Figure 2.7 correlates the Brunton nomenclature with that formerly used north of Shelburne in the Bruce Peninsula. The implications of the Brunton re-interpretation are discussed in more detail below.

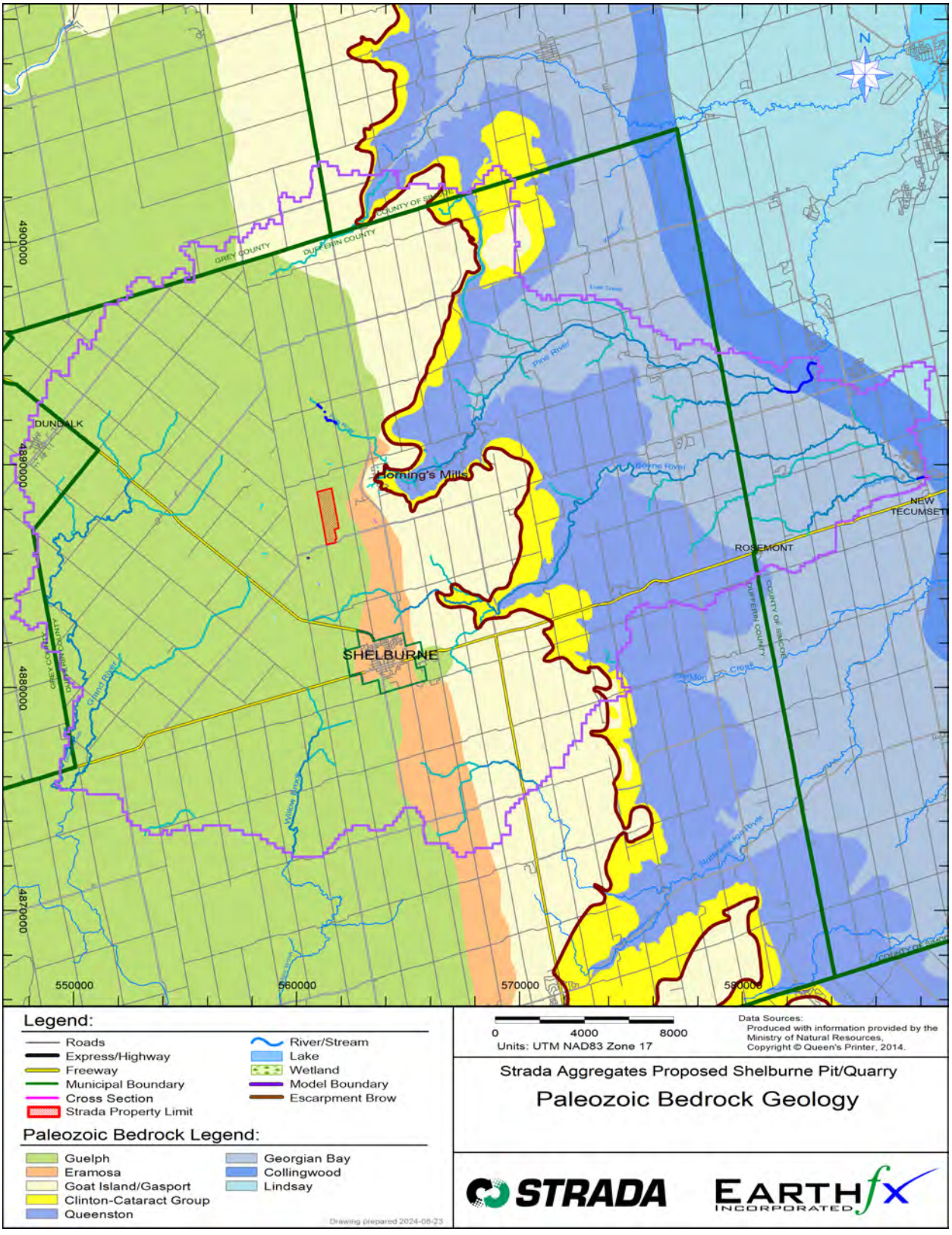


Figure 2.4: Paleozoic bedrock geology (after OGS/MacNaughton, 2014).

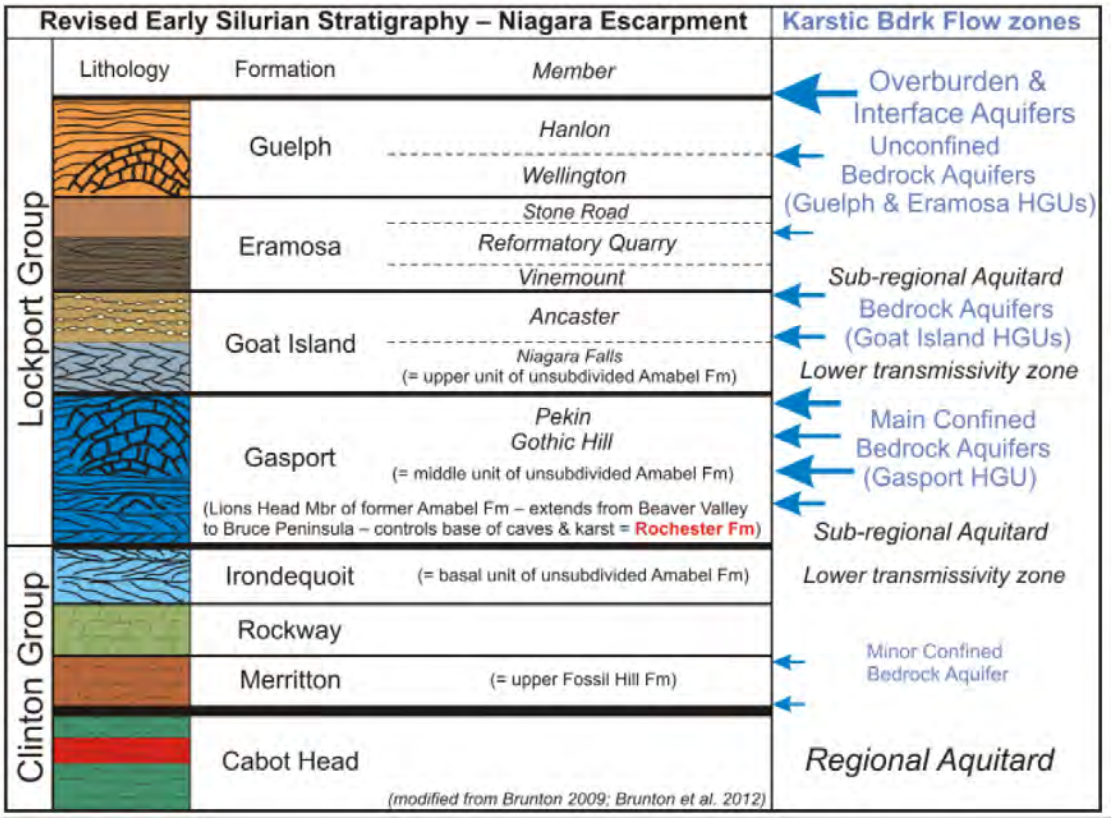


Figure 2.5: Revised Early Silurian stratigraphy and hydrostratigraphy (based on Brunton, 2012).

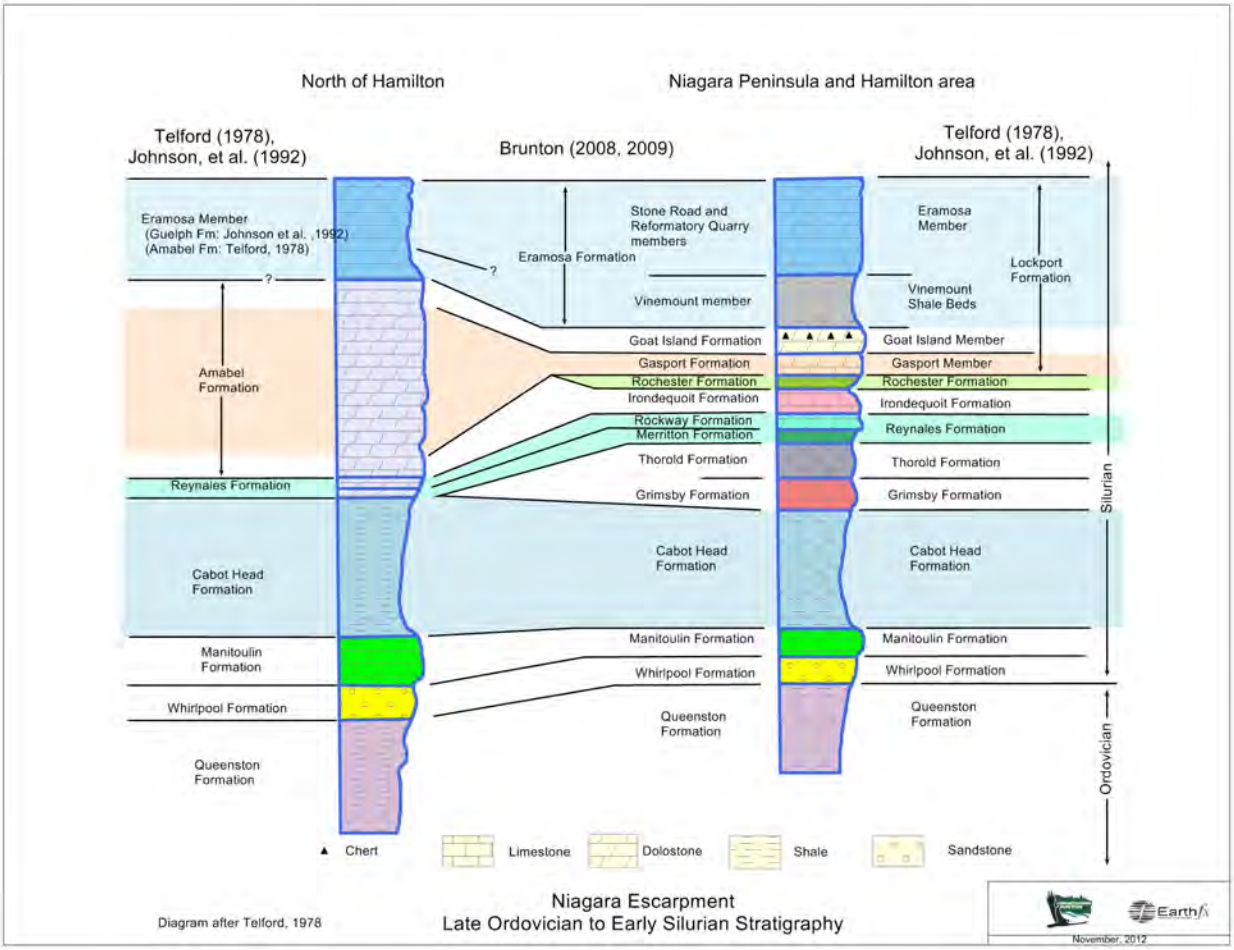


Figure 2.6: Southern stratigraphic relationships and nomenclature.

Revised Conceputualization Formation / Member		Previous Conceptualization Formation / Member	
Overburden		Overburden	
Guelph Formation	Hanlon Member	Guelph Formation	
	Wellington Member		
Eramosa Formation	Stone Road Member	Amabel Formation	Eramosa Member
	Reformatory Quarry Member		
	Vinemount Member		
Goat Island Formation	Ancaster / Niagara Falls Members		Wiarton / Colpoy / Lions Head Members
Gasport Formation	Gothic Hill Member		
Rochester / Irondequoit / Rockway / Merritton Formations			
Fossil Hill Formation		Cabot Head / Reynales Formation	

Figure 2.7: Revised conceptual bedrock nomenclature compared to that formerly used in the Bruce Peninsula area (after Brunton, 2009).

The Fossil Hill Formation (now referred to as the Merritton Formation by Brunton) is at the base of the overlying Early Silurian Clinton Group. It disconformably overlies the Cabot Head Formation and consists of cherty, dolomitic mudstone to wackestone (Brunton, 2009) and outcrops in the face of the Niagara Escarpment (Johnson *et al.*, 1992). The Rockway Formation disconformably overlies the Fossil Hill Formation and is described by Brunton (2008) as an argillaceous dolomicrite to wackestone with a distinctive, greenish-grey, finely crystalline matrix and thin shaly partings. Next in the sequence is the Irondequoit Formation, a porous, fine to medium crystalline limestone, with abundant fossils, particularly crinoid fragments. It is generally about two metres thick with one or two massive beds (Johnson *et al.*, 1992). The Irondequoit Formation was formerly thought to pinch out just west of Hamilton (Johnson *et al.*, 1992) along with the overlying Rochester Formation, but Brunton (2008, 2009) has traced it in drill core as far north as the Bruce Peninsula and considers it to be the basal unit of the unsubdivided Amabel Formation (see Figure 2.6 and discussion below). Collectively, these three units are frequently grouped together referred to as the IRM (Irondequoit, Rockway, Merritton).

Next in the succession are the thick, medium- to coarse-grained dolostones that form the caprock of the Niagara Escarpment. These rocks are mapped as Amabel Formation within the study area (Liberty *et al.*, 1976a). The Amabel Formation has been considered a facies equivalent of the Lockport Formation of the Niagara Peninsula with an arbitrary boundary north of Waterdown. This terminology was used in the OGS Geology of Ontario report (see Johnson *et al.*, 1992). However, Brett *et al.* (1995) have proposed raising the Lockport Formation to group rank and its members to formation rank. The Amabel Formation has also undergone a re-examination in the Guelph area by Brunton (2008, 2009), who subdivided the Amabel and correlated the subunits with the Irondequoit Formation and the Gasport and Goat Island formations - formerly members of the Lockport Formation - of the Niagara Peninsula and western New York (Figure 2.5). The Gasport Formation appears to make up the bulk of the unsubdivided Amabel, overlying the two-to three-metre-thick Irondequoit Formation. Brunton (2009) equates the Gasport Formation with the Wiarton and Colpoy Bay Members of the Amabel Formation (Bolton, 1953) (Figure 2.7).

The unsubdivided Amabel Formation is a regionally-important source of groundwater. In the Guelph area, Brunton (2008) has found that the major aquifer in the former unsubdivided Amabel Formation is within what he called the “Gasport hydrogeologic unit” (this informal unit has also been referred to as the “Amabel Production Zone”). Brunton and Brintnell (2011) noted that the variable paleotopography of the Gasport Formation was the main control on the character and presence or absence of the overlying Goat Island and Eramosa Formations. The Goat Island Formation is divided into two members. The Niagara Falls Member is composed of finely-crystalline, crinoidal grainstones and is overlain by the chert-rich finely crystalline Ancaster Member (Brunton, 2009). The Niagara Falls and Ancaster members are particularly important to the interpretation of the geologic setting at the Town of Shelburne and to the north. Brunton recently re-interpreted the Town of Shelburne wellfield data so that the Ancaster and Niagara Falls members is now considered an important aquitard that hydraulically isolates the deeper water supply wells from the shallower bedrock (see discussion above and Banks and Brunton, 2017).

The Eramosa Formation overlies the Goat Island and Gasport formations in much of the study area (Brunton 2008) and was formerly considered a member of the Amabel (see Johnson *et al.*, 1992). Brunton (2008, 2009) has divided this unit into three members. The lowest member is made up of shaley, fine-grained dolostones and has been named the Vinemount Member by Brunton (2008). Brunton (2008, 2009) considers it a regional aquitard where it is present. The Vinemount characteristically exhibits bituminous features, which have been observed in the OGS deep drill hole at Corbetton (Johnson *et al.*, 1983; Brintnell, 2012).

The upper two members of the Eramosa are the Reformatory Quarry Member (middle) and the Stone Road Member (upper), and consist of brown to cream-coloured dolostone, with pseudonodular, coarsely crystalline and coral-stromatoporoid biostromal lithofacies (Brunton, 2009). The Eramosa

interval that was recognized in the OGS Corbetton, DDH-6, DDH-10a, and DDH-10b drill holes is considered to be the Stone Road Member (Brintnell, 2012). As previously noted, the Eramosa and, more specifically, the Vinemount shale, are important regionally significant aquitards, but the mapping of the Eramosa in the study area has evolved.

The Guelph Formation is the youngest bedrock unit in the area and has a sharp, erosional contact with the underlying Eramosa Formation (Brunton, 2009; Brintnell, 2012). It is typically a tan, sucrosic, fossiliferous dolostone with open marine, medium-to thickly-bedded, cross-stratified crinoidal grainstones and wackestones and more thinly-bedded lagoonal facies wackestones and packstones with abundant megalodonts and gastropods (Johnson *et al.*, 1992; Brunton, 2009).

The Lockport Group of Brett *et al*. (1995) comprises the Gasport, Goat Island, Eramosa, and Guelph Formations, and roughly corresponds to the former Albemarle Group in the sense used by Johnson *et al*. (1992). Cramer *et al*. (2011) state that because Brunton (2008, 2009) has demonstrated that this concept of the Lockport Group can be extended throughout southern Ontario, the terms `Albemarle Group` and `Amabel Formation` are redundant and should be abandoned. Brunton (2009) found that the unit formerly named the Lions Head Member of the Amabel Formation is probably a Michigan Basin carbonate facies equivalent of the Rochester Formation and he has documented the northwesterly continuation of the Irondequoit Formation mentioned above - both formations are part of the Clinton Group (Figure 2.7).

The conceptual hydrostratigraphy of these units, i.e., their classification into aquifers and aquitard units, is discussed in more detail below.

2.3 *Quaternary Geology*

Overlying the Paleozoic bedrock is a suite of unlithified sediments (drift) of Quaternary age, deposited mainly in association with continental glaciation during the latter part of the Wisconsinan stage. Quaternary geology was mapped in the area by Gwyn (1975), Cowan (1976), and Burwasser (1974). These maps were incorporated into the Ontario Geological Survey digital compilation map of southern Ontario Quaternary Geology (OGS, 2010). A conceptual representation of the units is shown in Figure 2.8. Quaternary geology in the study area, based on the OGS compilation, is presented in Figure 2.9.

Gwyn, 1972, in his field notes, states that exposures were examined in which there were two or three tills in the section. As illustrated in Figure 2.8, any of the named tills could be at bedrock surface. The oldest exposed Quaternary sediment in the area is probably the Catfish Creek Till, a very compact to hard, stony to bouldery glacial diamicton with a sandy silt matrix (Cowan, 1976). The unit outcrops in the northwestern part of the area (OGS, 2010) and is quite extensive in the subsurface. The Port Bruce-aged Tavistock Till consists of sandy silt to silt to clayey silt diamicton deposited mainly by southerly flowing glacial ice (Gwyn, 1975). It outcrops extensively in the southwestern part of the model area and the coarse-textured phase is present north of Shelburne and west of Mono Centre (OGS, 2010). The younger Newmarket Till outcrops in the northeastern part of the area, mainly east of (below) the Niagara Escarpment, and was deposited by ice flowing to the southwest. It has a generally sandy silt to loam matrix with about 5 to 10% clasts (Gwyn, 1975). The youngest till in the area is the Kettleby Till, which outcrops in the eastern part of the area along the Highway 89 corridor west of Alliston (OGS, 2010). It is variable in texture, ranging from clay till to silt till with only 1 to 2% clasts (Gwyn, 1975).

The properties of the tills in the area are summarized and discussed in the 2018 report by the Grand River Conservation Authority (Janzen, 2018), which covers a large portion of the study area. All of these units are described as sandy silt diamictons. The Tavistock is, perhaps more stone-poor than the others, but the stone content has no impact on the hydrogeologic leakage of the units as the stones are isolated and “floating” in the fine-grained materials. The Catfish and Newmarket are frequently referred to as “hardpan” in the driller’s logs, which is consistent with their geotechnical description as “overconsolidated”. While overconsolidation might imply lower hydraulic conductivity, it can also lead to the development of vertical fractures. Studies of the Newmarket till (Gerber et. al, 2001) indicates that fracturing can result in vertical leakage, depending on the local layer thickness. To conclude, while tills are widely distributed in the study area, and control groundwater recharge and leakage to the deeper system, the minor differences between the tills are not hydrogeologically significant to the understanding of the flow system. Fracturing, weathering, layering (up to three tills in a vertical profile) and till thickness all affect the hydrogeologic function. The fine-grained nature of the tills does support their use as low permeability barriers, where proper lift placement and compaction control can ensure their hydraulic properties.

There are no known occurrences of the fine-grained Maryhill Clay Till in the area. The high clay content and plasticity of the Maryhill would, if present, act as a more significant aquitard.

Glaciofluvial deposits of sand, gravel, and minor silt are extensive in the study area (Figure 2.9), particularly in the central and eastern parts near the proposed Strada Shelburne pit/quarry. These bodies of granular material take the form of either ice-contact stratified deposits – eskers, kame moraines, and kame terraces – or outwash deposits formed in braided proglacial streams (Gwyn, 1975, Cowan, 1976). There are limited postglacial lacustrine deposits of fine sand, silt, and clay in the extreme eastern part of the area (Figure 2.9). Recent deposits include alluvial sediment of fine sand and silt along modern stream flood plains, as well as thin deposits of wind-blown fine and coarse silt (Gwyn, 1975).

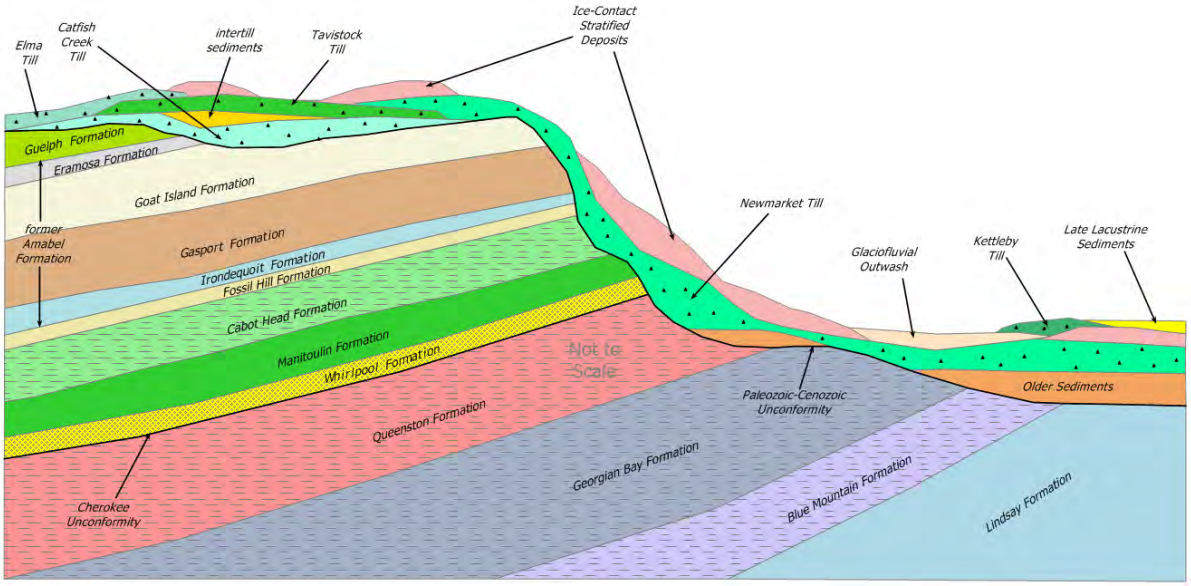


Figure 2.8: Conceptual geologic framework for the study area.

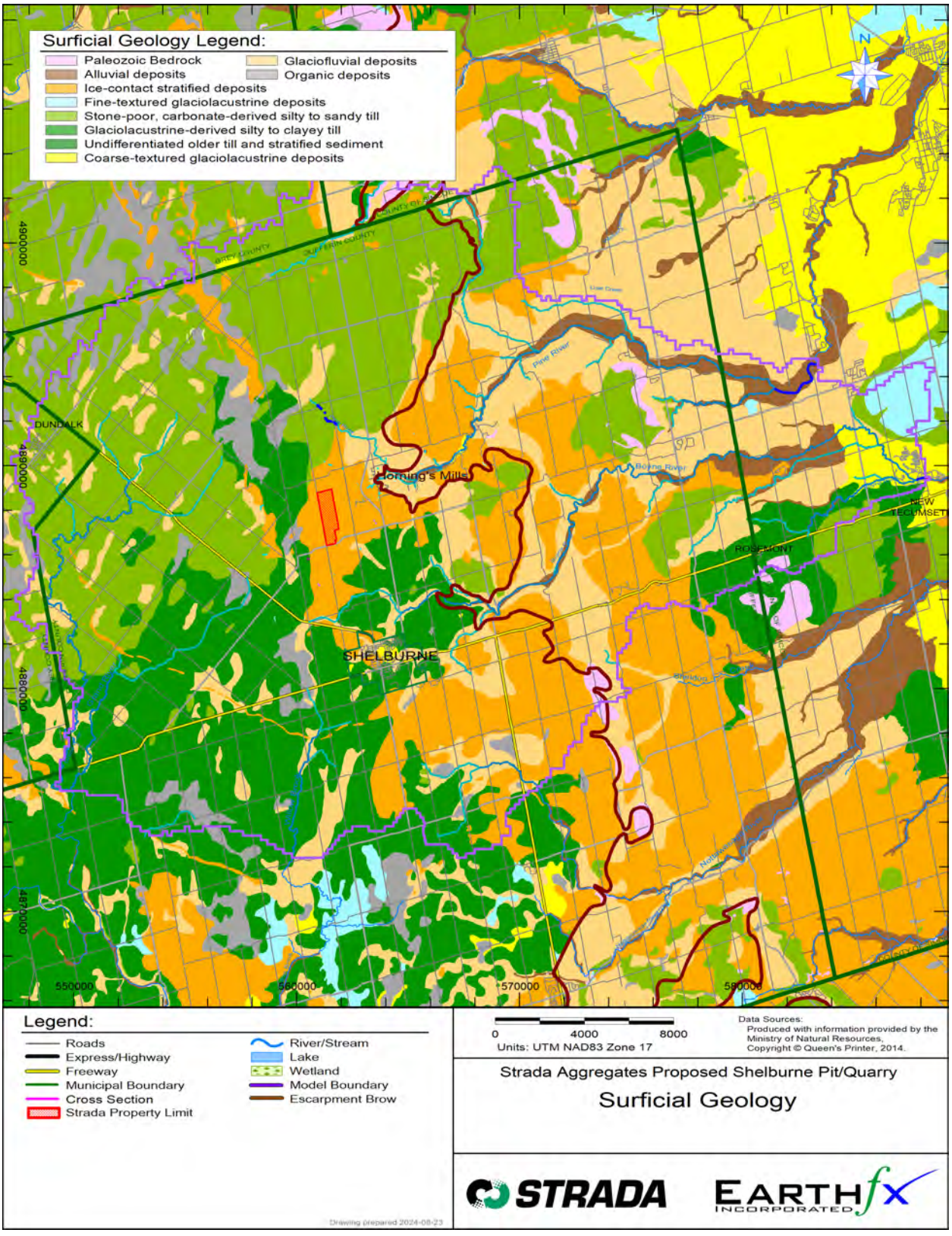


Figure 2.9: Quaternary (surficial) geology in the study area (after OGS, 2010).

3 Conceptual Hydrostratigraphic Model

The geologic units discussed in the previous section provide a framework for delineating the aquifer and aquitard layers in the study area. The conceptual hydrostratigraphic model incorporates the information related to the geometry (thickness and lateral extent) and hydraulic properties of the geologic units. Geologic units with similar properties were sometimes combined into single hydrostratigraphic units. The conceptual hydrostratigraphic model is also used in assigning water level observations to the appropriate aquifers prior to analysis of the data.

The conceptual hydrostratigraphic model was built for the study area based on extensive geologic information, including borehole data collected at the pit/quarry site, detailed drilling and testing both north and south of the site, and insights from a previous geologic model development conducted as part of the Shelburne WHPA update study (Earthfx, 2022). A sketch of the conceptual geologic model, showing the different geologic units, is presented in Figure 2.8. A more detailed representation of the conceptual hydrostratigraphic model was created by mapping the tops of each unit and then overlaying them to create a fully three-dimensional representation. The methodology followed in the mapping process is described below.

3.1 *Three-dimensional Model Construction Methodology*

The “tops” of the overburden and key bedrock units were determined (“picked”) in a multi-step process which began by inspecting drillers’ log data from the Ontario Ministry of Environment, Conservation, and Parks (MECP) Water Well Information System (WWIS), geotechnical boreholes, and high-quality boreholes drilled by the OGS, logs for on-site monitors, and logs for wells drilled by other consultants within the study area. This information was supplemented by the bedrock outcrops in the OGS surficial geology coverage (OGS, 2010), where the top of bedrock could be fixed to ground surface, particularly near the Niagara Escarpment. OGS Oil and Gas well log data were used for the deeper formations; however, many of those wells lie at considerable distance down-dip from the study area. The geologic "picks" data (i.e., borehole location, unit names, and contact elevation) were recorded in a special table in the study database.

The picks for each geologic unit were interpolated using a geostatistical technique known as “kriging” to form provisional surfaces. Locations of the wells (and pick elevations) used in defining the top surfaces are shown in the figures for the various layer tops. As an example, Figure 3.39 shows the top of bedrock and the locations of wells penetrating the bedrock surface. The top of bedrock is typically noted in the drillers’ logs and the coverage (and reliability) of this data set is very high. Overburden thickness, shown in Figure 3.40, is a derived surface created by subtracting the interpolated top of bedrock surface from the DEM. Its reliability is also high. Drift thickness above the Niagara Escarpment ranges from zero to a maximum of 35 m but averages about 10 m thick (Figure 3.40). Quaternary sediments have a maximum thickness of more than 100 m below the Niagara Escarpment.

Geologic picks included wells where the formation was absent (assigning an elevation based on the top of the underlying unit). “Push-down points” were added where the base of the unit was known to be below the bottom of the borehole. Post-processing of the interpolated geologic surfaces was conducted to identify areas where the surfaces crossed (a common occurrence where data are particularly sparse) or the interpolation did not appear correct. The surfaces were corrected where needed by rechecking the borehole data or by adding three-dimensional constraint lines on sections in VIEWLOG. The three-dimensional constraint lines represent interpretations by senior Earthfx geologists and are commonly used to bridge data gaps and resolve problems involving inconsistent data. The corrected and constrained data were then re-interpolated and the surfaces inspected.

The MECP WWIS data are of limited use in picking the tops of units within the bedrock. Carbonate rocks are generally lumped together by water well drillers as 'limestone' and only where a distinctive change was noted could a unit to be picked from the WWIS data with any degree of confidence. Observant drillers log obvious lithologic changes, such as a change from 'limestone' to 'shale', which is of some use in picking formation tops such as the Cabot Head shale. However, water wells drilled above the Niagara Escarpment typically do not penetrate below the major Silurian carbonate sequence and rarely encountered any of the shale units. Most of the useful bedrock unit data came from consultant boreholes drilled at or near existing quarries, proposed quarry development sites, and municipal wellfields. This resulted in the data tending to be clustered. Because the subsurface bedrock units tend to have a fairly uniform dip to the south-southwest and do not have large variations in thickness, the data clustering did not impede producing a reasonable three-dimensional hydrostratigraphic stratigraphic model.

3.2 *Hydrostratigraphic Cross Sections*

To provide a visual context, three hydrostratigraphic cross sections (Figure 3.1) were prepared to illustrate the completed model. Cross section A (Figure 3.2) is parallel to the strike of the bedrock surfaces and shows the sub-crop of the various units towards the Niagara Escarpment. The sections illustrate the regional aquifers and aquitards that are important to the overall flow system. The Cabot Head shale defines an impermeable base to the active regional flow system. The Niagara Falls and Ancaster Member of the Goat Island Formation form a confining unit that isolates the deeper system from the shallow flow system. Till units in the overburden separate the more permeable outwash and ice-contact deposits from the underlying bedrock aquifer.

Cross section B (Figure 3.3) is nearly perpendicular to Section A and follows a north to south direction. Cross section C (Figure 3.4) is parallel to the strike of the bedrock formations, so the units appear to be flat lying.

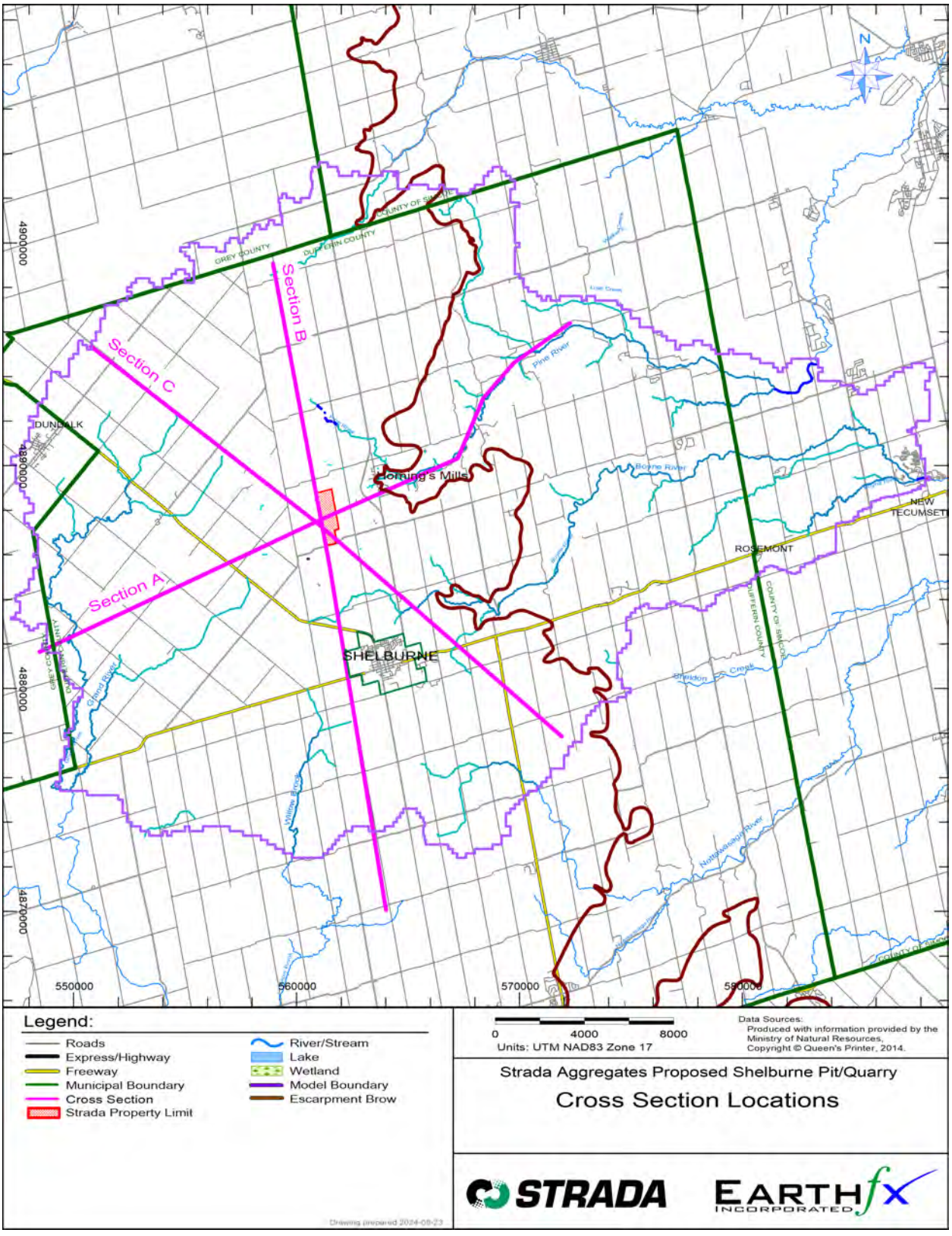


Figure 3.1: Cross section locations.

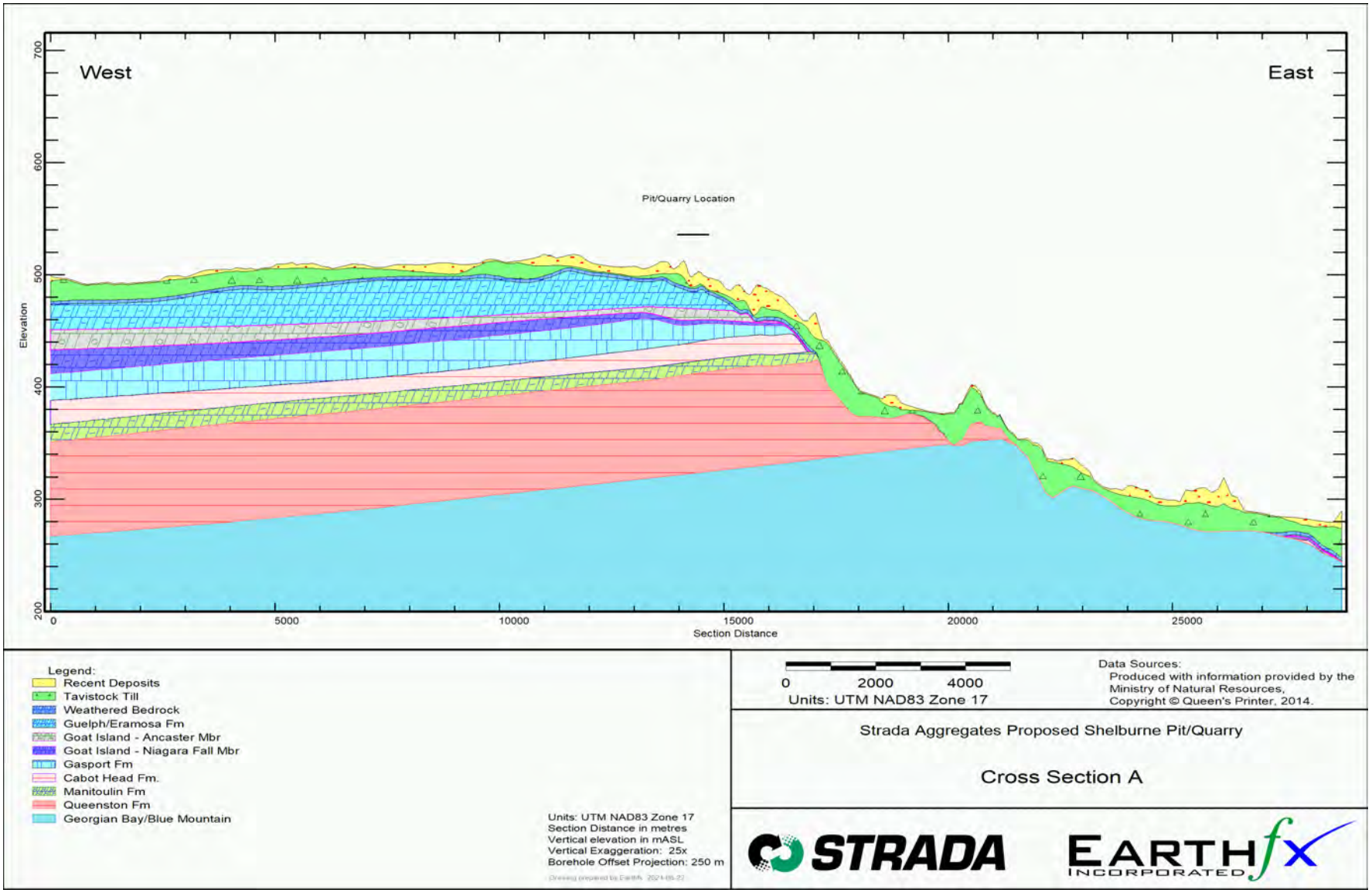


Figure 3.2: Cross section A.

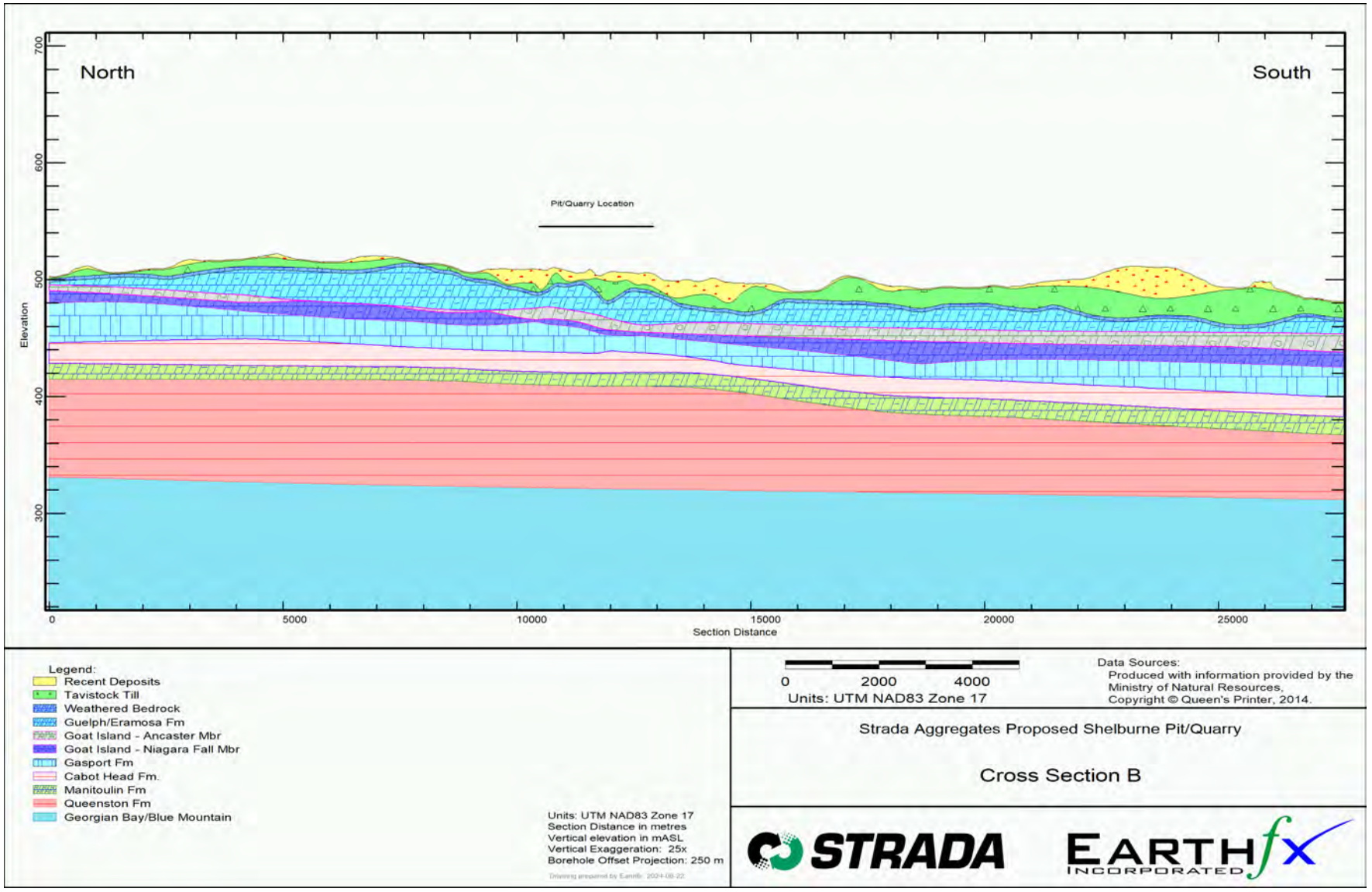


Figure 3.3: Cross section B.

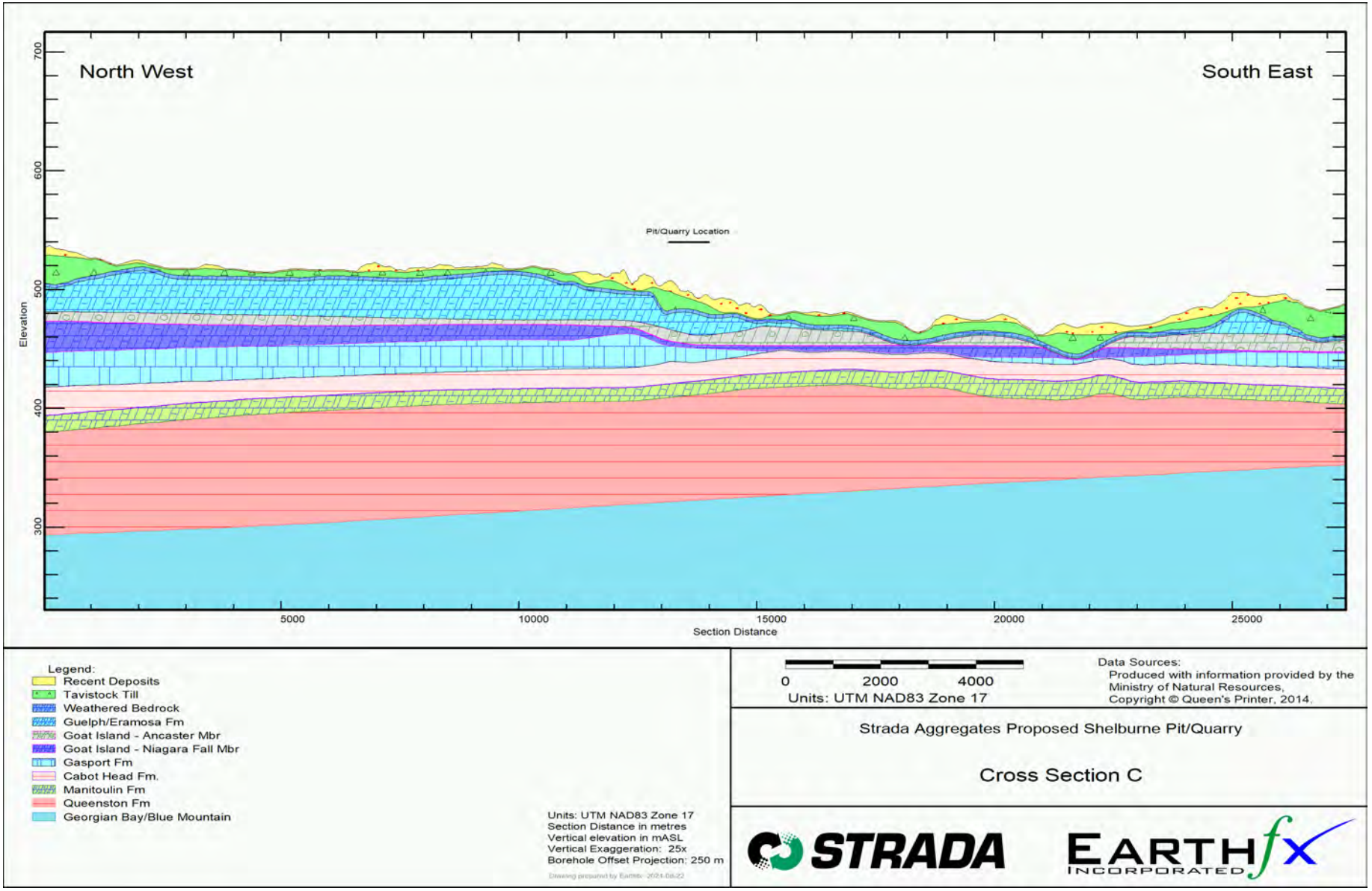


Figure 3.4: Cross Section C.

3.3 *Bedrock Units*

The site cores logs and formations were introduced in the Appendix A and B. The following discussion builds on those descriptions, and presents the extrapolation of the units across the study area. The core photos and descriptions are included here for context. Figure 3.5 presents a schematic borehole log and representative core photos for the key units.

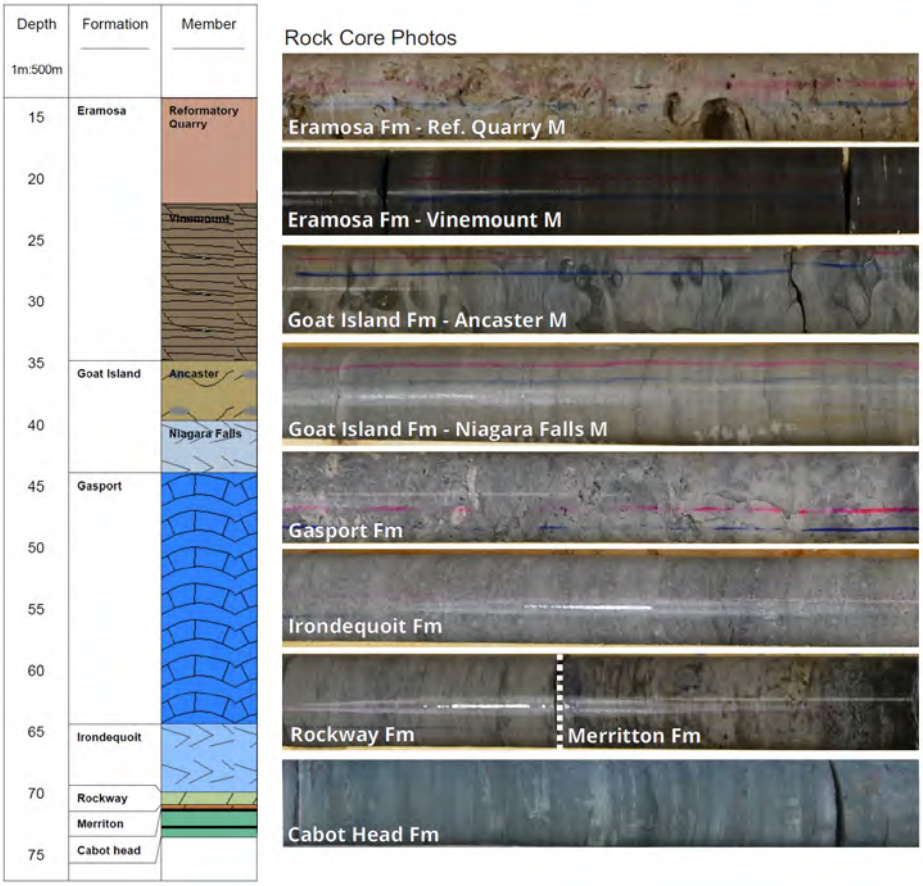


Figure 3.5: Representative photos of each stratigraphic unit (After Munn, 2018 Figure 4.2.)

3.3.1 Cabot Head Formation

The rocks of the Cabot Head Formation are predominantly thinly laminated, grey and green, noncalcareous shales with minor interbeds of sandstone, limestone, and dolostone. It is the uppermost unit of the Cataract Group in the study area (Liberty, *et al.*, 1976a). A photo of the Cabot Head Shale from Core #3 is show in in Figure 3.6. The Cabot Head Formation is continuous across the study area and was interpreted as the base of the flow system from the perspective of the proposed pit/quarry impact analysis.



Figure 3.6: Cabot Head Shale from Core #3.

The deeper units above the Niagara Escarpment are particularly difficult to identify in the western part of the study area because of their depth. Very few water wells penetrate these units. The OGS Corbetton well is located at the western edge of the study area and was key to defining the tops of these units in the study area. The only other formation data is found in deep oil and gas wells southwest of the study area.

The interpolated top of the Cabot Head Formation is shown in Figure 3.8 and its thickness is shown in Figure 3.9. The Cabot Head Formation appears continuous across the study area and was interpreted as the base of the flow system from the perspective of the possible impacts from pit/quarry dewatering.

The Queenston Formation is readily identifiable below the Niagara Escarpment. The top of the unit is coincident with the top of bedrock in this area. Differentiating between the Cabot Head and Queenston shale in the water wells can be difficult, and requires careful understanding of the dip and subcrop of the units.

3.3.2 Irondequoit, Rockway, and Merritton (IRM) Formations

The Merritton Formation (formerly known as the Reynales Formation) is at the base of the overlying Early Silurian Clinton Group. It unconformably overlies the Cabot Head Fm. and consists of cherty, dolomitic mudstone to wackestone (Brunton, 2009) and outcrops in the face of the Niagara Escarpment (Johnson *et al.*, 1992). The Rockway Formation conformably overlies the Merritton Formation and is described by Brunton (2008) as an argillaceous dolomicrite to wackestone with a distinctive, greenish-grey, finely crystalline matrix and thin shaly partings. Next in the sequence is the Irondequoit Formation, a porous, fine to medium crystalline limestone, with abundant fossils, particularly crinoid fragments. It is generally about two metres thick with one or two massive beds (Johnson *et al.*, 1992). The Irondequoit Formation was formerly thought to pinch out just west of Hamilton (Johnson *et al.*, 1992) along with the overlying Rochester Formation, but Brunton (2008, 2009) traced it in drill core as far north as the Bruce Peninsula and considers it to be the basal unit of the former Amabel Formation (see Figure 2.5) and discussion below). A photo of the IRM from Core #3 is show in in Figure 3.7.



Figure 3.7: IRM from Core #3.

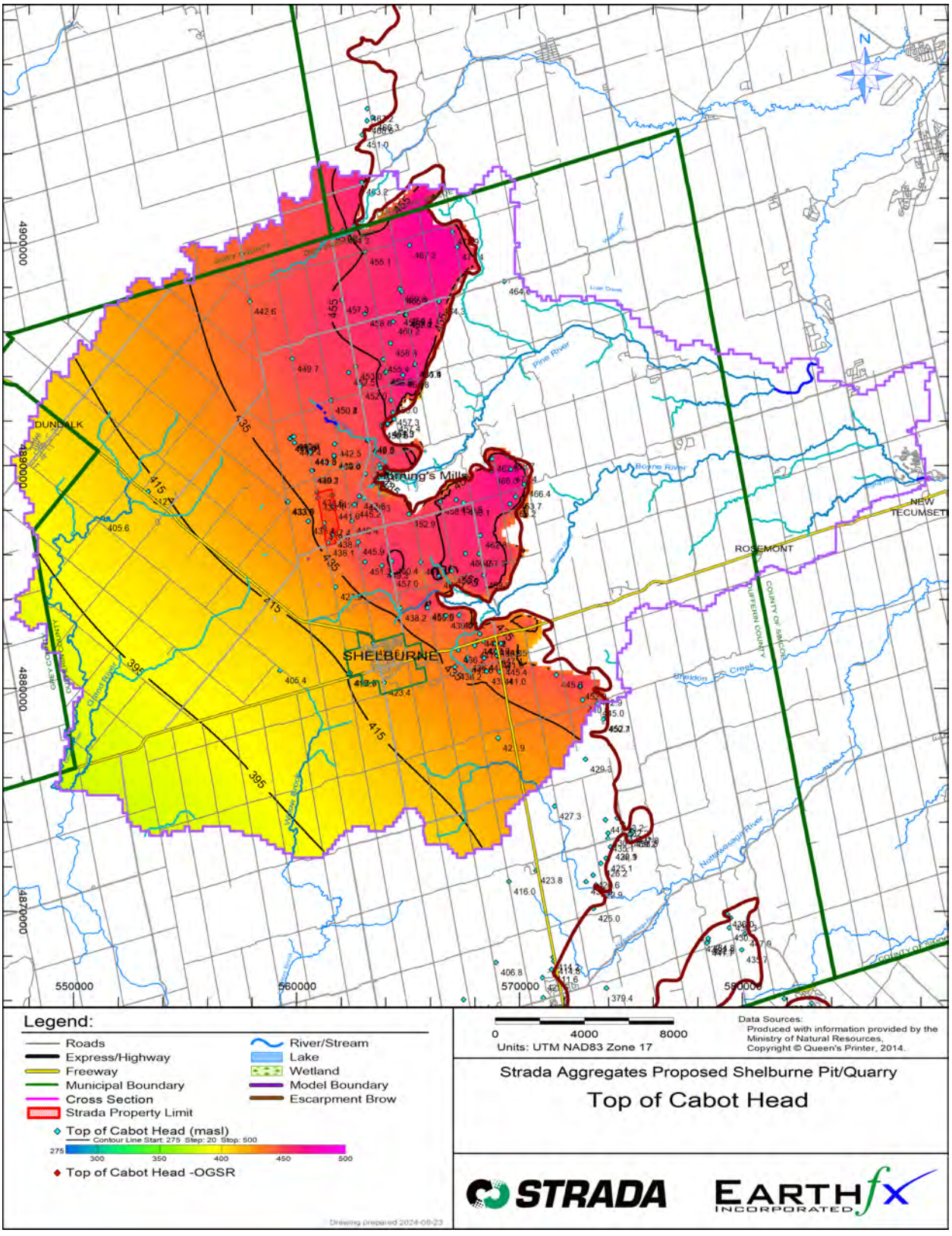


Figure 3.8: Top of the Cabot Head Formation (masl).

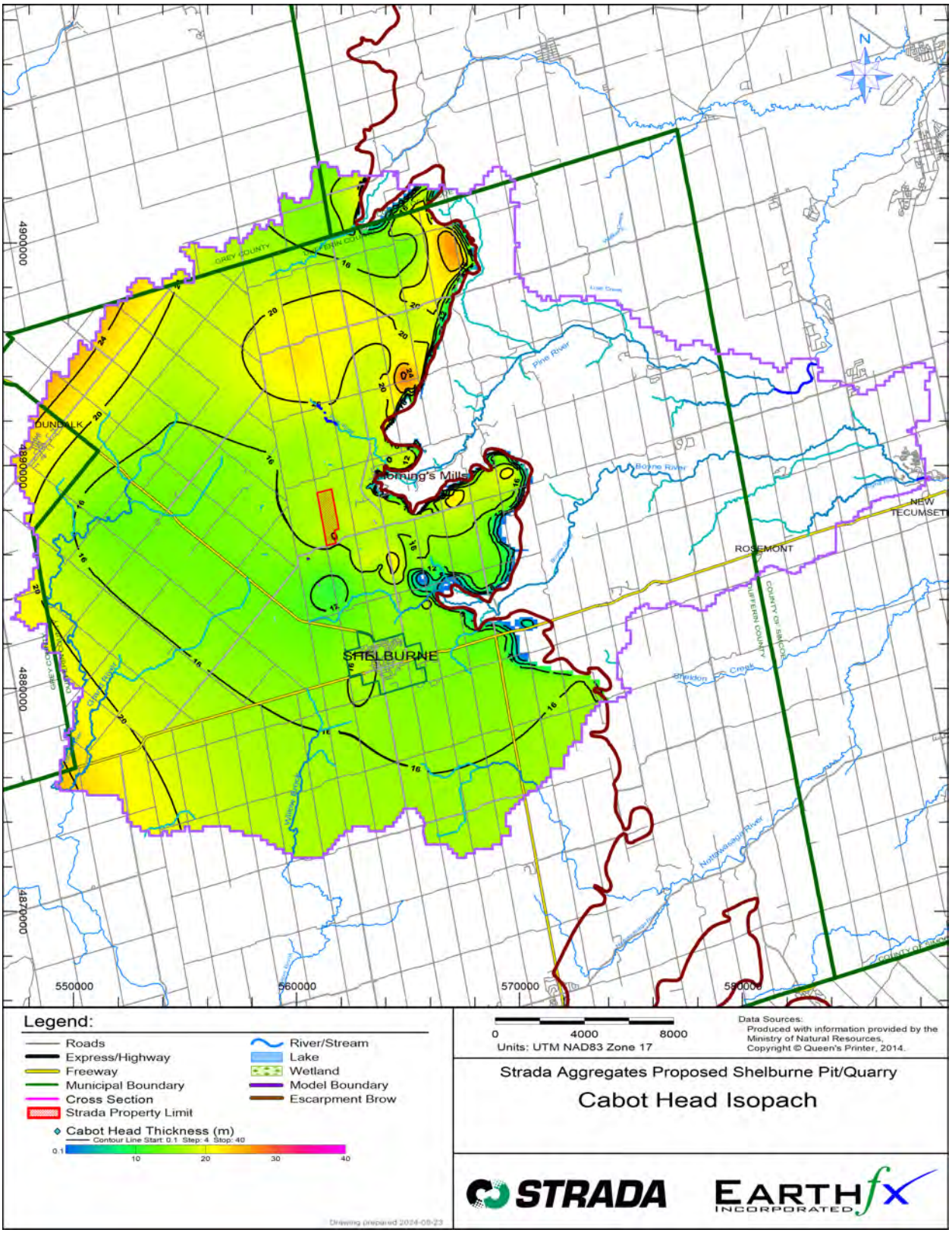


Figure 3.9: Cabot Head thickness (m).

While the Cabot Head shale can be differentiated from carbonate rocks (dolostones) in water well records, the IRM unit cannot be reliably identified. Further, the hydrogeologic properties of the IRM are largely the same as the overlying Gasport, and so this unit was combined with the Gasport in the conceptual 3-D model.

3.3.3 Gasport Formation

The Gasport Formation, formerly referred to as part of the unsubdivided Amabel Formation, is a regionally-important source of aggregate as well as groundwater. Light pinkish-grey, regionally transgressive, cross-bedded grainstone to packstone containing microbial–crinoidal reef mound lithofacies transitioning upward to rhynchonellid brachiopod–bryozoan–bivalve coquinas. The site core exhibits the irregular elongate mottles that are commonly observed in the Colpoy Bay Member (now Gasport), as discussed in Dekeyser (2006, Figure 3.1).

In the Guelph area, Brunton (2008) found that the major aquifer in the former unsubdivided Amabel Formation is within what he called the “Gasport hydrogeologic unit” (this informal unit has also been referred to as the “Amabel Production Zone”). Brunton and Brintnell (2020) noted that the variable paleotopography of the Gasport Formation was the main control on the character and presence or absence of the overlying Goat Island and Eramosa Formations.



Figure 3.10: Gasport Formation from OW27 (Core #3).

The Gasport and Goat Island Formations cannot be easily distinguished in ordinary water well logs, however in some cases a color change is noted. The top of the Gasport Formation was delineated from oil and gas wells, cored boreholes wells at the Strada site, Shelburne wellfield (including, and the OGS10A well), Highland property, the OGS Corbetton borehole (Figure 3.11). The estimated thickness of the Gasport is shown in Figure 3.12.

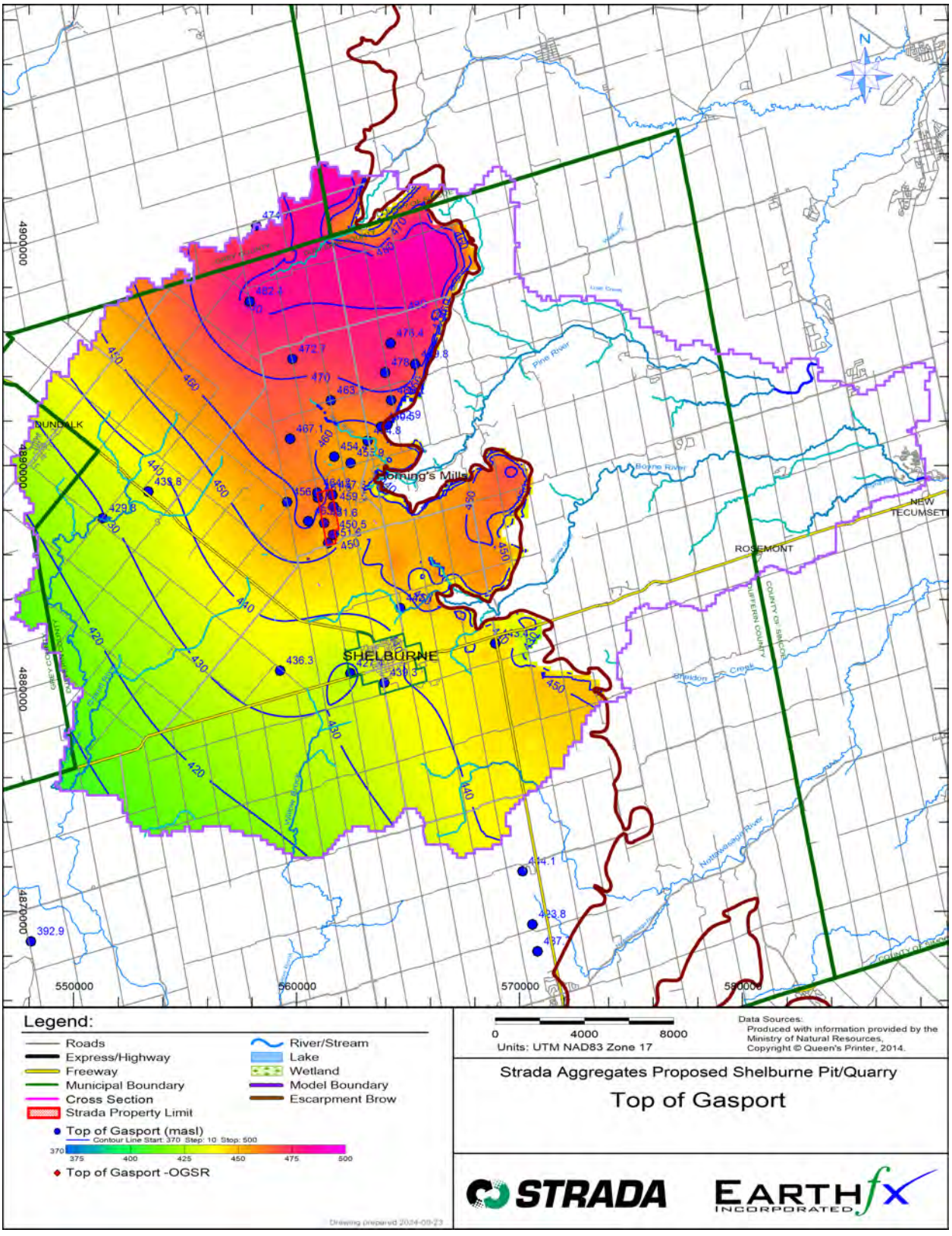


Figure 3.11: Top of the Gasport Formation (masl).

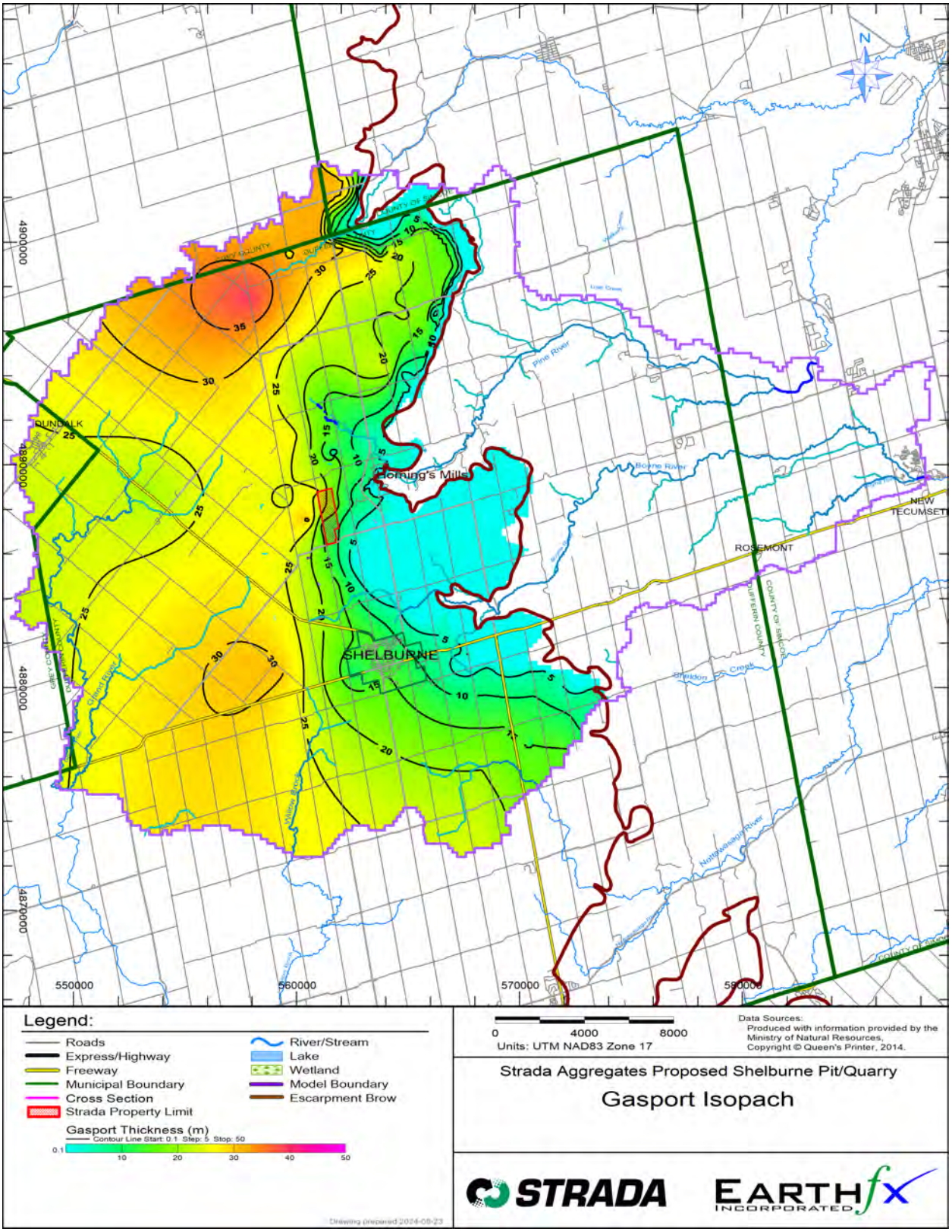


Figure 3.12: Gasport Formation thickness (m).

3.3.4 Goat Island – Niagara Falls Formation

The Goat Island Formation is divided into two members. The Niagara Falls Member of the Goat Island Fm. is composed of finely-crystalline, crinoidal grainstones and is overlain by the chert-rich finely crystalline Ancaster Member (Brunton, 2009). Brunton recently re-interpreted the geological data from the Town of Shelburne wellfield, and wellfield testing confirmed that the Niagara Falls member is an important regional aquitard that hydraulically isolates the deeper aquifer system from the shallower bedrock (Banks and Brunton, 2017). Therefore, the Niagara Falls Member of the Goat Island Fm. is interpreted as the key aquitard that confines the Gasport at the site. The Niagara Falls Member exhibits a characteristic "pin-stripe" pattern, and also characteristically exhibits a "sheen" reflection when wiped with a wet rag due to the fact that the moisture is not absorbed into the core (see Figure 3.13).



Figure 3.13: Niagara Falls member of the Goat Island Formation from Core #2.

The top elevation of the Niagara Falls member of the Goat Island Formation was locally identified from picks in the cored site boreholes and the Shelburne wellfield (including OGS10A) and was found in all 7 cored holes at the Strada site. Regionally, the base of the Ancaster Member was used to help delineate the top of the Niagara Falls Member. Chert nodules are characteristic of the Ancaster and are found both in OGS10a, at the Strada property, and in numerous wells at the Highland property. The top elevation and total thickness of the Niagara Falls aquitard are shown in Figure 3.14 and Figure 3.15, respectively.

The low permeability of the Niagara Falls and Ancaster members are clearly identified in the packer test results from the Strada site (See Appendix A, Figure B15), and from the pumping tests, such as from the Shelburne wellfield testing (see Section 5.5.2, for example).

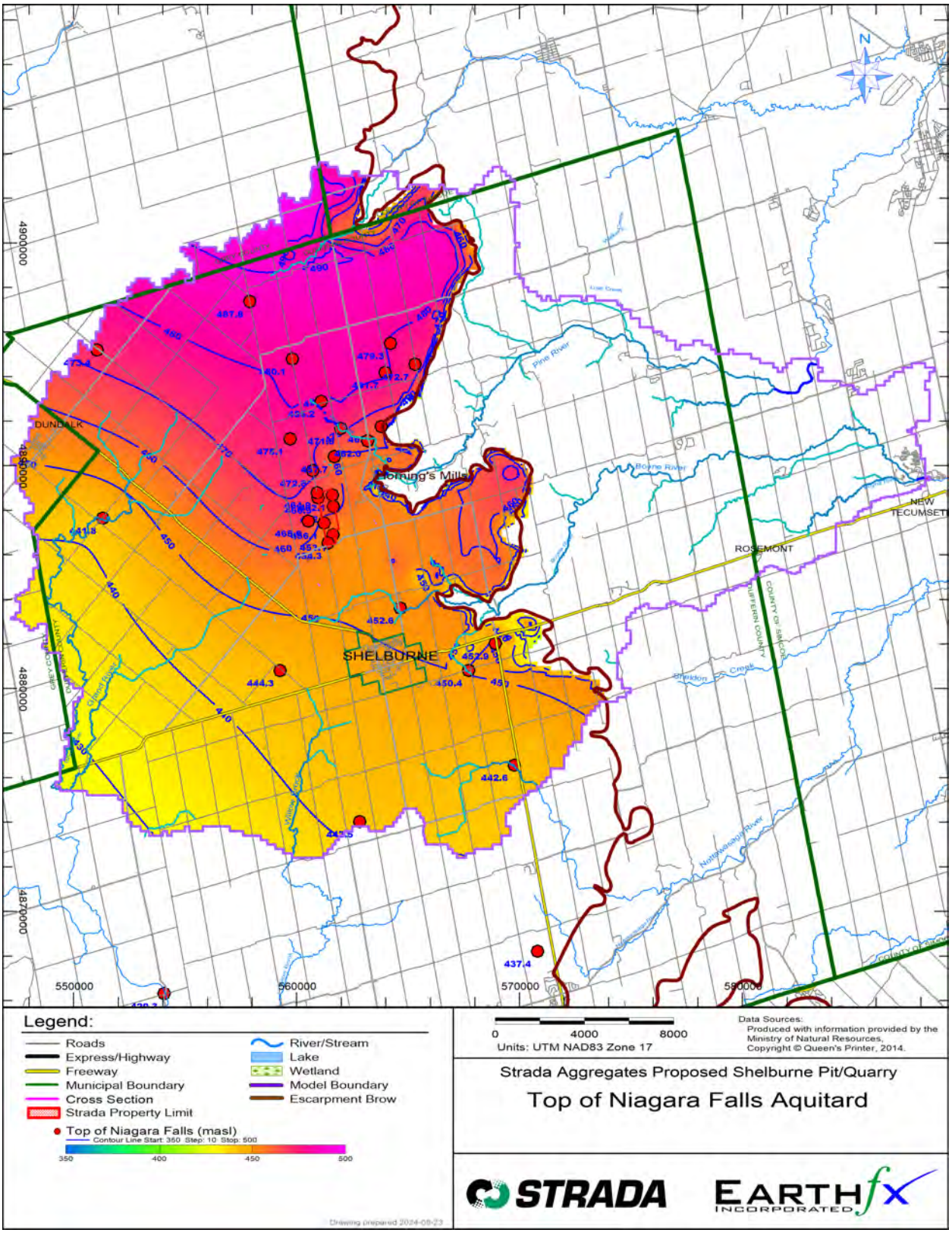


Figure 3.14: Top of the Niagara Falls Member (masl).

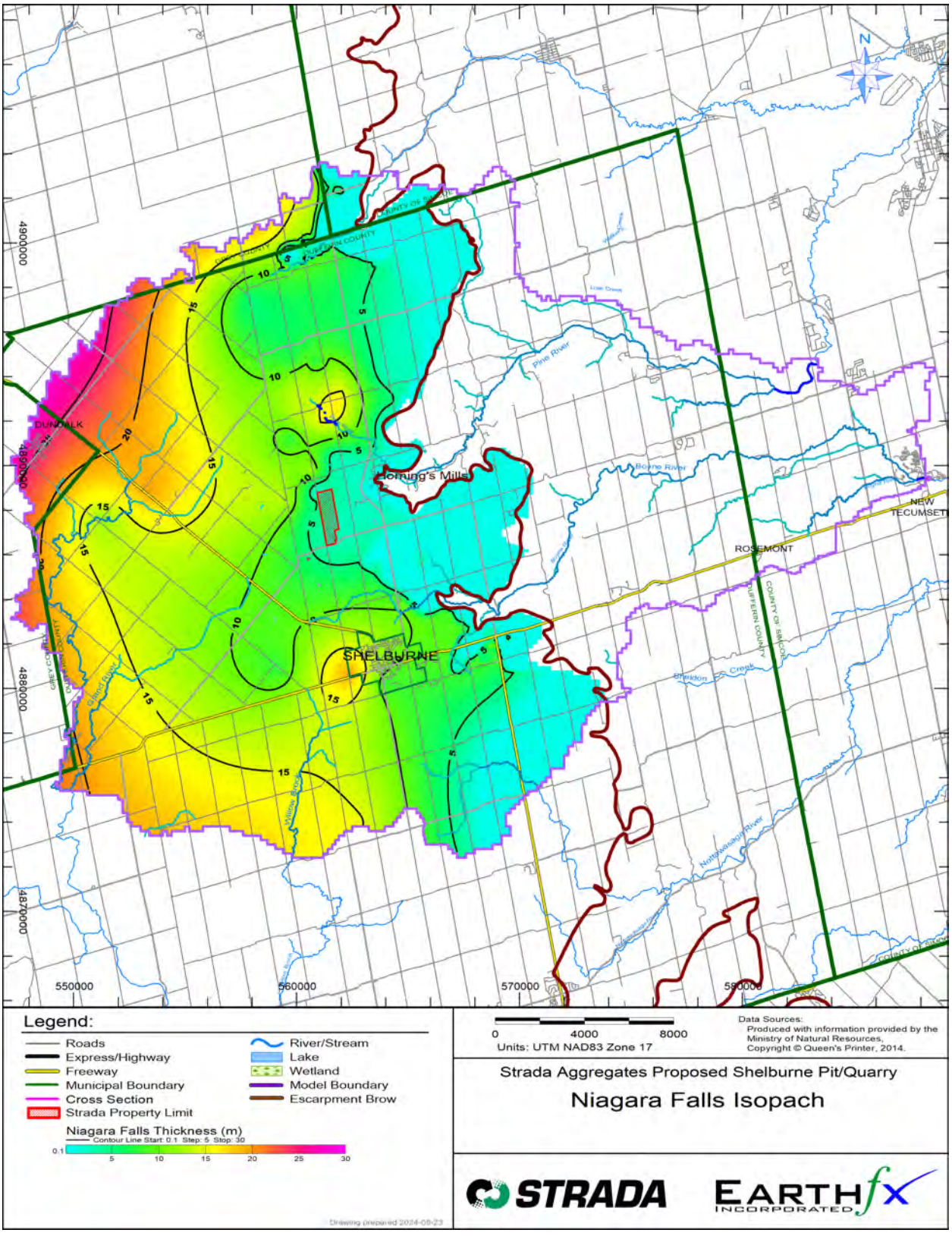


Figure 3.15: Thickness of the Niagara Falls Member (m).

3.3.5 Goat Island – Ancaster Formation

The Ancaster Member of the Goat Island Formation is a regionally significant marker aquitard, for it exhibits the characteristic and unique presence of chert nodules (Figure 3.16). Recently, the grainstone chert nodules have been used effectively to map the Ancaster unit in boreholes that were previously interpreted as unsubdivided Amabel Formation.



Figure 3.16: Chert nodules in the Ancaster member of the Goat Island formation from Core #2.

The Ancaster was clearly identified in all 7 cored holes at the Strada property as well as the OGS boreholes drilled in the Shelburne wellfield. A zone of chert nodules was also identified the Highland core holes, proving that the unit extends on a regional basis across the study area. The top elevation and total thickness of the Ancaster aquitard are shown in Figure 3.17 and Figure 3.18.

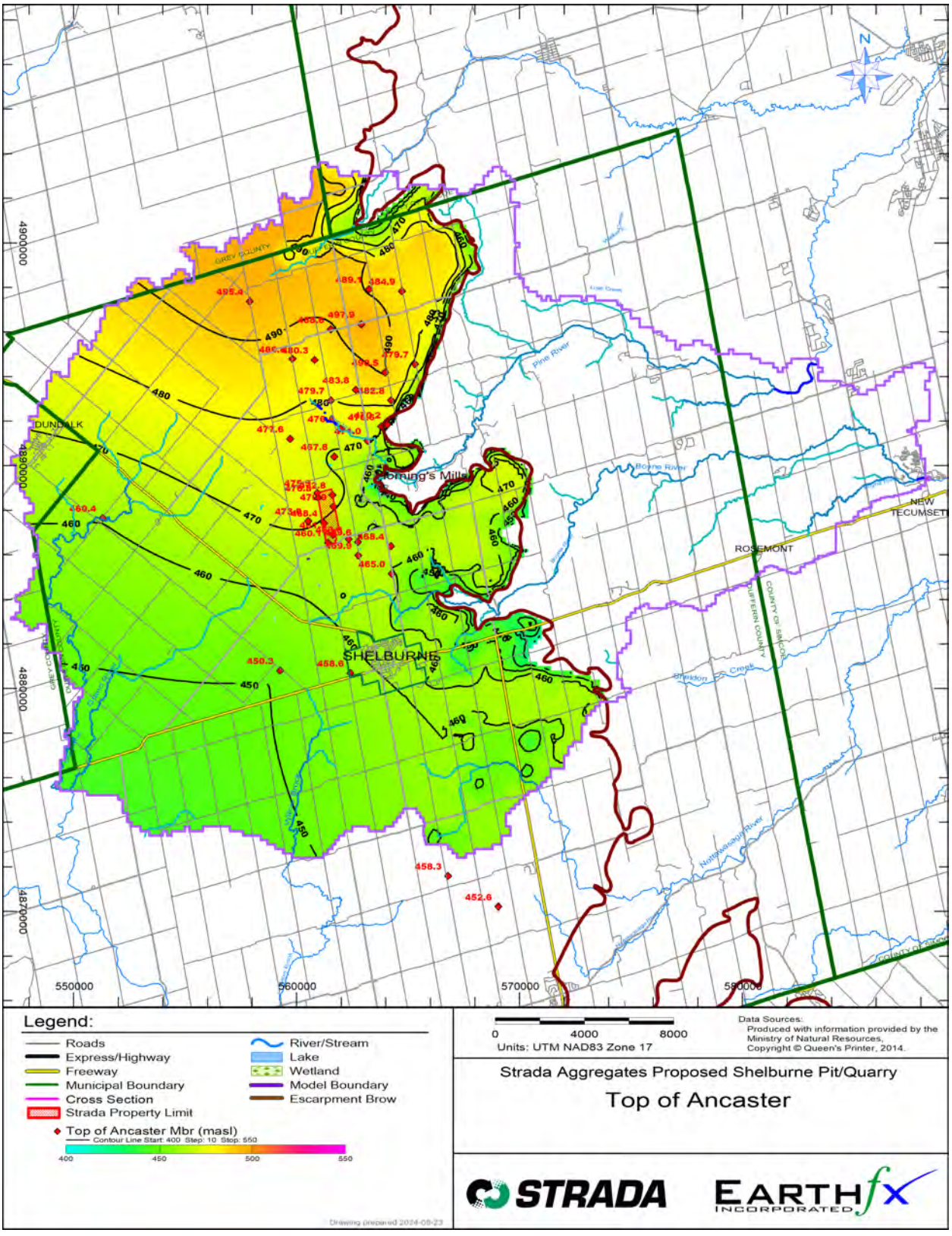


Figure 3.17: Top of the Ancaster Chert Member (masl).

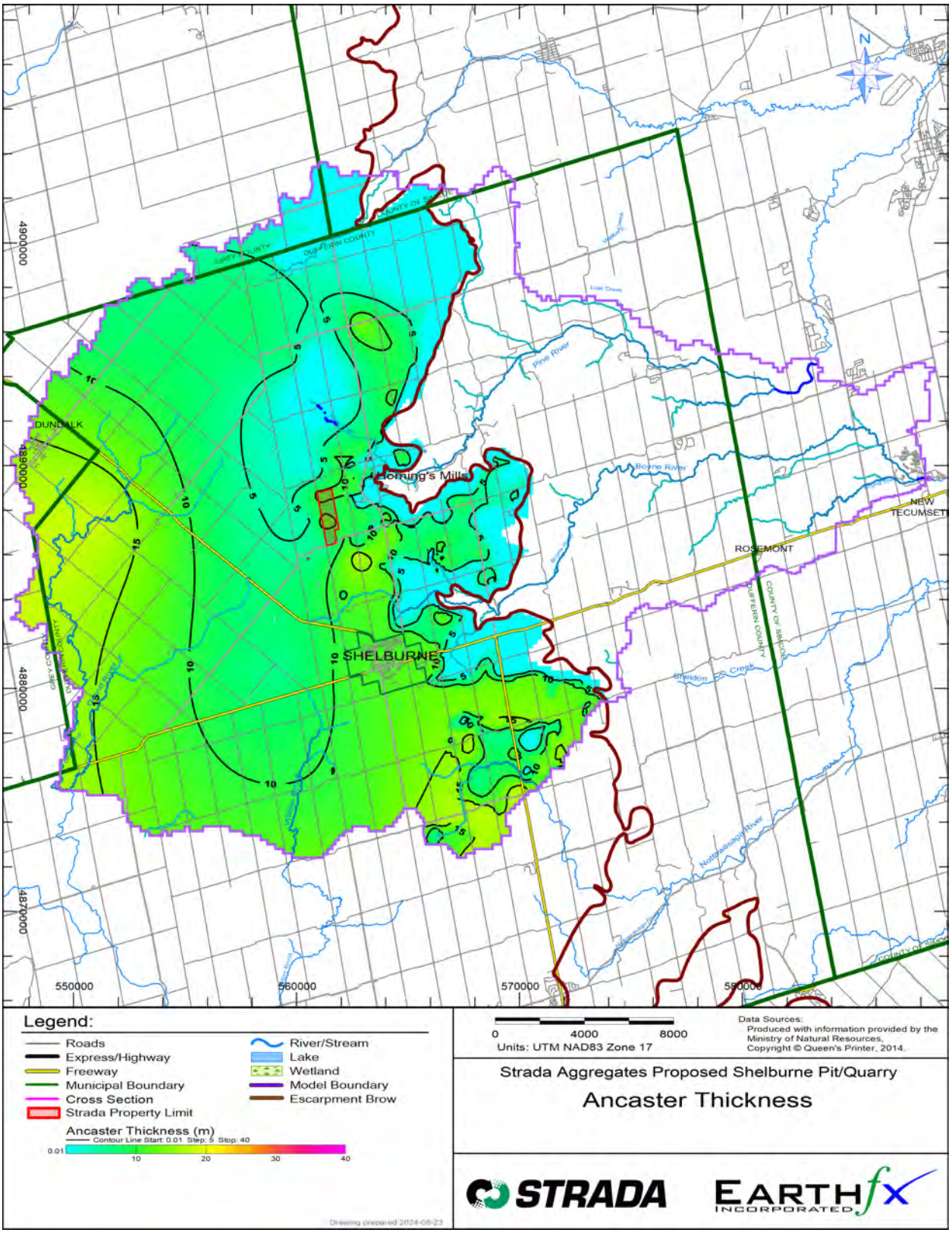


Figure 3.18: Thickness of the Ancaster Chert Member (m).

3.3.6 Eramosa Formation

The Eramosa Formation typically overlies the Goat Island Formation in southern Ontario.

The lowest member of the Eramosa Fm. is a very shaley, fine-grained dolostones referred to as the Vinemount Member. The unit is characteristically very dark to black and Brunton (2008) and others consider it a regional aquitard, where present. The Vinemount characteristically exhibits a bituminous smell, which was observed in the OGS deep drill hole at Corbetton (Johnson *et al.*, 1983; Brintnell, 2012). Some shale indicators are observed in the upper portion of the bedrock in the vicinity of the Shelburne wells (Earthfx, 2022), but no shale unit has is identified at the Strada property.

The upper two members of the Eramosa formation include the Reformatory and Stone Road members, (with the Reformatory likely observed at the Strada property). These dolostone members are light to medium brownish grey, fine crystalline, with some vugs (due to fossils), and are strong and thick to medium bedded with good RQD. Unlike the overlying Guelph, thin, black, wavy stylolites are common (Figure 3.19), and the colour is more brown-grey than the whiter Guelph. The Eramosa is less porous than the Guelph, with a clear reflective sheen when wet, unlike the Guelph, which readily absorbs applied water (Figure 3.19). As noted, the Eramosa has been referred to as an aquitard by Brunton.



Figure 3.19: Sample of Eramosa formation showing characteristic black, wavy stylolites.

Differentiating between the Guelph and Eramosa in the area has been challenging. The Eramosa was initially mapped by the Ontario Geological Survey in Shelburne well OGS10a (Golder, 2013) but this unit was later remapped as Guelph in the logs presented in Banks and Brunton (2017) (Earthfx, 2022).

3.3.7 Guelph Formation

The upper most rock core collected at the Strada property grades downwards from a white/light grey color into a tan to buff-brown colour. The upper portion of the core is softer and more porous (Figure 3.21) and generally matches the characteristics of the Guelph Formation (Figure 3.20).

The Guelph Formation is a white to light grey dolostone. It is finely crystalline to sucrosic, and medium to thick bedded. The unit is porous, quickly soaking up water on surface. Small vugs 1-2 mm and occasional large vugs to 30 mm are found sometimes filled with poorly cemented dolomite crystals (Figure 3.21). There is a complete absence of natural breaks that exhibit a black stylolitic shale surface.



Figure 3.20: Guelph Formation core photo (https://kocurekindustries.com/our-products/guelph-dolomite-cores).



Figure 3.21: Upper portion of OW26 (Core #2) – Guelph Formation.

The Guelph and Eramosa distribution at the site is variable, and is observed in the cores as follows:

- OW25 - Mostly Guelph, some Eramosa
- OW26 – Mostly Guelph, stylolite zone at base of Guelph interpreted as Eramosa
- OW27 – Mostly Guelph, stylolite zone at base of Guelph interpreted as Eramosa
- OW28 – All Eramosa – no Guelph
- OW29 – 50:50 Guelph and Eramosa
- OW30 – All Eramosa – no Guelph

The Guelph and Eramosa units have been differentiated at the site, however there is insufficient regional information to differentiate the units across the full study area. For the purposes of pit/quarry impact assessment, the Guelph/Eramosa is considered one hydrostratigraphic unit. The elevation of the top of this unit is shown in Figure 3.22 and is coincident with the top of bedrock where present. Figure 3.23 presents an isopach (thickness) map for the Guelph Formation. The white areas in the east and northeast indicate where the unit is missing.

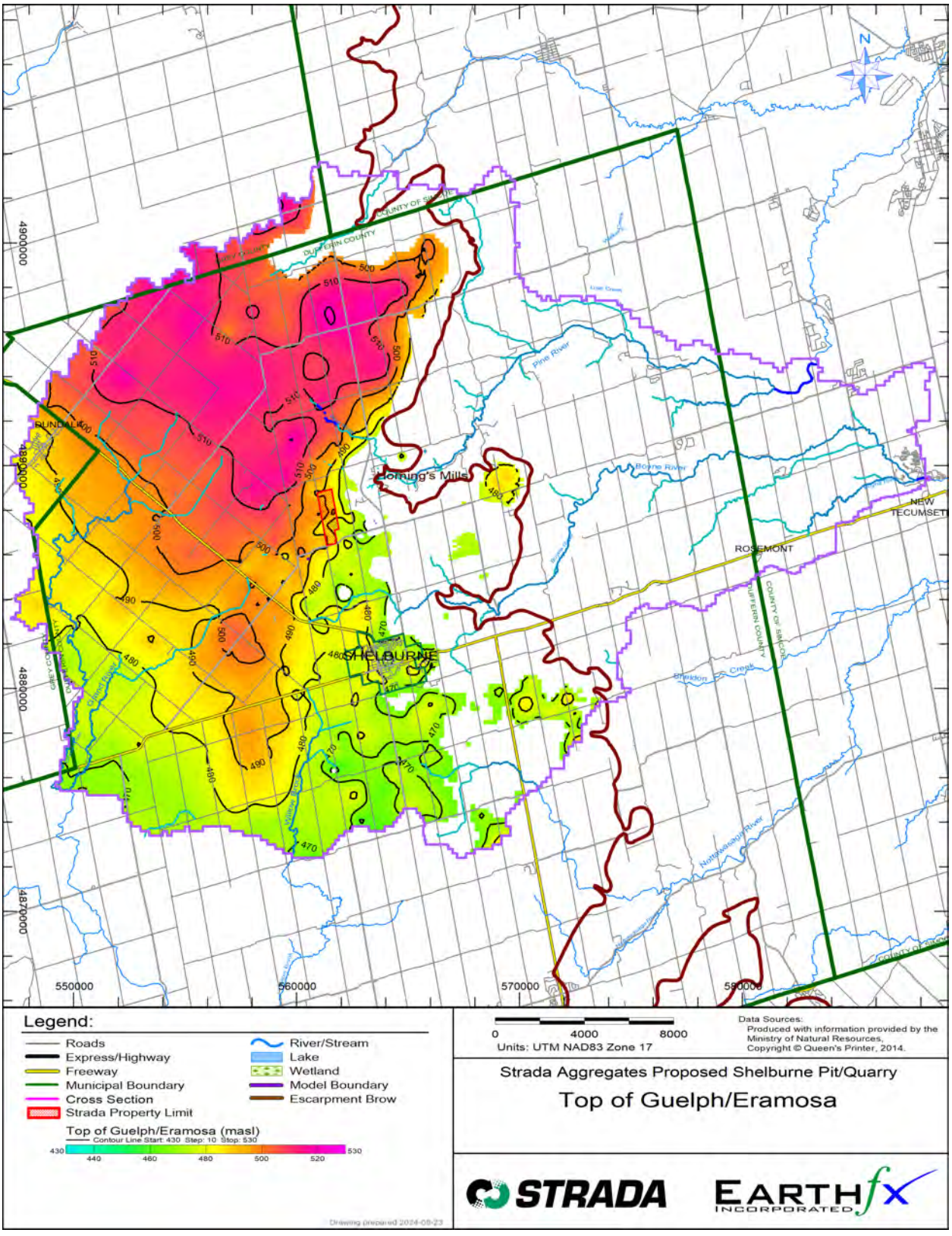


Figure 3.22: Top of the Guelph Formation (masl).

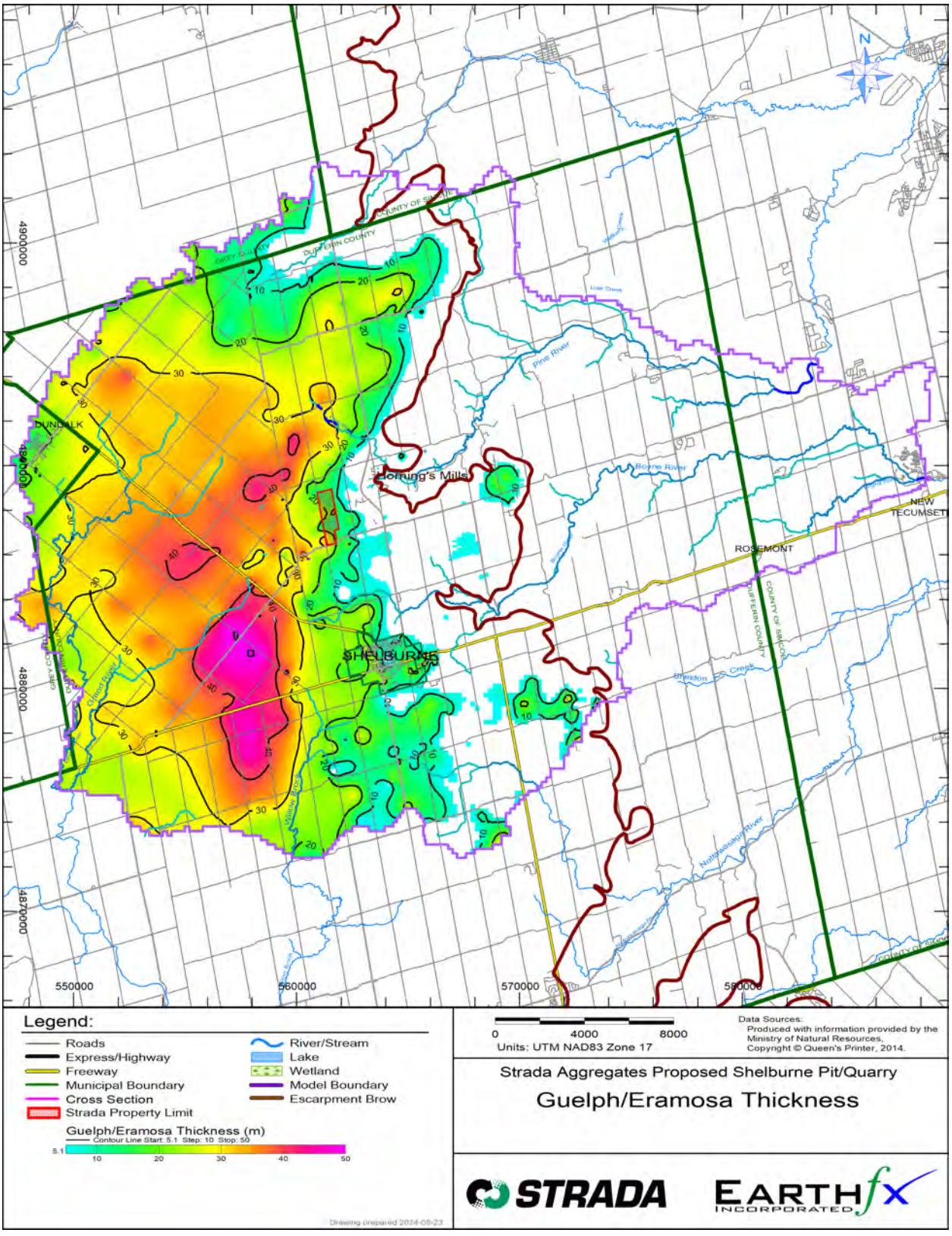


Figure 3.23: Thickness of the Guelph and Eramosa formations (m).

3.3.8 Site Scale Geologic Maps and Cross Sections

The seven cored boreholes on the Strada property provide detailed local information about the hydrostratigraphic units. There is some variation in the thickness of the unit across Strada property, but that is to be expected over a 2.3 km distance. Most important, the combined Ancaster and Niagara Falls aquitard unit is present in all seven of the cored boreholes.

The cores allow the differentiation of the Guelph and Eramosa formations on site. These units have similar hydrogeologic properties and behave as an integrated aquifer unit, so they are not differentiated in the regional scale conceptual model surfaces.

To illustrate the local site conditions, a set of conceptual hydrostratigraphic surfaces were generate at a high resolution across the Strada property. These surfaces

Geologic cross sections (Section locations shown in Figure 3.24) showing the geologic layers are shown in Figure 3.25 Figure 3.2through Figure 3.28.

Further to the above cross sections, a series of maps illustrating the key formations at the site scale are included in Figure 3.29 through Figure 3.37.

A key aspect of the site conditions is the total thickness of the Ancaster + Niagara Falls aquitard at the site, shown in Figure 3.32, and ranging between 10 to 15 m in thickness. Note that OW02, which pump tested at a very low rate (See Section 5.5.3), is located in a very thick aquitard zone. The aquitard zone also correlates well with the packer testing completed across the site (See Appendix B, Section B5.2).

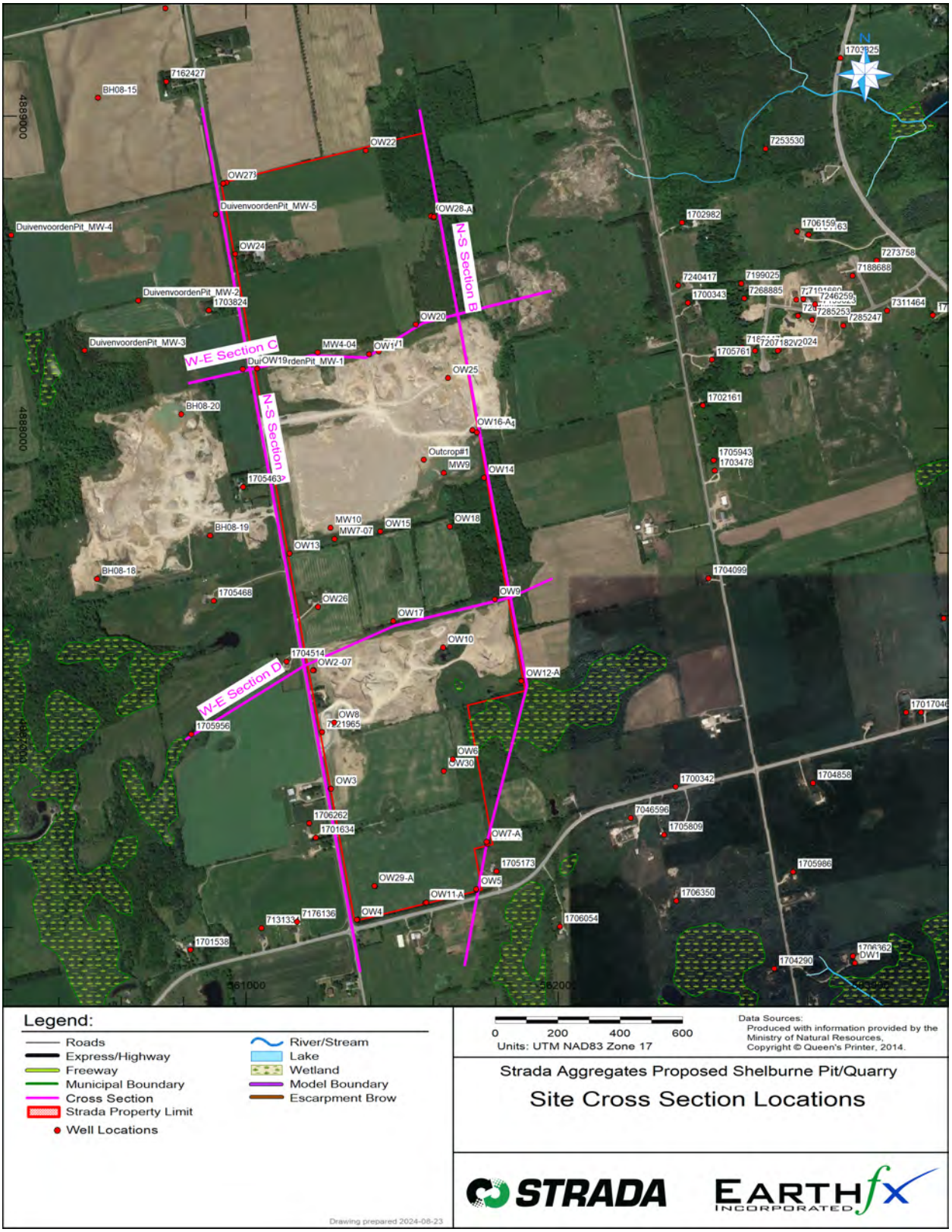


Figure 3.24: Site scale cross section locations.

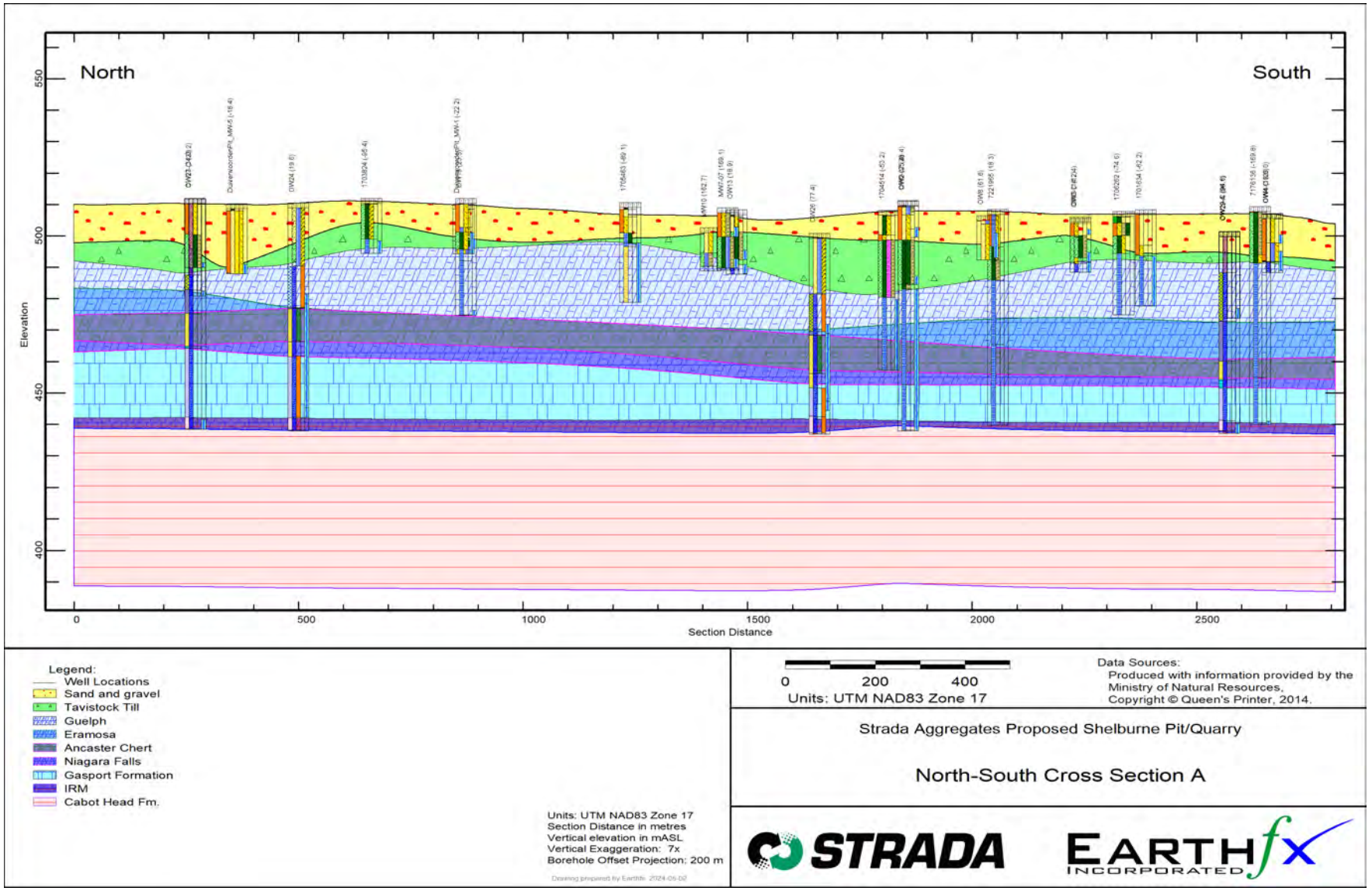


Figure 3.25: North-South Site Cross Section A.

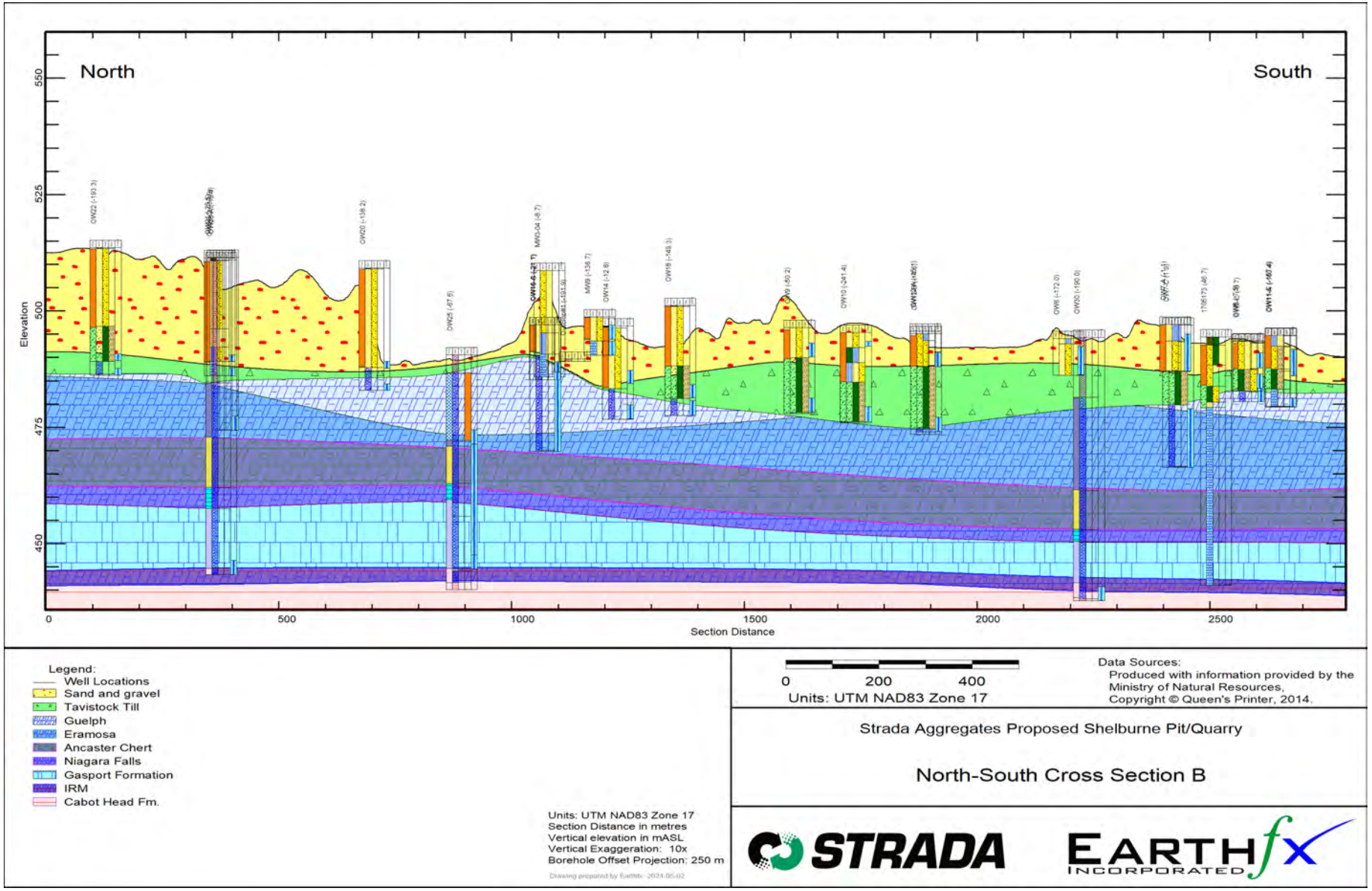


Figure 3.26: North-South Site Cross Section B.

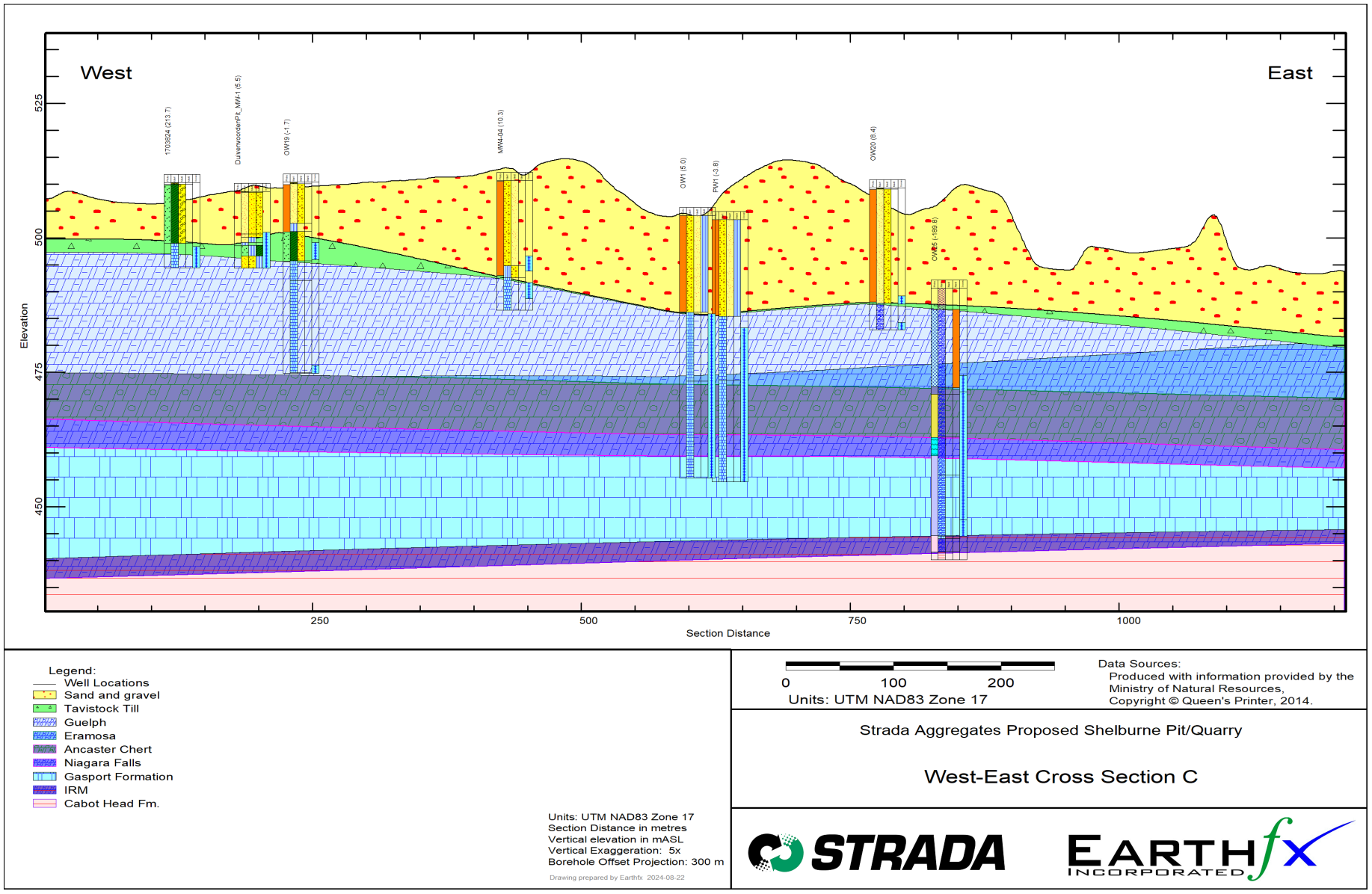


Figure 3.27: West-East Site Cross Section C.

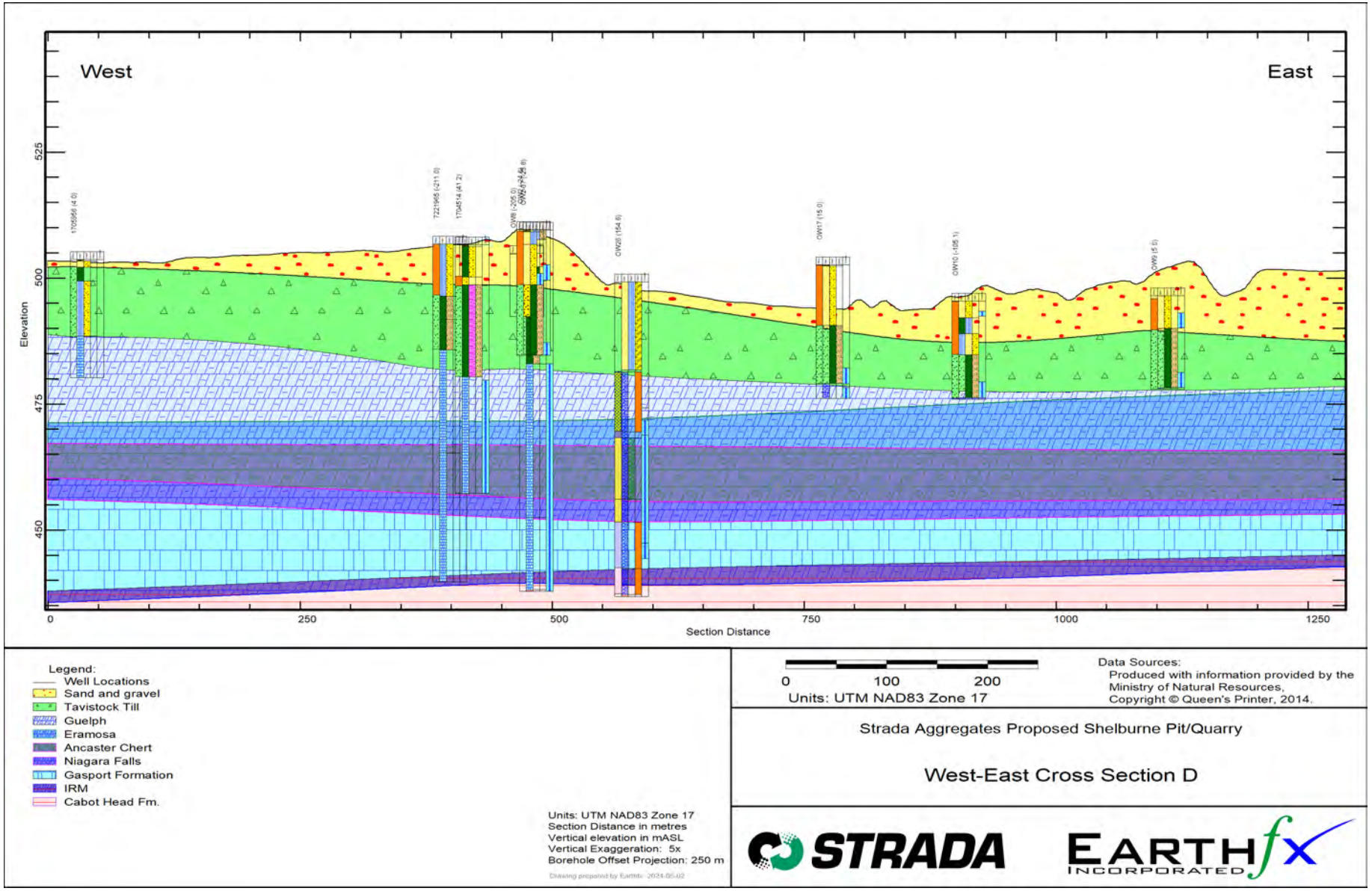


Figure 3.28: West-East Site Cross Section

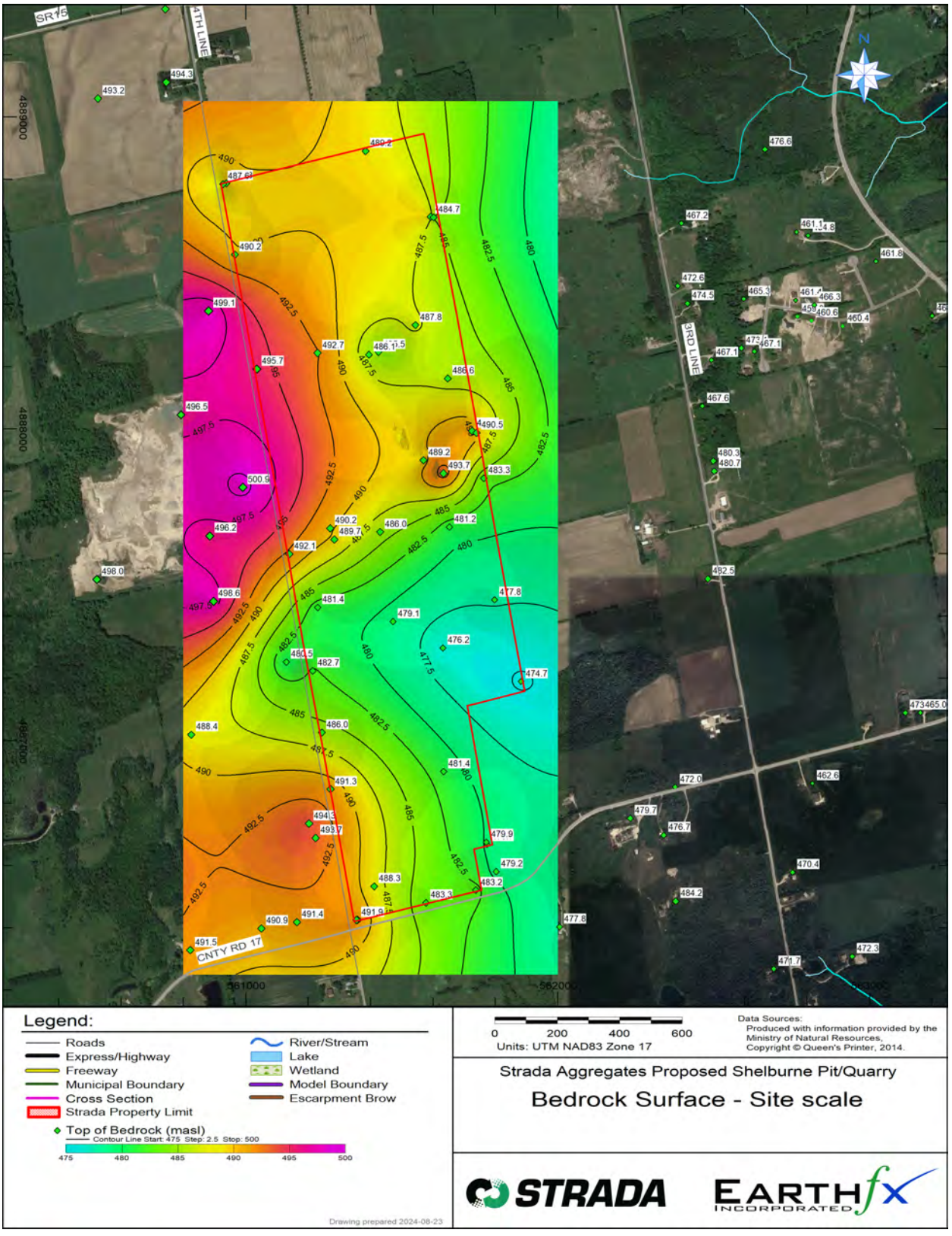


Figure 3.29: Bedrock Surface - Site Scale

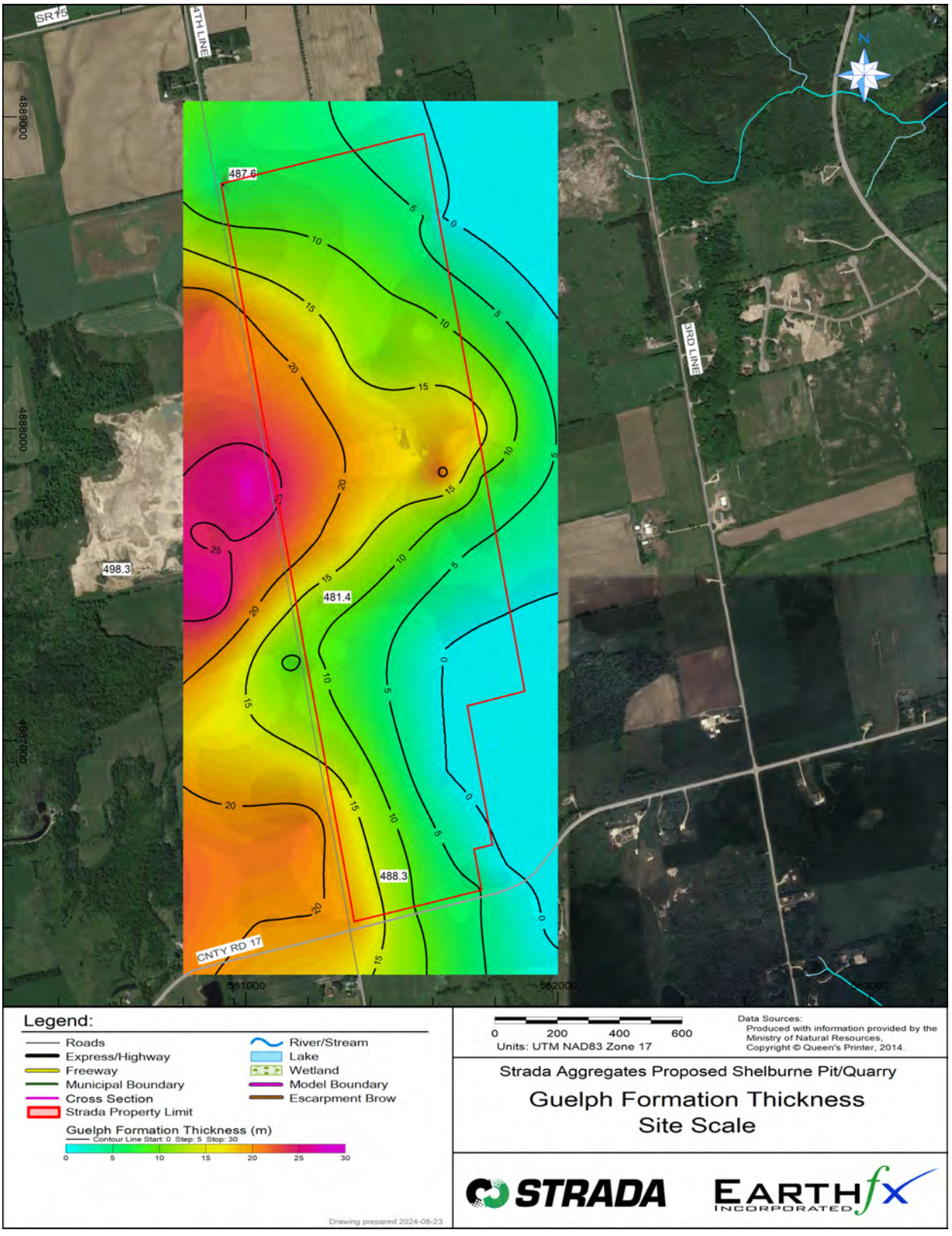


Figure 3.30: Guelph formation thickness - Site Scale

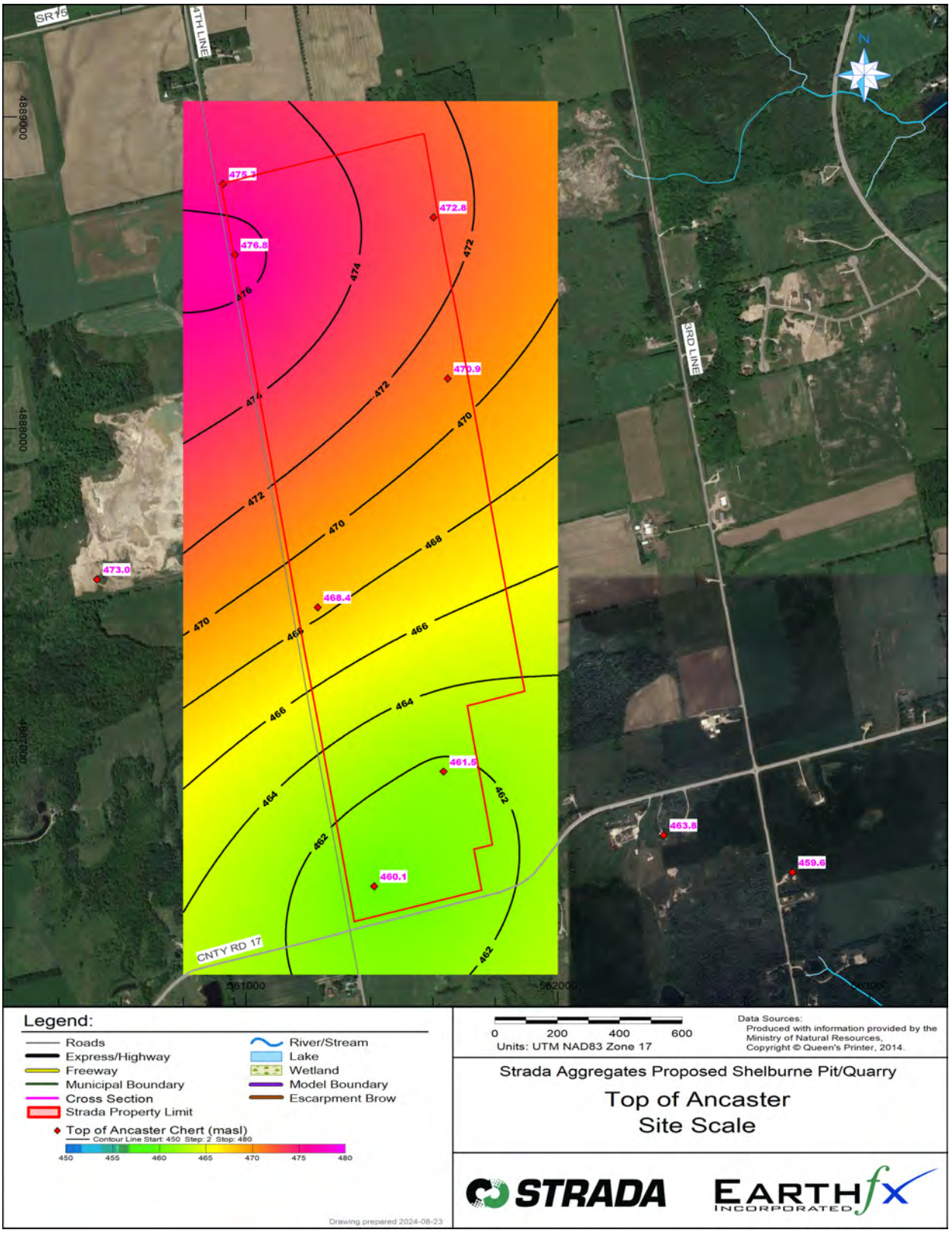


Figure 3.31: Top of Ancaster Member - Site Scale

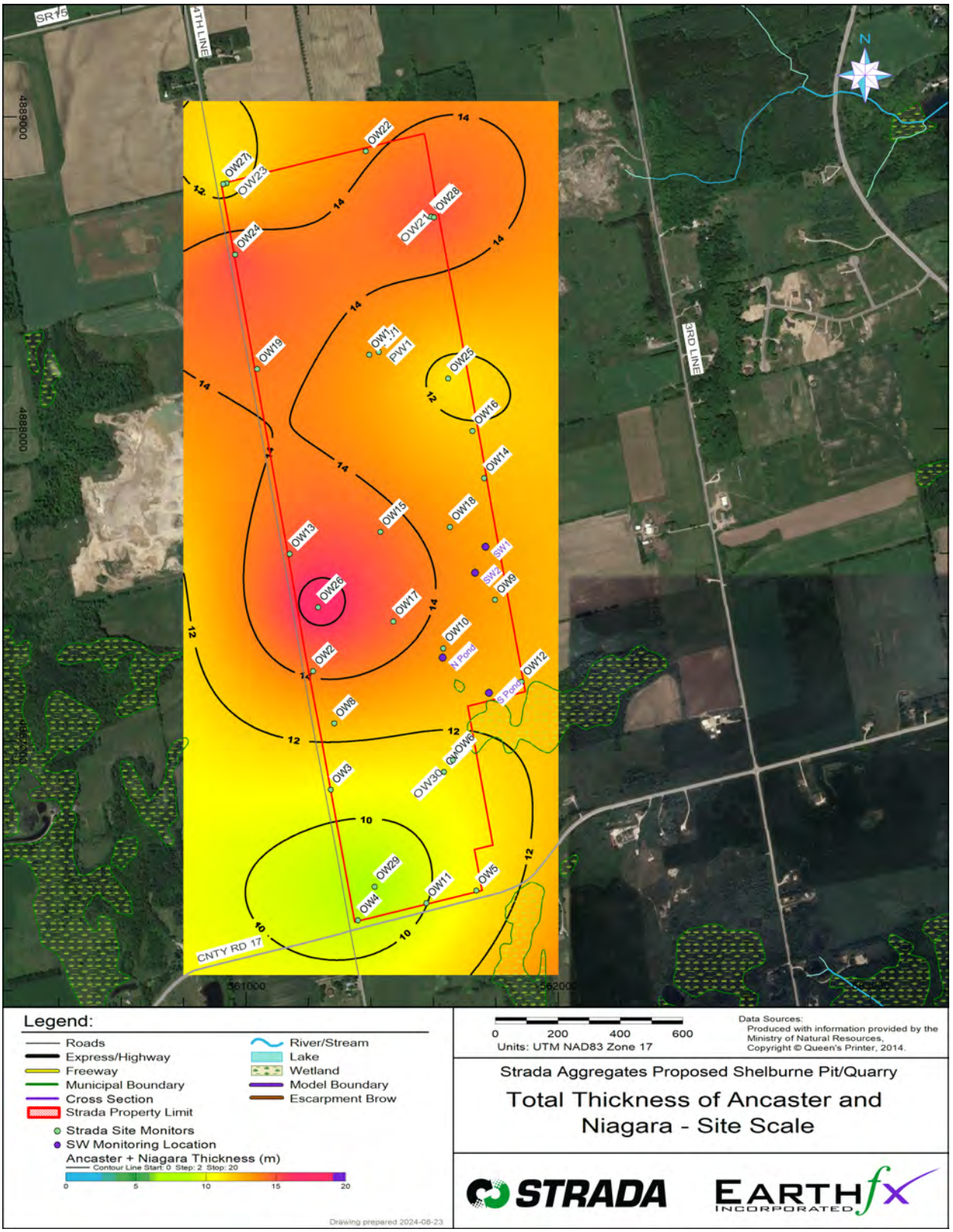


Figure 3.32: Total thickness of Ancaster and Niagara Falls aquitard - Site Scale

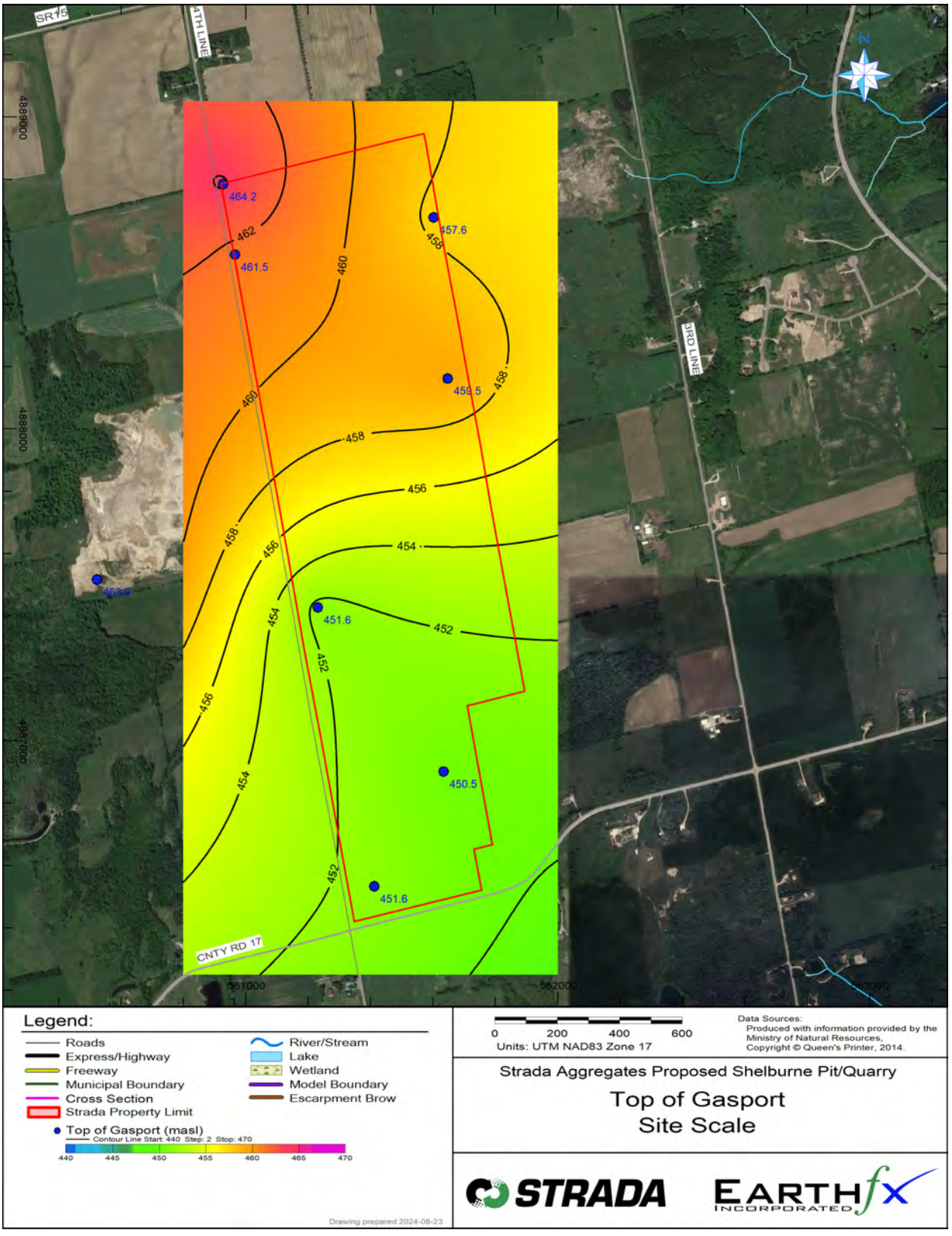


Figure 3.33: Top of Gasport - Site Scale

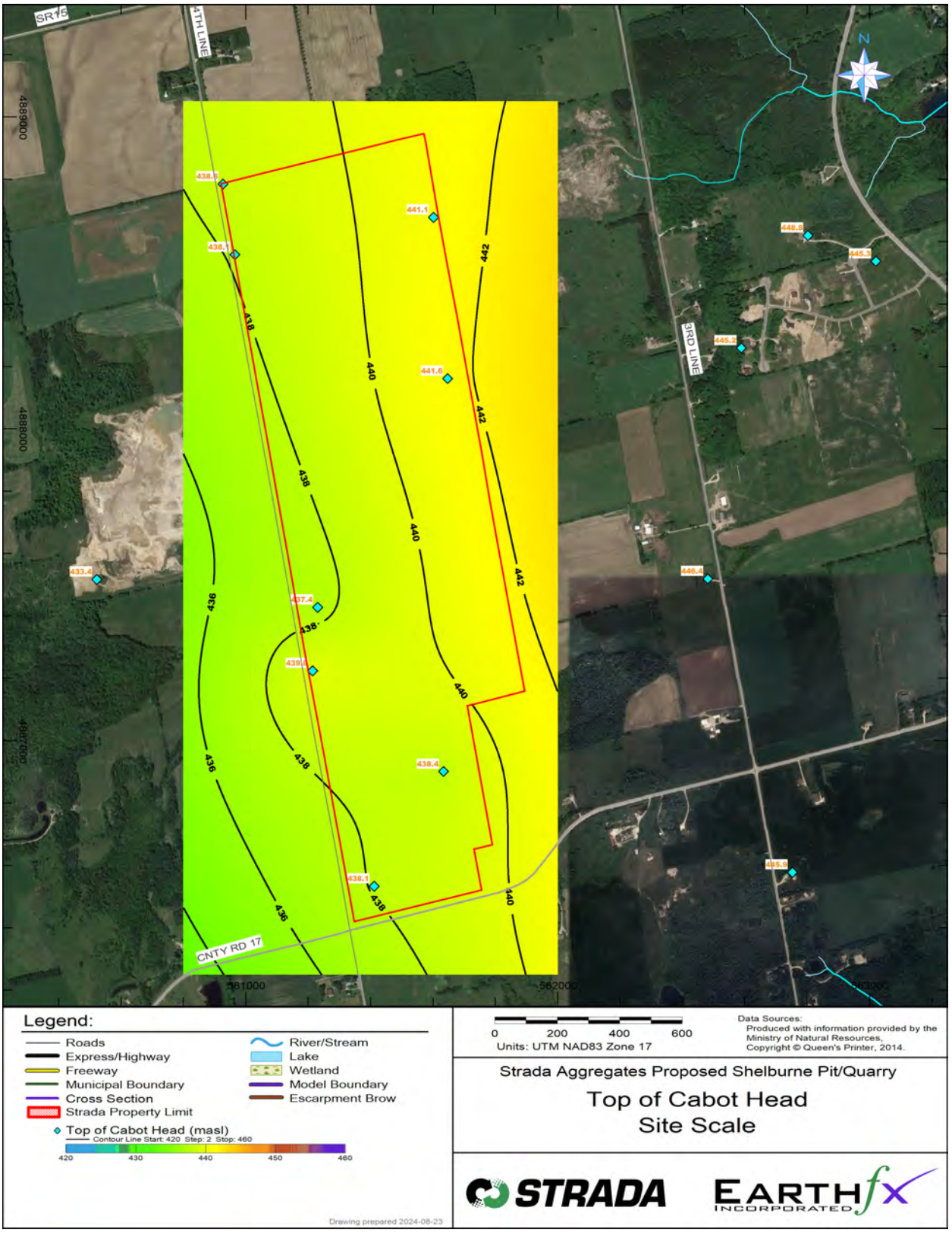


Figure 3.34: Top of Cabot Head - Site Scale

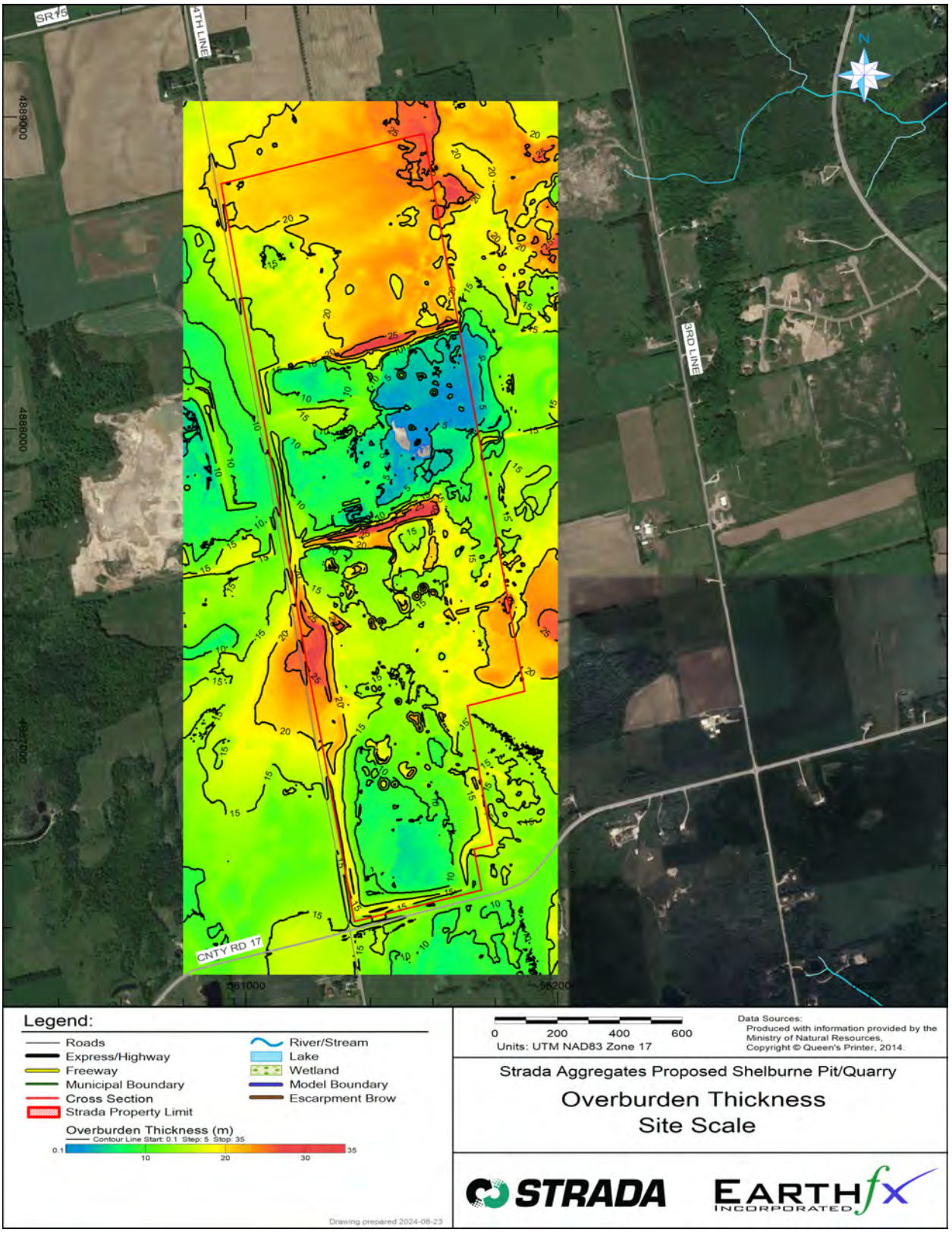


Figure 3.35: Overburden Thickness - Site Scale

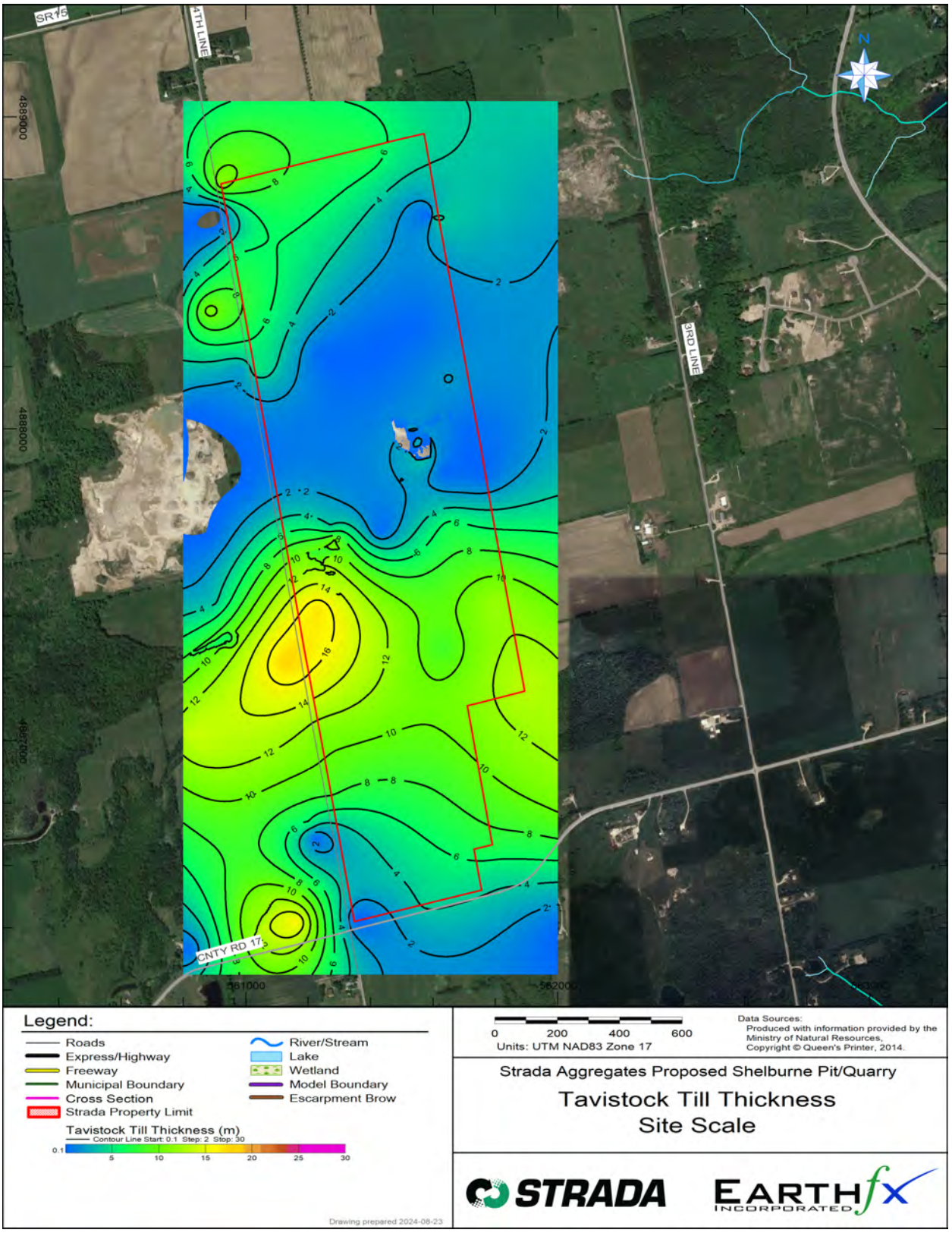


Figure 3.36: Tavistock Till Thickness - Site Scale

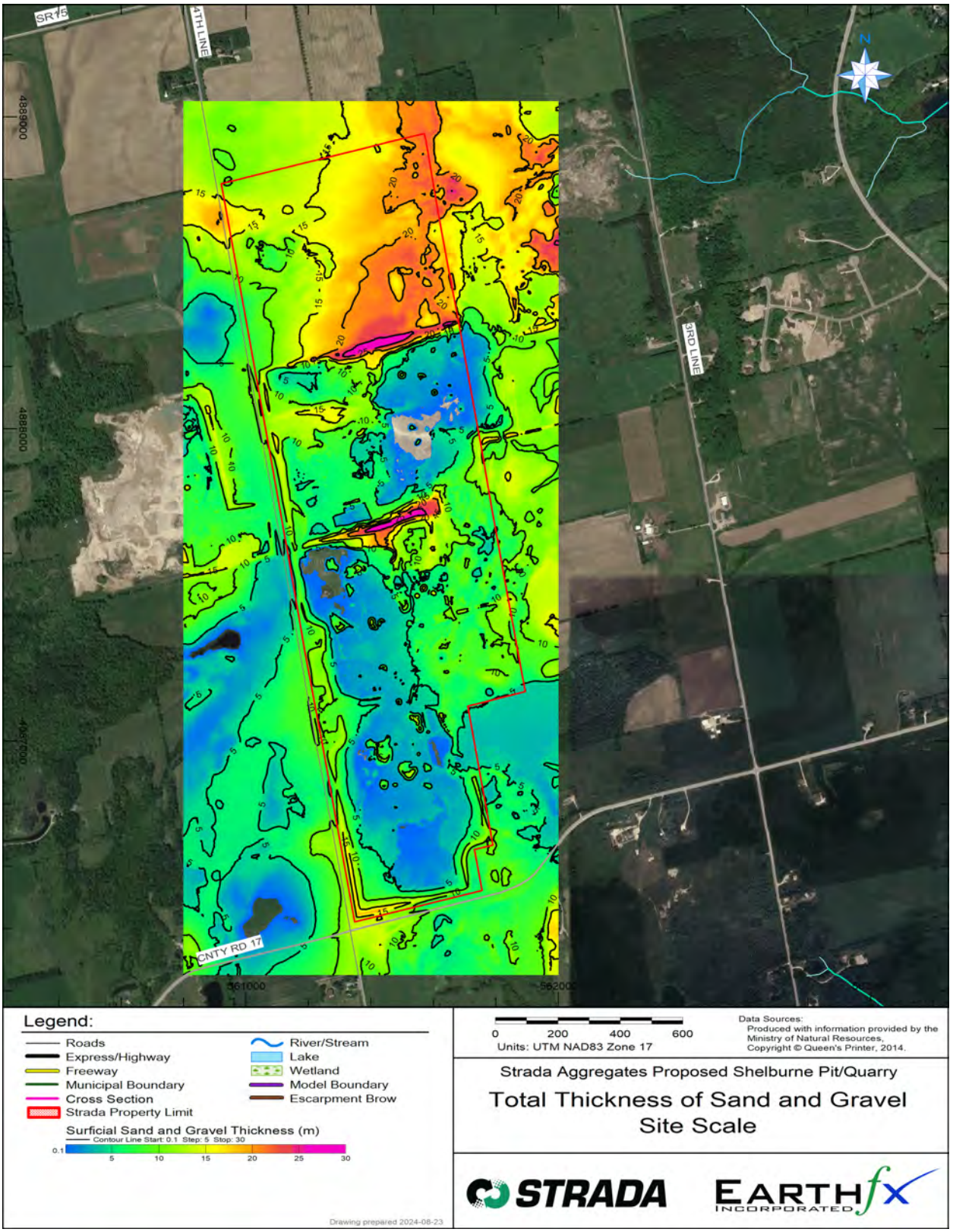


Figure 3.37: Total thickness of Sand and Gravel - Site Scale

3.4 *Quaternary Units*

Overlying the Paleozoic bedrock is a suite of unlithified sediments (drift) of Quaternary age, deposited mainly in association with continental glaciation. A schematic representation of the overburden is shown in Figure 2.8. Quaternary geology was mapped in the area by Gwyn (1975), Cowan (1976), and Burwasser (1974). These maps were incorporated into the Ontario Geological Survey digital compilation map of southern Ontario Quaternary Geology (OGS, 2010). Figure 3.38 shows an enlargement of the surficial geology map in the vicinity of the proposed Strada Shelburne pit/quarry. As can be seen, the site lies within an area where the surface deposits have been mapped as ice-contact stratified deposits. There are till units surrounding and, most likely, underlying the ice contact deposits. The coarse-grained and till units are discussed further below.

The bedrock surface elevation and total overburden thickness are shown in Figure 3.39 and Figure 3.40. Overburden deposits are generally thin above the Niagara Escarpment, but can thicken considerably in the Pine and Boyne River valleys. While multiple tills may be present above the bedrock, analysis suggests that the Tavistock unit is the most prevalent around the Strada property.

The Quaternary materials were subdivided into two key units: an overlying sand and gravel unit, generally associated with ice contact stratified deposits and outwash materials and the Tavistock till, as shown in the cross sections (Figure 3.2 to Figure 3.4). At the site scale, the overburden thickness is shown in Figure 3.35, and the local bedrock surface topography is shown in Figure 3.29.

3.4.1 Tavistock Till

As noted in Section 2.3, there are multiple silt tills in the study area, and as Gwyn, 1972 noted, there can be up to three tills layered in one exposure. As discussed, their properties are not significantly different from a hydrogeologic perspective. Further, their properties are too similar to differentiate them in the subsurface logs. For this reason, till materials are mapped as a single unit referred to as Tavistock Till. The hydrogeologic properties of the unit are further discussed in Appendix D (Earthfx Inc., 2024a). The thickness of the overburden till unit is shown at the regional scale in Figure 3.41, and at the site scale in Figure 3.36.

3.4.2 Surficial Coarse-Grained Deposits

Glaciofluvial deposits of sand, gravel, and minor silt are extensive in the vicinity of the Strada property, particularly in the northern and eastern areas passing through the Niagara Escarpment (OGS, 2010). These bodies of granular material take the form of either ice-contact stratified deposits – eskers, kame moraines, and kame terraces – or outwash deposits formed in braided proglacial streams (Gwyn, 1975, Cowan, 1976). The deposits are possibly time-correlated with the units of Mackinaw Interstadial (MIS) or Oak Ridges Moraine (ORM) deposition, but some coarser inter-till deposits are also present. There are limited post-glacial lacustrine deposits of fine sand, silt, and clay in the extreme eastern part of the area (OGS, 2010). Recent deposits include alluvial sediment of fine sand and silt along modern stream flood plains, as well as thin deposits of wind-blown fine and coarse silt (Gwyn, 1975). The wind-blown units are thin and assessed as part of the soil zone the hydrologic model discussed in Appendix D (Earthfx Inc., 2024a).

In 13 of the 26 monitoring nests at the Strada site, a significant deposit of sand and gravel was found to overlie a dense silt till on bedrock The other 13 nests have only sand and gravel lying directly on bedrock. In only one nest, OW-10, located in the south-central portion of the site beside a shallow pond, a thin silty clay unit was identified. The total thickness of sand and gravel deposits overlying the till are shown regionally in Figure 3.42, and locally in Figure 3.37.

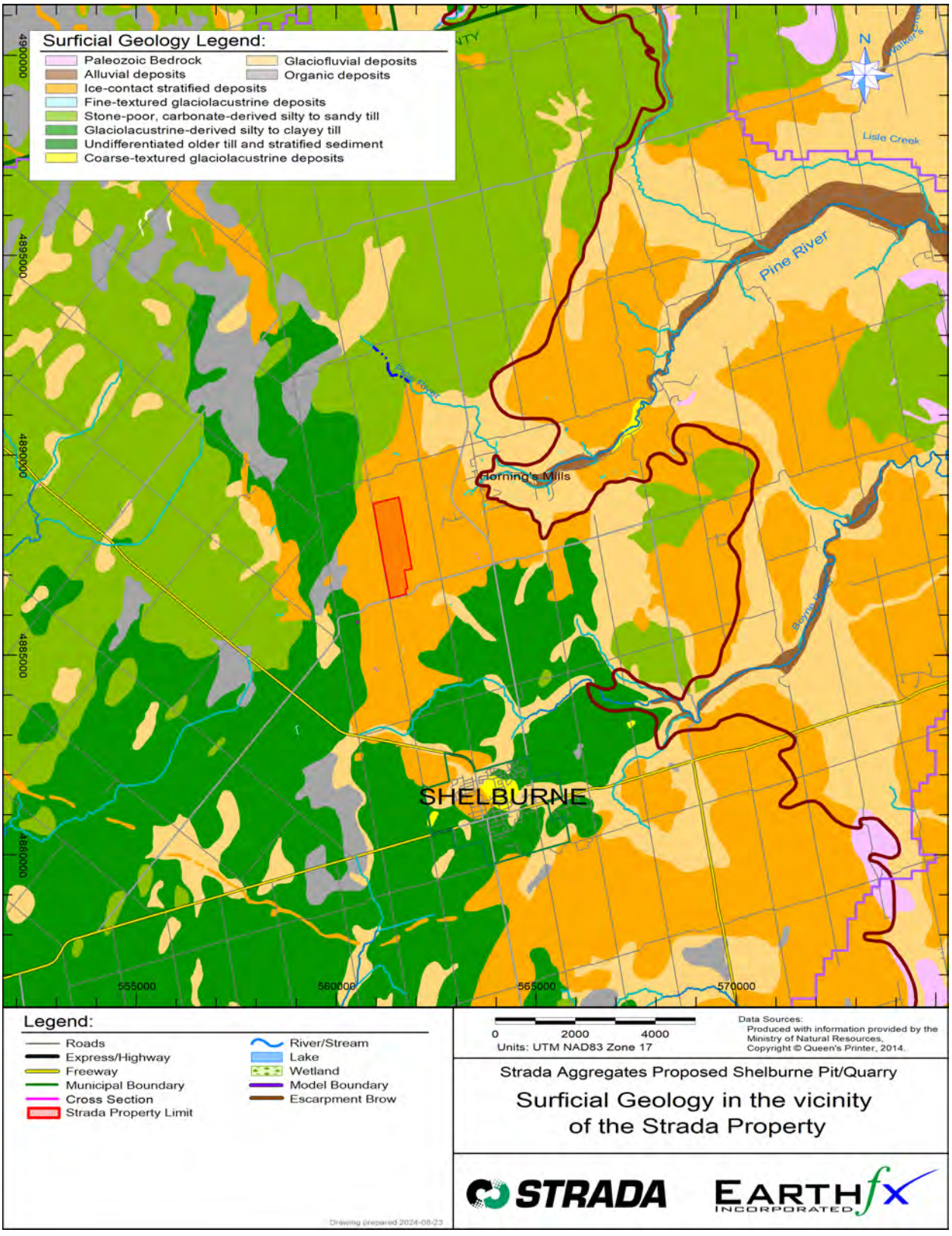


Figure 3.38: Surficial geology in the vicinity of the proposed Strada Shelburne pit/quarry.

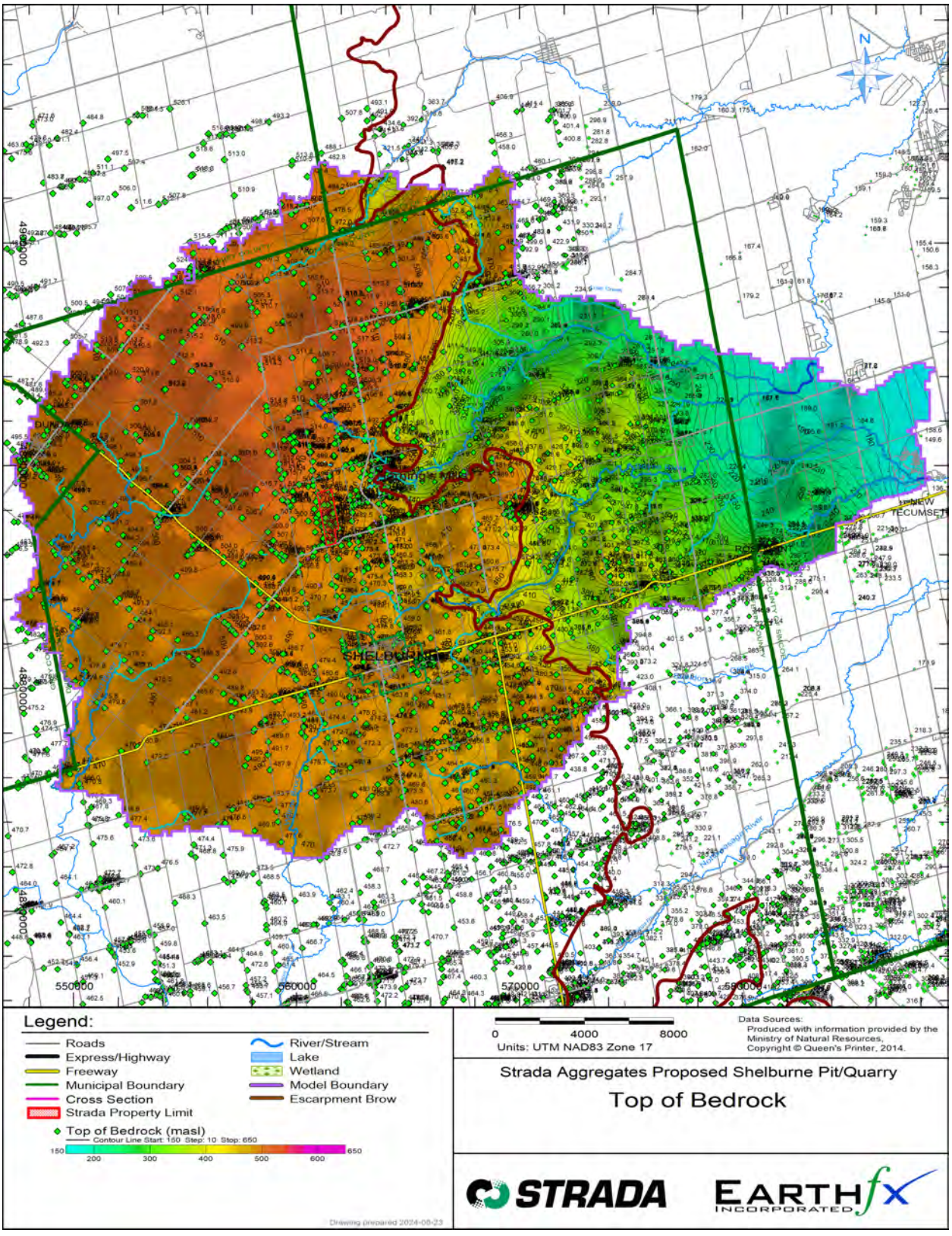


Figure 3.39: Top of bedrock (masl).

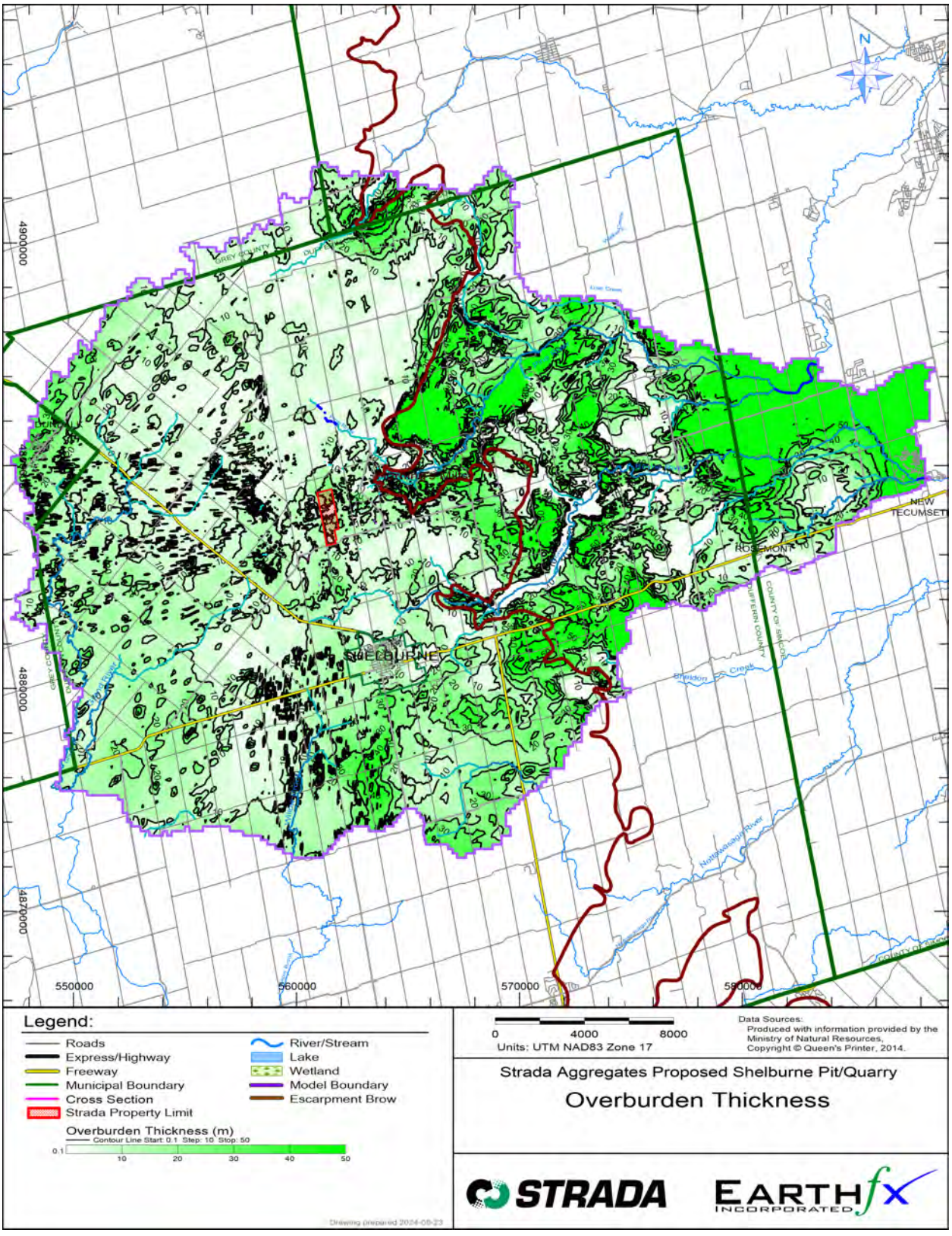


Figure 3.40: Overburden (drift) thickness (m).

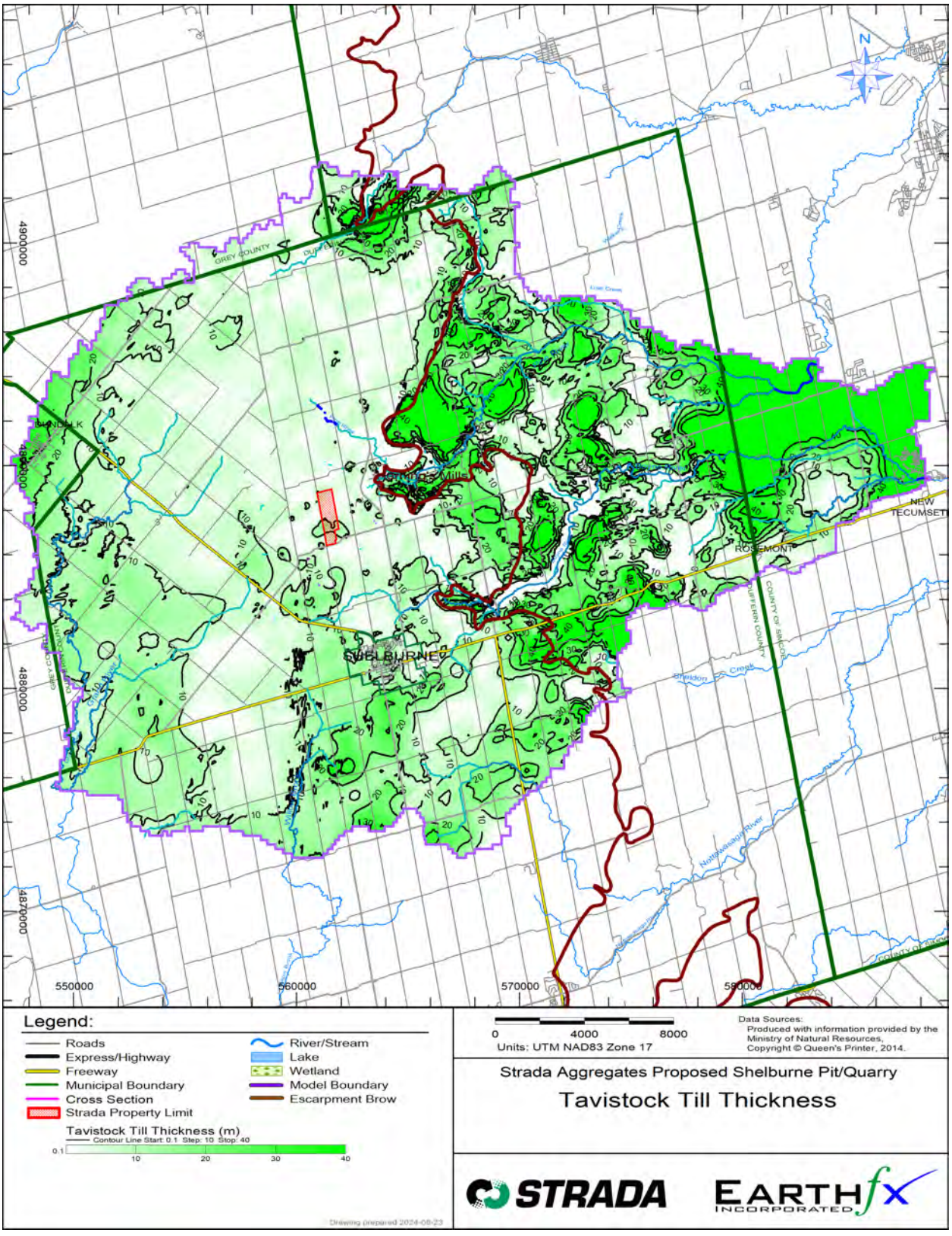


Figure 3.41: Tavistock Till thickness (m)

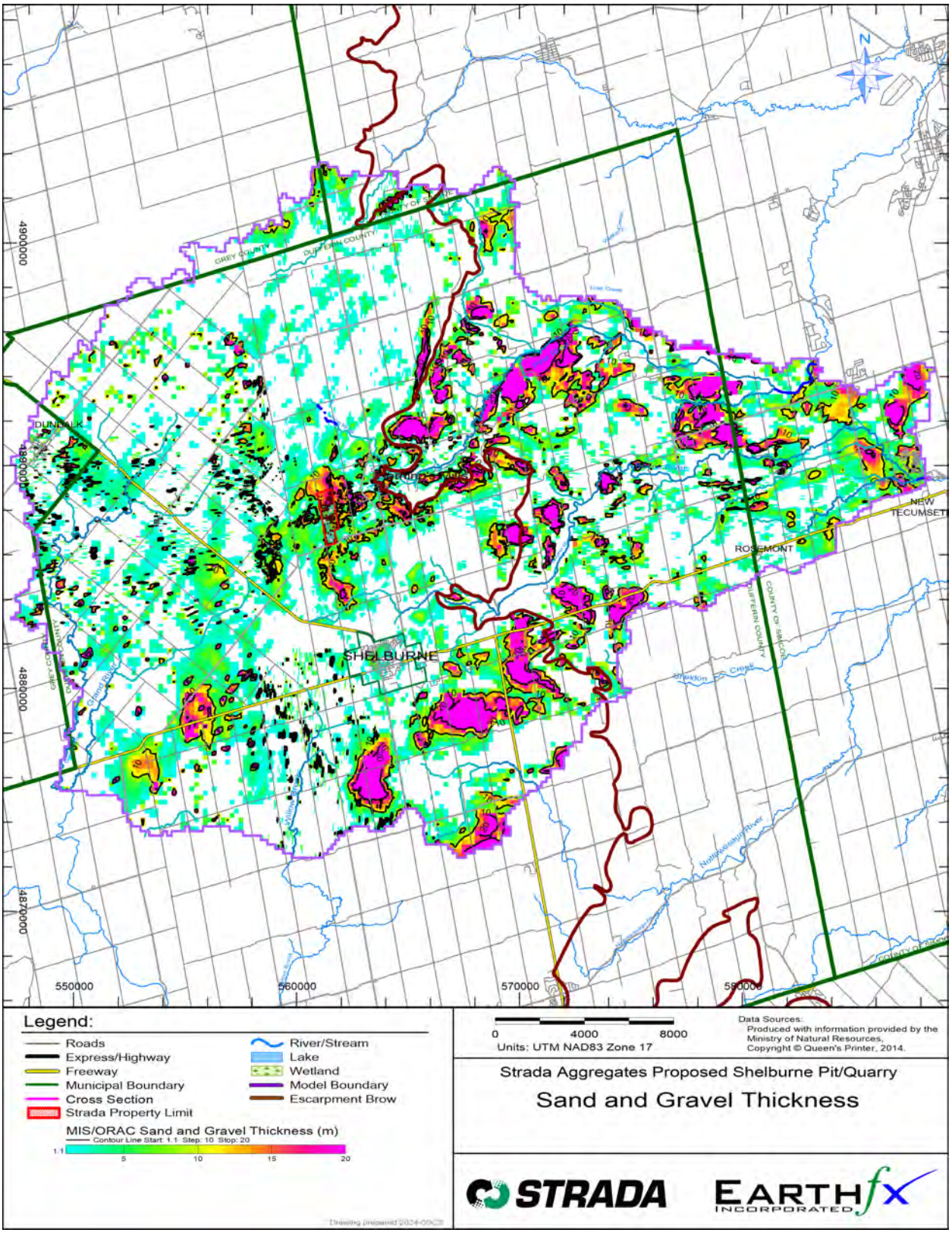


Figure 3.42: Surficial sands and gravels

4 Hydrologic Setting

The conceptualization of the hydrologic model addresses the information available for the development and calibration of the surface water model. A more detailed explanation and usage of this information can be found in Section 3 of Appendix D (Earthfx Inc., 2024a).

4.1 *Climate*

There is a large number of historic and a limited number of active climate stations in the vicinity of the proposed Strada pit/quarry, as shown in Figure 4.1. Climate data used for this study have been compiled from Environment Canada's Atmospheric Environment Service (AES). Additional sources used in model development include radar-derived precipitation data from the Canada Precipitation Analysis (CaPA) system and stations run by Grand River Conservation Authority (GRCA).

There are four main climate time-series required for the GSFLOW model:

1. **Precipitation**: the model accepts daily precipitation data and converts it to either rainfall or snowfall according to daily temperature.
2. **Daily minimum and maximum temperature**: required by the evaporation/ET, snowmelt, and precipitation routines.
3. **Daily net solar irradiation**: also required for the evaporation/ET and snowmelt routines.
4. **Hourly rainfall distribution**: used to analyze historical rainfall patterns during the year.

The period of record varies among the available climate data sources. In total, 66 stations that recorded precipitation and 58 stations that recorded temperature were available during the period of record spanning from water year (WY) 1866 through WY2020. The maximum distance from the model area to an observation site was about 35 km.

4.1.1 Precipitation and Temperature

4.1.1.1 Environment Canada Climate Data

Characterization of the climate of the study area began with an assessment of data from Environment Canada (EC) Atmospheric Environment Service (AES) climate stations in and surrounding the study area with data from 1955 to the present. Station locations are shown in Figure 4.1. Stations that remain active since WY2000 are shown separately on the figure.

Annual and monthly precipitation totals from the AES climate stations are illustrated in Figure 4.2 and Figure 4.3 for the periods spanning WY1950 to WY2020 and WY2000 to WY2016, respectively. Annual precipitation over the 70-year period ranged from 500 mm in some stations during the period WY2015 to WY2016, to near 1300 mm in WY1968. The variability in observed annual precipitation for any specific year can be as high as 350 mm in WY2013. Over the 20-year period, monthly precipitation ranged from near 20 mm in November 2013 to 220 mm in April 2000.

Figure 4.4 shows the monthly statistics for precipitation at AES stations over the 70-year period as box-whisker plots. Mean precipitation in November, as either rainfall or snowfall, was highest; mean monthly precipitation in July and August was very close. The highest monthly values over the period were observed in June and September.

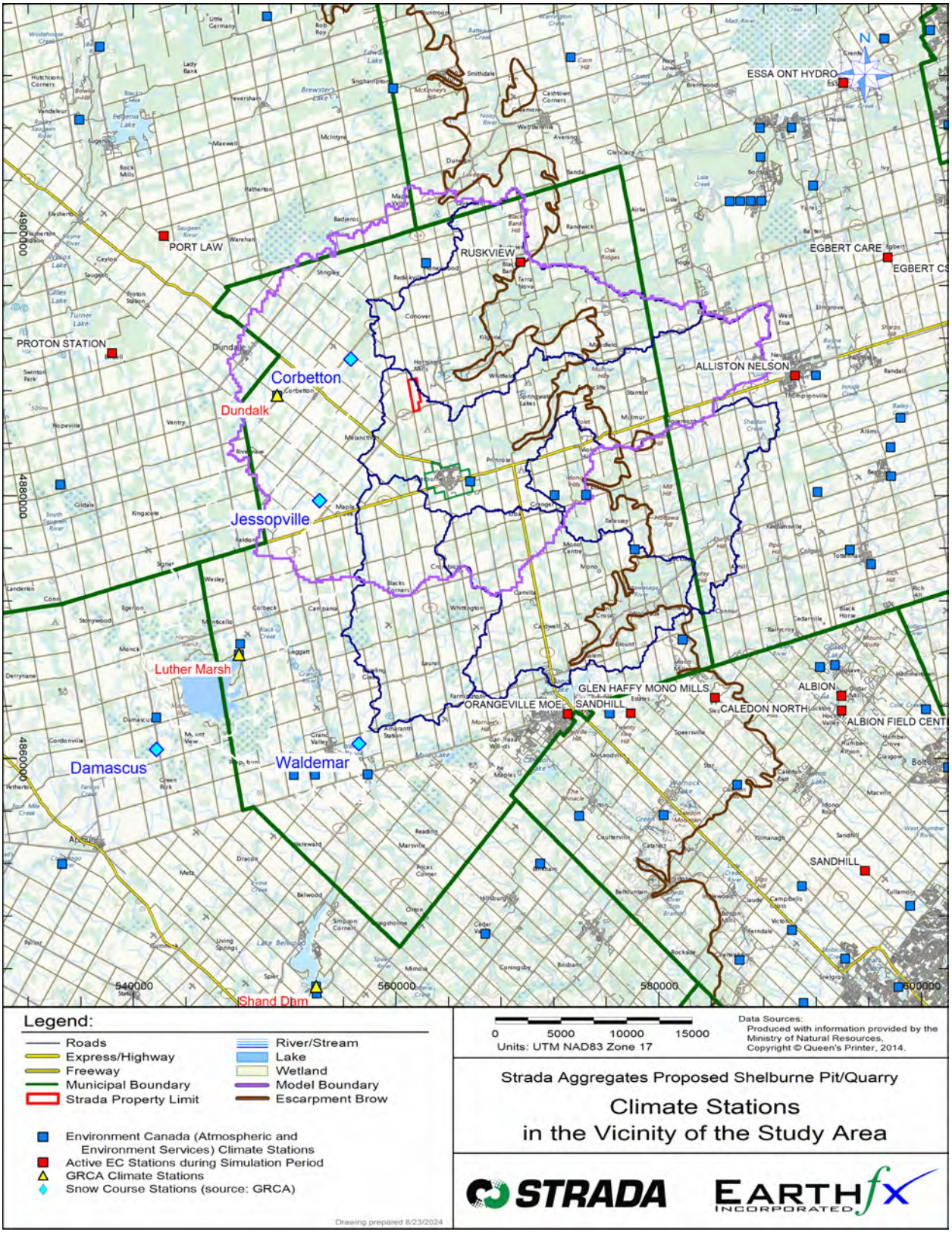


Figure 4.1: Environment Canada AES climate stations within 35 km of the project area.

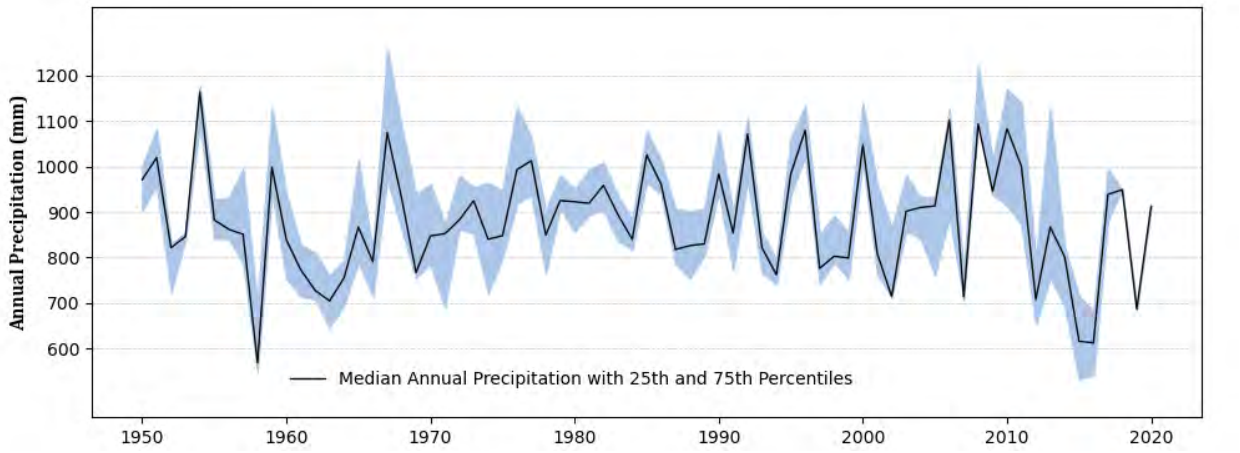


Figure 4.2. Annual precipitation quartiles in the study area (1950-2020).

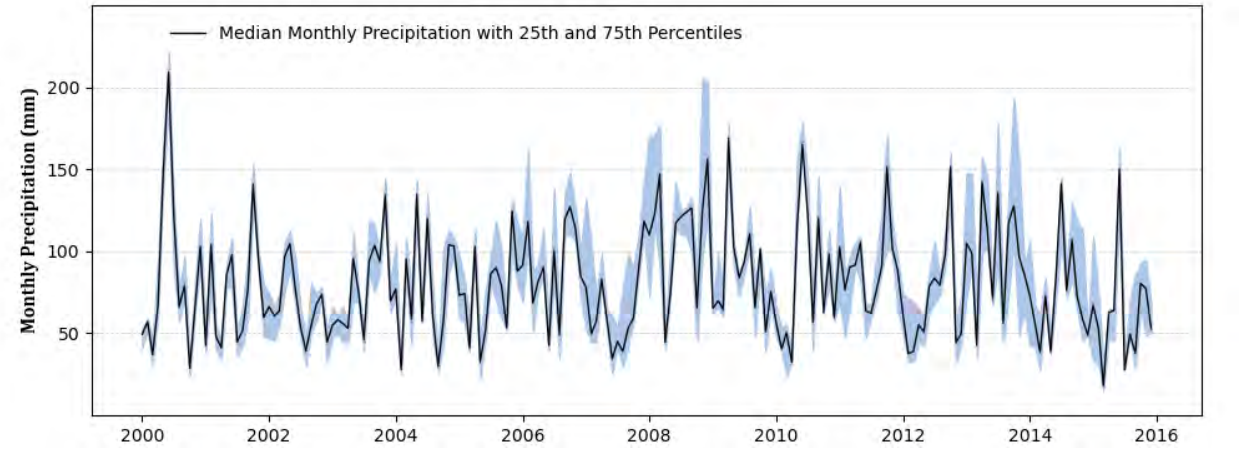


Figure 4.3. Monthly precipitation quartiles in the study area (2000-2016).

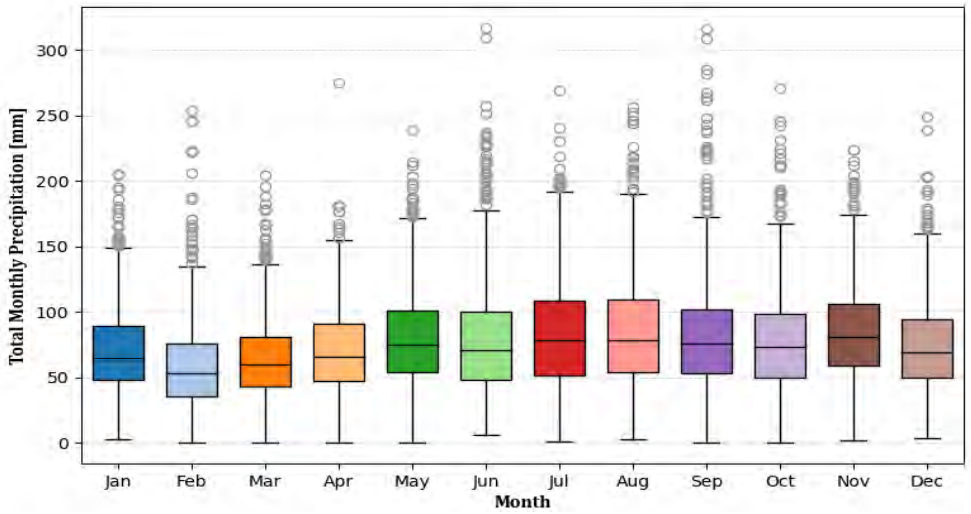


Figure 4.4. Box-whisker plot for monthly precipitation in the study area (1950-2020).

4.1.1.2 Grand River Conservation Authority Climate Data

The availability of active precipitation stations has significantly decreased in the study area since the 1990s (red trace in Figure 4.5) and with it the ability to properly represent spatial precipitation distributions. In the EC network, the number of stations reached its minimum in WY2017 (Figure 4.5 and also in Figure 4.2 and Figure 4.3). Data from stations maintained by the Grand River Conservation Authority (GRCA) were included in this analysis to fill the spatial and temporal data gap. Station locations are shown in Figure 4.1. However, a long-term solution for hydrologic modeling across Canada is likely not in data from physical stations but rather in radar-derived precipitation, as discussed below.

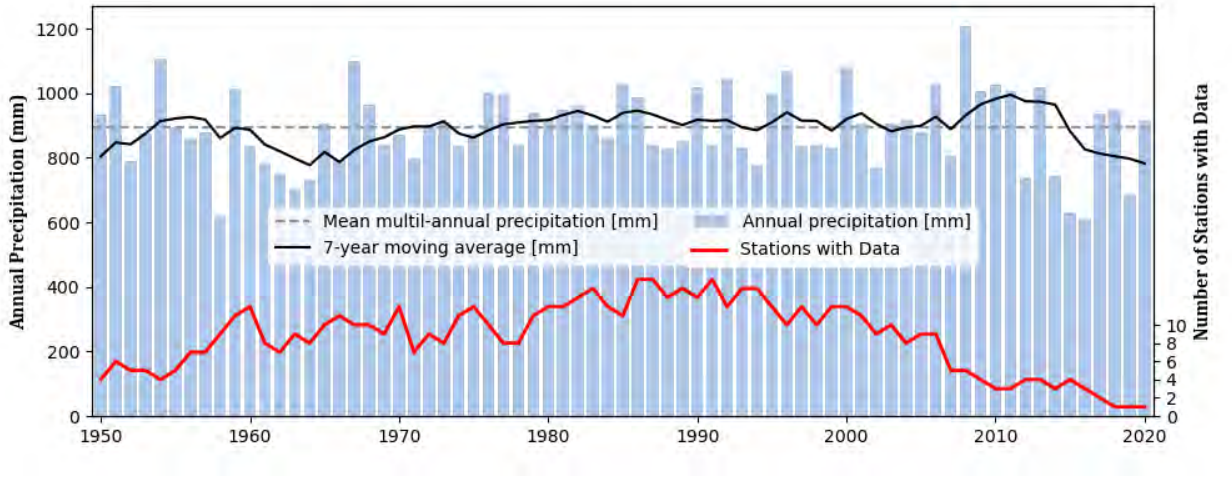


Figure 4.5. Annual average precipitation in the study area defined by 6.5 km search box around the model boundary (1950-2020).

4.1.1.3 CaPA Dataset

The Canadian Precipitation Analysis (CaPA) system has been implemented to complement precipitation data from gauged stations, at least in southern Canada. The CaPA system consolidates data from radar and precipitation gauges. Initially, the network included only of EC gauges, but recently (Environment and Climate Change Canada, 2021), networks from local agencies (GRCA and TRCA) were incorporated into new data to be released. Currently, three products are available from the CaPA data system:

- 2.5 km gridded precipitation data, available starting in 2016.
- 2.5 km gridded snowpack data, available starting in 2017.
- 10 km gridded precipitation data, available for 2002-2016, with a several month gap in 2012.

At this time, none of these products includes the GRCA and TRCA precipitation networks. For the Strada project, all three products were downloaded for WY2002 to WY2021. The data were processed, assigned to virtual climate stations at the centroid off the grid cells, and stored in the study database. Figure 4.6 shows the locations of the virtual climate stations for each data product along with the active climate stations in the area.

4.1.2 Final Precipitation Dataset

To have a comprehensive dataset that encompassed both the calibration and evaluation periods of this study, the CaPA dataset was used as the key precipitation dataset for the 19-year simulation period WY2003 to WY2021. Interpolated data from the EC and GRCA stations were used to infill periods with data gaps.

In spite of the discrepancies of the data at both monthly and annual time scales described previously, the use of a consistent data set throughout the period of analysis was key to obtaining useful model comparisons between pre-quarry and post-quarry conditions. Some limitations in the quality of the model calibrations to observed flows were expected due to limitations in the CaPA data set, however.

We understand that the CaPA dataset is far from being perfect and that it continues to be updated, most recently with network data from local agencies including the GRCA. The differences noted between gauge and CaPA stations should be significantly reduced in future releases of the CaPA dataset.

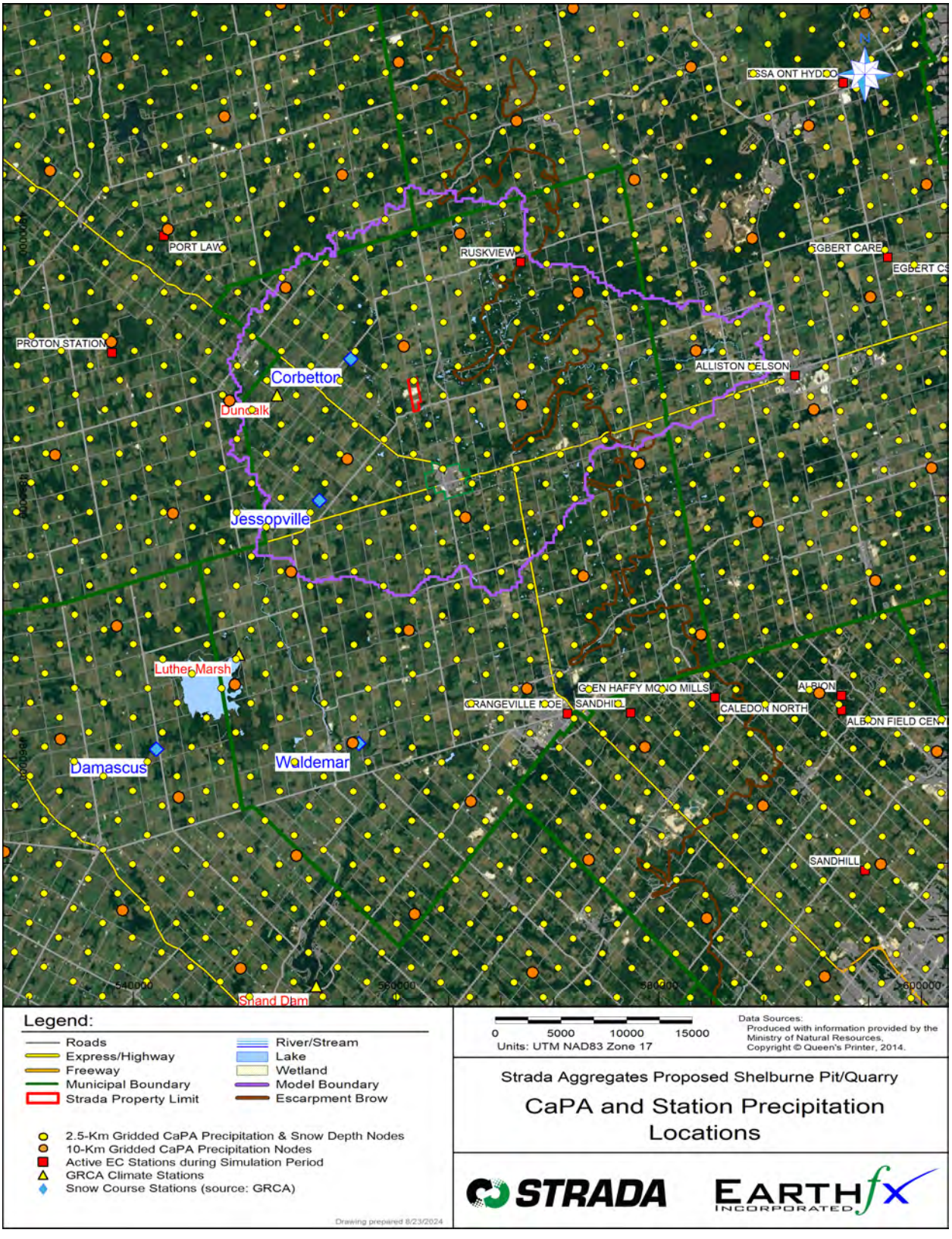


Figure 4.6: Virtual CaPA climate stations for the 2.5-km dataset (precipitation and snow depth) and the 10-km precipitation dataset along with active EC and GRCA precipitation stations.

4.1.3 Solar radiation

Solar radiation is the main source of energy present in the hydrological cycle. The amount of shortwave radiation emitted by the sun that finally arrives to the Earth' surface after passing through the upper layers of the atmosphere is known as incoming solar radiation.

Incoming solar radiation between 1956 and 2005 was based primarily on the average of measurements from four climate stations maintained by EC. These stations include: 611KBE0 (Egbert CARE); 6142285 (Elora Research Station); 6158350 (Toronto); and 6158740 (Toronto MET Research Station). The period of record of these sites only extends to August 2003; therefore, the remaining data up to 2021 had to be infilled using a combination of measurements from the University of Waterloo, York University, University of Toronto (Mississauga), and the Burford Tree Farm (GRCA). Where direct observations were unavailable, solar radiation was estimated by the Hargreaves and Samani (1982) method which uses daily minimum and maximum temperatures.

4.1.4 Snow Depth

Snow depth (or snowpack) is not an input dataset but it is an important environmental parameter that can be used in the calibration process to evaluate how the model interprets the snow accumulation and melting processes. In PRMS, the snow module computes snow pack accumulation on a cell-by-cell basis and evaluates snowpack depletion based on snowpack density, temperature, and albedo conditions on a sub-daily basis.

The GRCA collects snow course data within their watershed including snow depth and snow water equivalence. Four GRCA stations are in the vicinity: Jessopville, Corbetton, Damascus, and Waldemar (Figure 4.1). Of these, only Jessopville and Corbetton are located within the PRMS model domain. The measurement of snow depth and water equivalent start October 1 of every year and measurements are made every 2 weeks until the end of April. A total of 14 measurements are taking every water year at each site. Their time series for snow depth is shown in Figure 4.7.

Part of the CaPA system dataset includes 2.5-km gridded snow depth based on radar-derived estimates. This dataset is available from WY2016 to the present. Snow depth data are shown in Figure 4.8 for virtual CaPA stations located closest to the centroid of the four gauged catchments used for model calibration. Unlike the biweekly nature of the GRCA snow course time series, the CaPA snow depth dataset is continuous and more apt to capture both sudden melting and accumulation events. Both datasets were used in assessing the calibration and evaluation periods for the PRMS model.

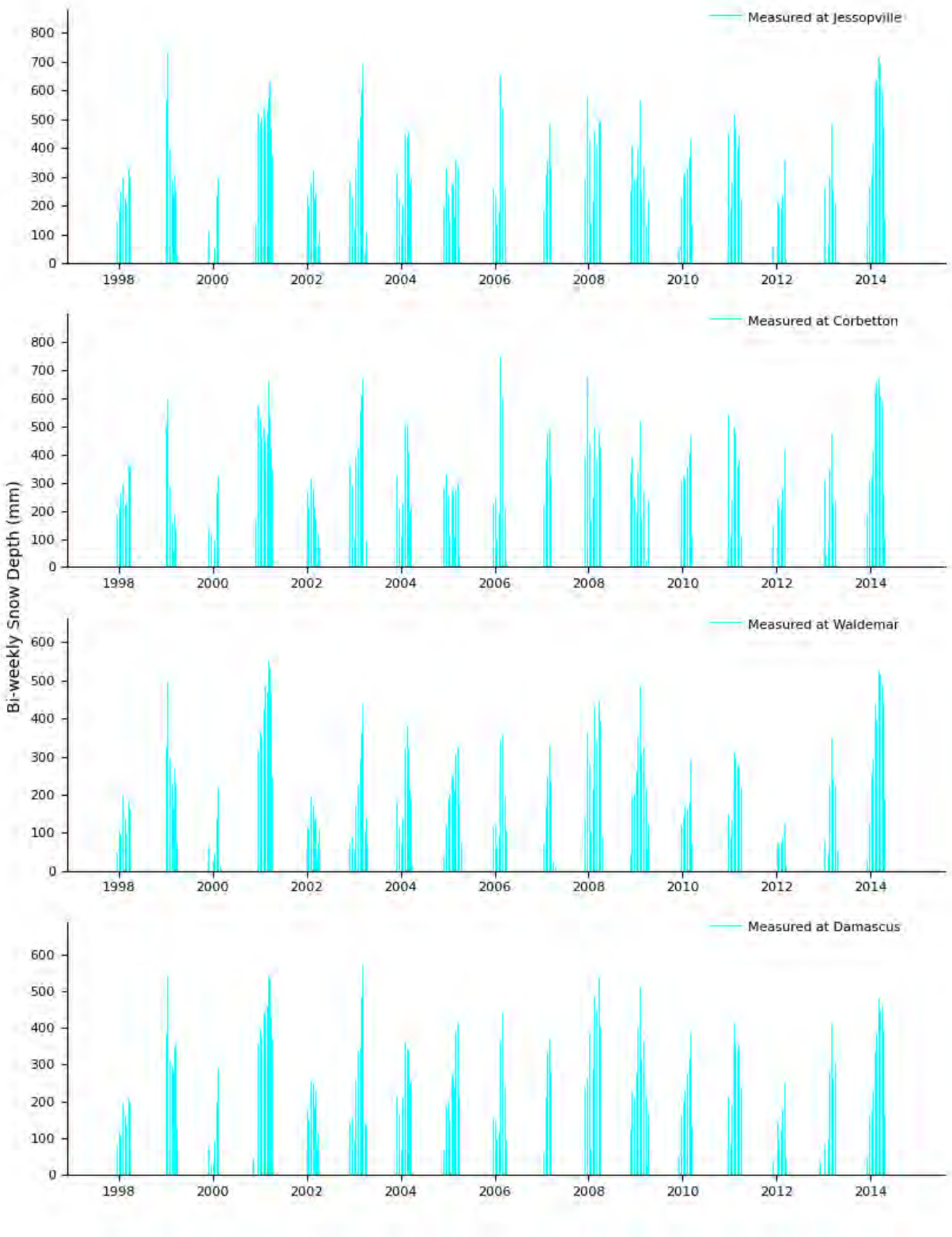


Figure 4.7: GRCA snow course data showing snowpack depth, in mm.

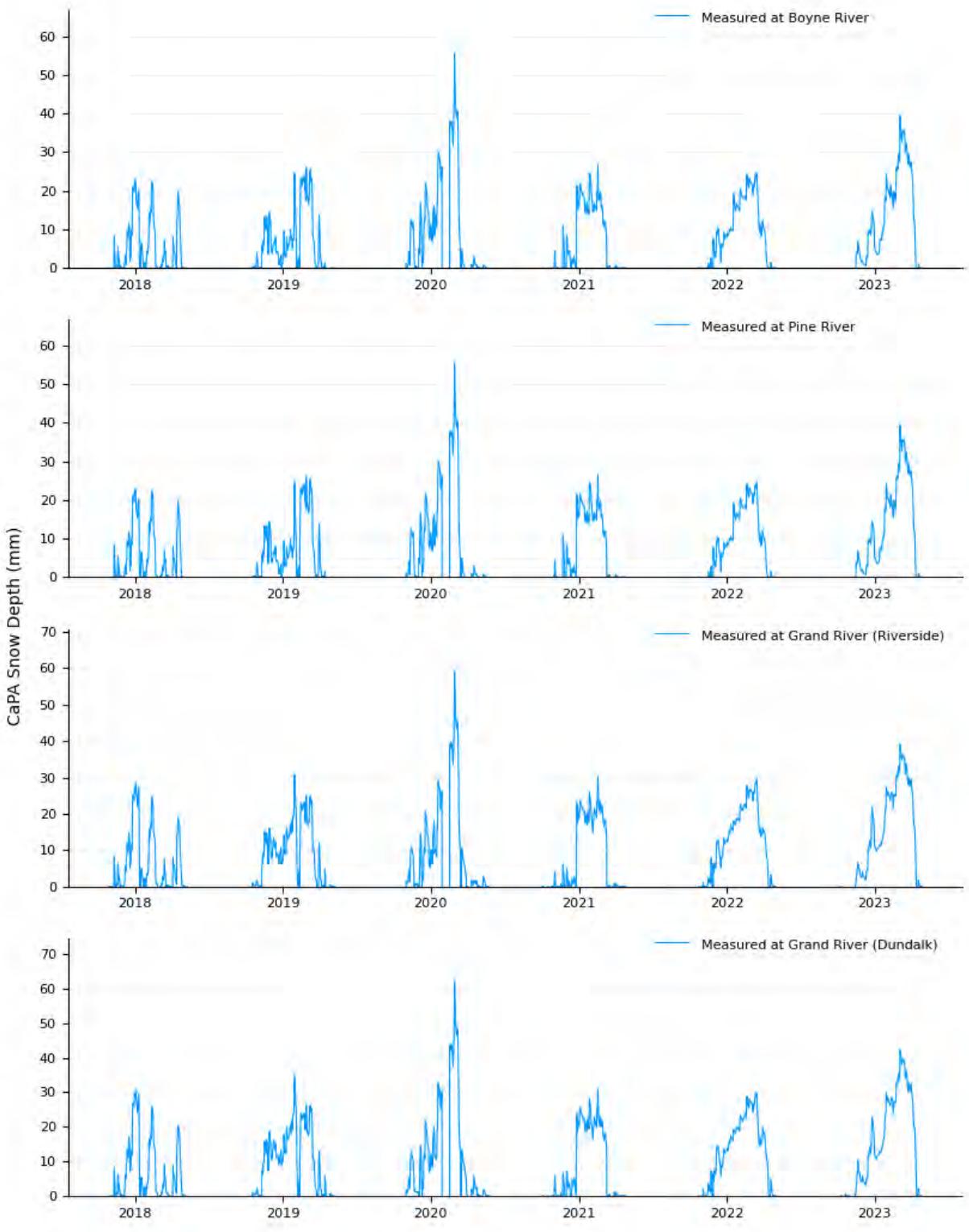


Figure 4.8: CaPA snow depth (in cm) at virtual stations close to the centroids of the four calibration catchments.

4.2 *Land Cover and Land Use*

Land use and land cover strongly influence hydrologic response, especially in a fully distributed model such as PRMS. SOLRIS v3.0 (MNRF, 2019) was the first source of land use data considered for the study area. However, the percentage of land use labeled as 'undifferentiated' (37%) within the model area was very high. Therefore, additional work was undertaken to reduce this unknown characterization was comparing it with the Grand River Conservation Authority's (GRCA) land cover classification from the year 1999. The 'undifferentiated' category included polygons classified as pasture, forage, and bare agricultural fields in the GRCA land use coverage, which are land use categories non-existent in the SOLRIS dataset. Areas falling within these categories were then reclassified as a single land use category named 'Pasture/Forage/Bare Agricultural Fields' with the SOLRIS code of 251 and assumed to share similar hydrological features. The remaining undifferentiated area was less than 25%.

The resulting land use coverage for the study area spans the time period between 1999 and 2015, which encompasses the period chosen for hydrological analysis. The distribution of land use classes is summarized in Figure 4.9. The land use data was broken down into 18 categories that were used as a basis for assigning hydrologic properties to model cells. The dataset was indexed and sampled to the PRMS grid (Figure 4.10). A spatial coverage of tile drainage is also included within with the land use mosaic shown in Figure 4.10.

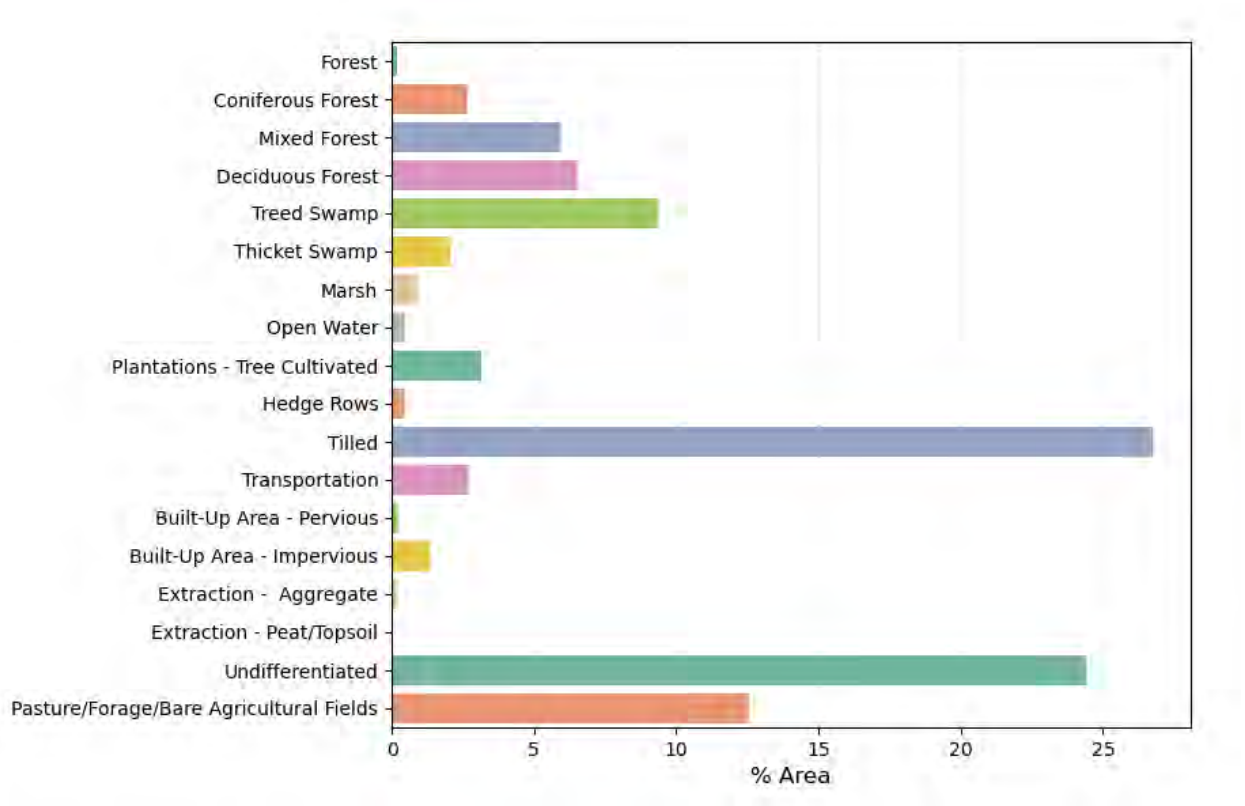


Figure 4.9. Land use breakdown in the model area.

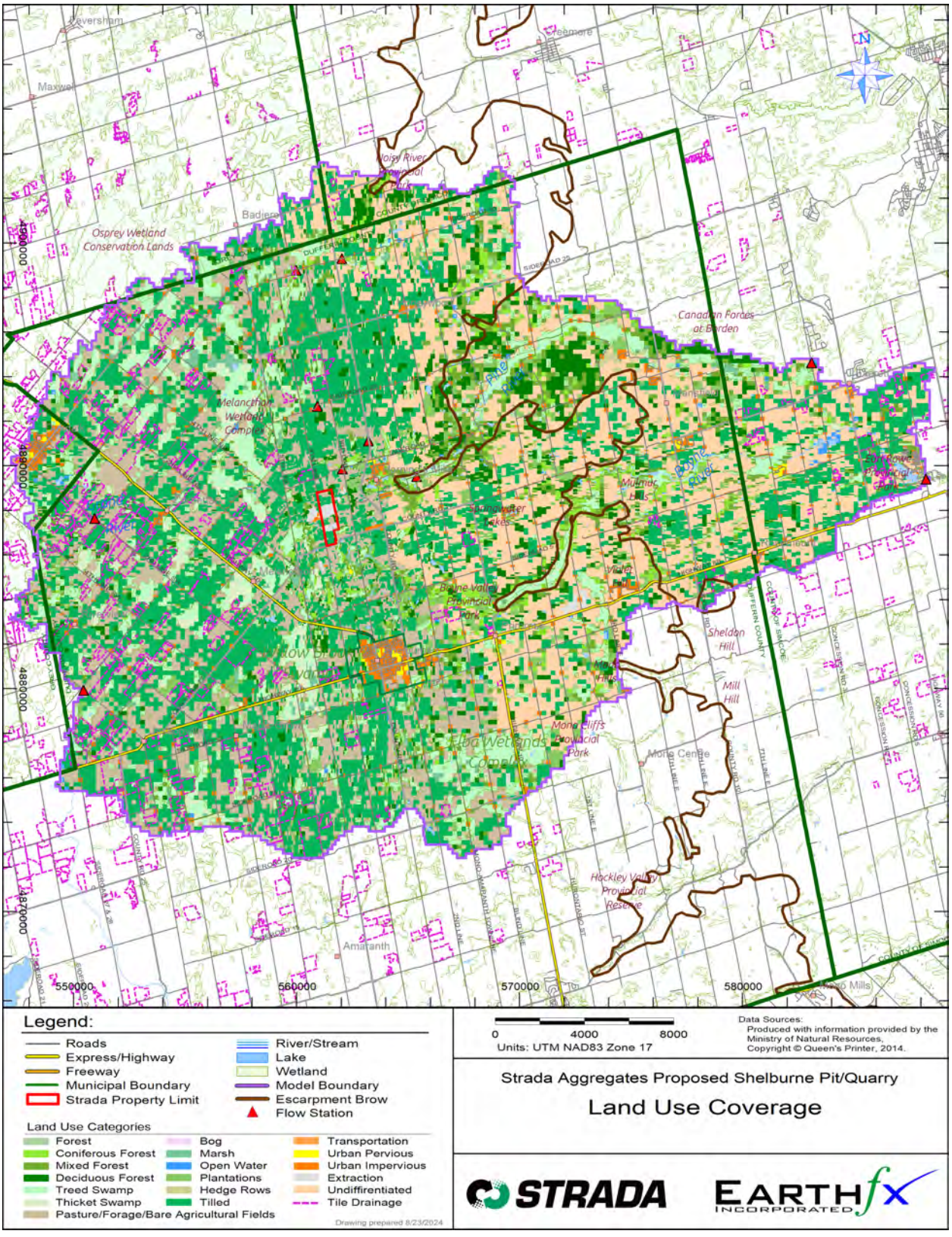


Figure 4.10: Land use classification.

4.3 *Surficial Geology and Soil Properties*

The surficial geology map offered by the Province of Ontario's the Ministry of Northern Development, Mines, Natural Resources, and Forestry as a public service to the Ontario Geological Survey (OGS, 2010) was used to distribute hydrological properties of surficial materials over the model area (Figure 2.9). These properties were assigned to cells using tabulated look-up values. The surficial geology breakdown within the model area is listed in Table 4.1. Pie charts of the surficial geology composition are presented in Figure 4.11.

In no case were the properties defined or assigned based on watersheds, catchments or sub-catchment boundaries. Catchments and watershed boundaries were used only for illustrative purposes or summarization (for example, the pie carts presented below). Multiple watershed boundary coverages are available (for example, from Conservation Authorities and the Water Survey of Canada) and none of those have been updated to the reflect the new 2023 Provincial LiDAR DEM.

All properties were assigned to a cell-based grid for input into the numerical models discussed in Appendix D (Earthfx Inc., 2024a). Overland flow and runoff processes in the model presented in Appendix D was based on 2023 Provincial LiDAR mapping and was not limited or constrained by catchment boundaries.

The agricultural soil texture map developed by Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA, 2019) also used to distribute hydrological properties (Figure 4.12). The older 1964 Soil Survey of Dufferin County document and map (Hoffman and Matthews, 1964) was also reviewed, as was a report by Torrance, 2009, on the Honeywood Soil Series. Specifically, the Soil Conservation Service (SCS) soil type codes (needed to assign curve number (CN) values) were assigned based on the drainage condition of the soils. The breakdown of the soil texture categories found in the model area is presented in Table 4.2 and their distribution within the calibration catchments is depicted as pie charts in Figure 4.13.

Table 4.1: Surficial geology composition in the model area.

Index	Description	%Area	Index	Description	%Area
150	Various (Bedrock, Sandstone, dolostone, shale)	0.61	**410**	Sand, minor gravel	14.61
151	Limy mudrock and clastic sedimentary rock	0.04	**420**	Glacial-outwash Gravel	1.54
212	Catfish Creek till	19.86	**511**	Mainly silt and clay (Glaciolacustrine)	0.43
217	Elma till	0.88	**630**	Mainly fine to very fine sand (Glaciolacustrine)	1.01
219	Newmarket till	6.34	**900**	Gravel, sand, silt, clay; 1-8m thick; River Deposits	1.90
254	Tavistock till	18.21	**1400**	Fine Sand in Sand Dunes (Wind-blown Deposits)	0.02
262	Newmarket till, Clayey silt till	0.14	**1600**	Gravel, sand, silt, clay, muck; Modern River Deposits	0.49
265	Glacial deposits (Wildfield/ Kettleby Till)	1.54	**1700**	Peat, Muck, And Marl (Bog Deposits)	2.85
300	Sand and gravel including some till or silt	18.15	**9999**	Unassigned	9.28
400	Gravel and gravelly sand	2.10		Total Area %	100%

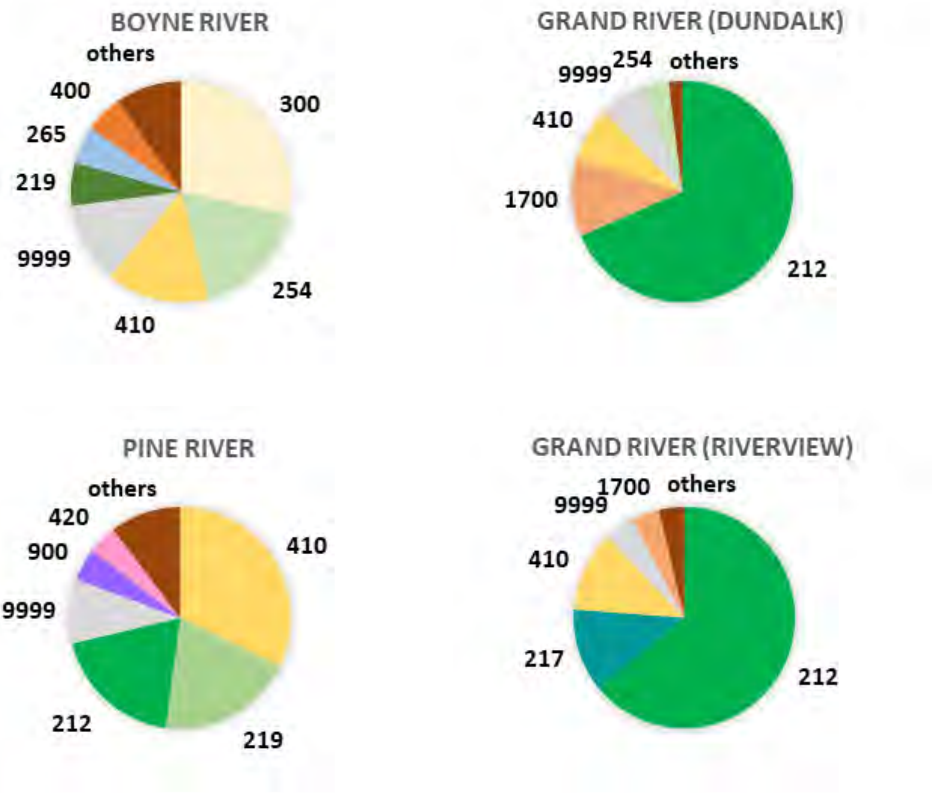


Figure 4.11: Surficial geology composition in the calibration catchments.

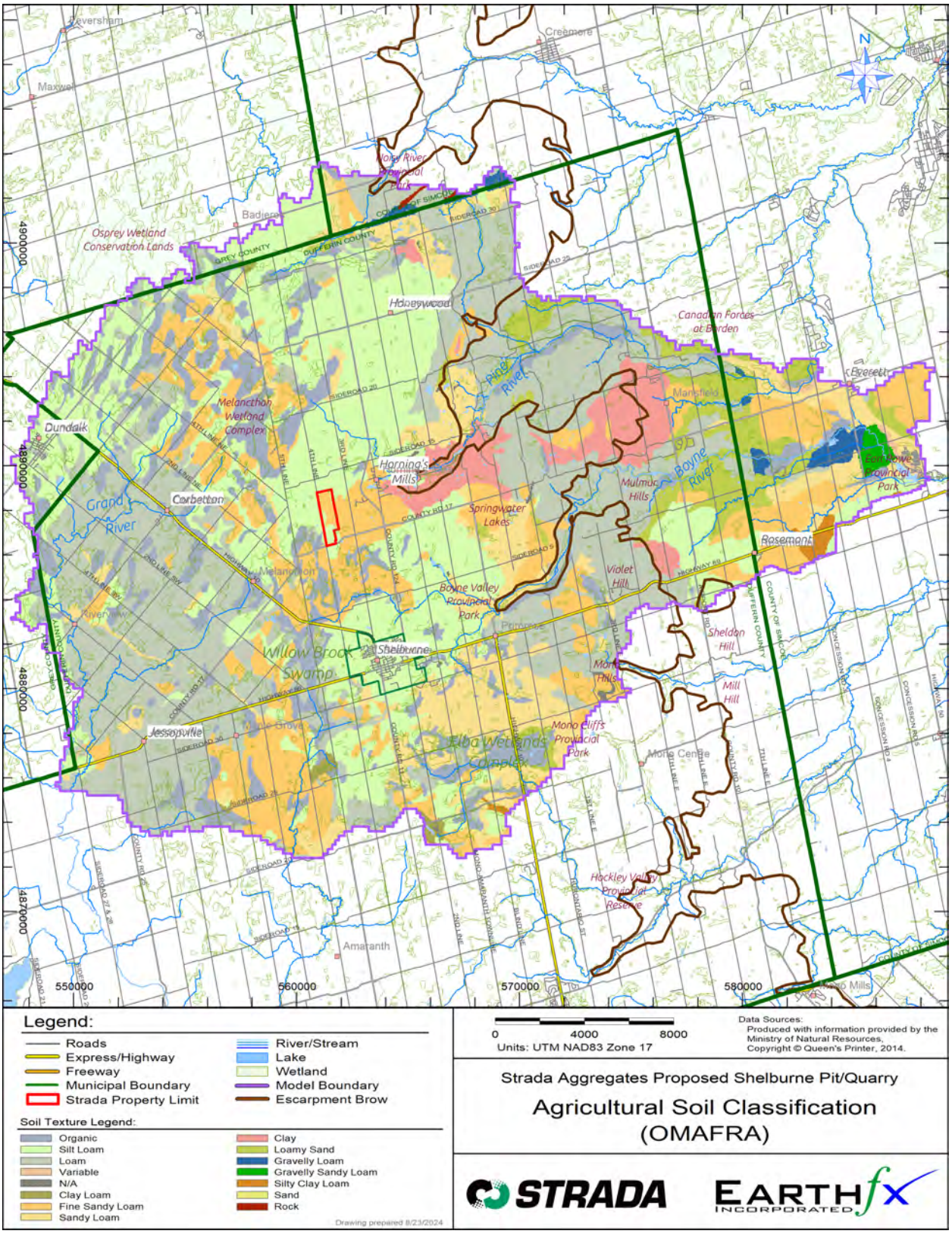


Figure 4.12: Agricultural soil classification.

Table 4.2: Agricultural soil classification (OMAFRA).

Map Id	Texture	% Area
L	Loam	26.8
SIL	Silt loam	18.8
FSL	Fine Sandy Loam	12.3
LS	Loamy Sand	12.0
SL	Sandy Loam	10.8
ORG	organic	10.4
No Data	N/A	3.5
C	Clay	2.1
SICL	Silty Clay Loam	1.6
GL	Gravelly Loam	0.7
VAR	Variable	0.4
CL	Clay Loam	0.2
GSL	Gravelly Sandy Loam	0.2
R	Rock	0.1
S	Sand	0.0

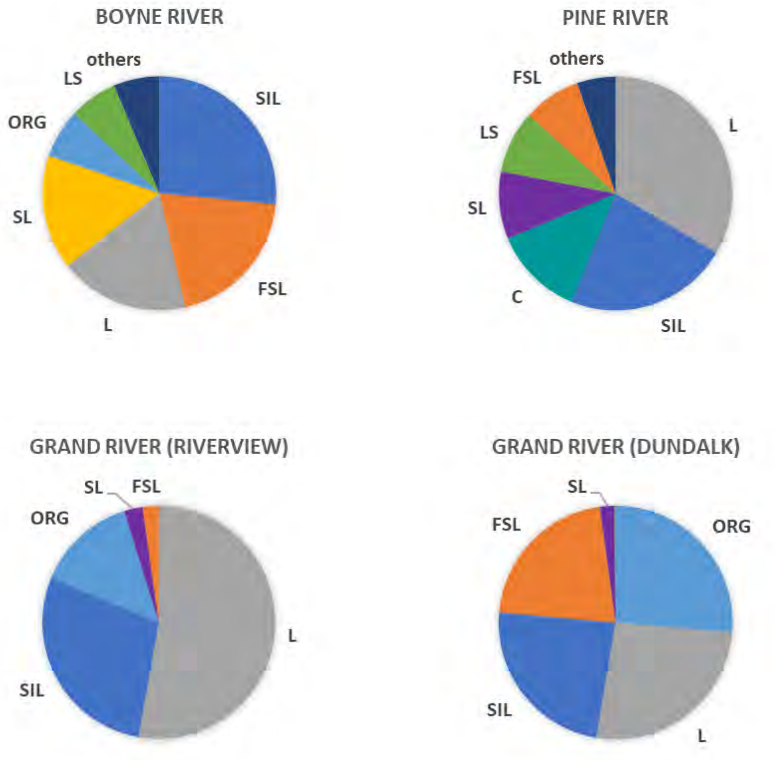


Figure 4.13: Agricultural soil composition in the calibration catchments.

4.4 *Surface Water*

Streams, lakes, and wetlands that drain the study area are shown in Figure 4.14. The Strada property falls within the uplands of the Boyne River and Pine River watersheds. These watersheds are bounded by the Grand River watershed to the west and south, the Nottawasaga River watershed to the south and southeast, and the Noisy River watershed to the north. The nearest stream features are about 500 m east and 1040 m northeast of the Strada property; both are tributaries to the Pine River. A Boyne River tributary is located approximately 1100 m to the southeast.

Surface water data from several sources, including streamflow measurements, previous modelling efforts, and surface feature mapping were complied. Stream networks were mapped and classified using the MNRF OHN Watercourses (OHNWCRS) coverage. The stream, lake, and wetland mapping data were processed and a composite map is provided in Figure 4.14. Also shown are the locations of the Water Survey of Canada (WSC - a division of Meteorological Service of Canada, Environment Canada) stream gauges within the study area, together with GRCA stream gauges and temporary gauges installed for the Highland Melancthon quarry application (Genivar Inc., 2011).

There are a large number of wetlands and wetland complexes within the study area, most of them located above the Niagara Escarpment (Figure 4.14). Provincially significant wetland (PSW) complexes are present approximately 2350 m to the west and approximately 2500 m to the east, along the main branch of the Pine River. The latter wetland complex extends above and below the escarpment brow and surrounds a provisional stream gauge installed by Genivar (DP-SW10).

4.4.1 Stream Flow Monitoring

Daily mean and instantaneous streamflow data were compiled from different sources around the study area. Table 4.3 provides a list of these gauges including their period of record and specific discharge.

Table 4.3: Streamflow gauges available within the model area from different sources.

Streamflow Station	Station ID	Monitoring Period	Mean Flow (m^3/s)	Drainage Area (km^2)	Spec. Disch. ($m^3/s/km^2$)
Environment Canada Gauges (Water Survey of Canada, WSC)					
Boyne River at Earl Rowe Park	02ED102	Oct/1967 - Dec/2021	2.11	217.9	$9.68x10^{-3}$
Pine River near Everett	02ED014	Oct/1967 - Dec/2016	2.18	190.4	$1.14x10^{-2}$
Grand River Conservation Authority					
Grand River near Dundalk*	14518	Mar/2002 - Dec/2021	1.07	66.2	$1.62x10^{-2}$
Grand River near Riverview*	15050	Aug/1999 - Dec/2021	2.77	115.9	$2.39x10^{-2}$
Highland Companies - Melancthon Quarry monitoring sites – subbasins on the headwaters of Pine River					
Genivar DP-SW5	SW5	Apr/2008 – Jul/2010	0.08	12.79	$6.25x10^{-3}$
Genivar DP-SW7	SW7	Apr/2008 – Jul/2010	0.42	16.58	$2.53x10^{-2}$
Genivar DP-SW8	SW8	Apr/2008 – Jul/2010	0.04	3.76	$9.57x10^{-3}$
Genivar DP SW10	SW10	Jun/2008 – Jul/2010	1.04	58.3	$1.78x10^{-2}$

Based on their longer period of record (Table 4.3), the EC and GRCA streamflow gauges were used for PRMS model calibration (See Appendix D (Earthfx Inc., 2024a)). The Highland gauges have a

short period of record but still provided valuable insight during model calibration, especially because of their location at the headwaters of the Pine River and because of their proximity to the Strada property.

Specific discharge is calculated by dividing mean flow by the drainage area of the streamflow gauge being examined. The Pine and Boyne River catchments have similar values for specific discharge as their mean flows and their drainage areas are also similar. The specific discharge for the downstream gauge at the Grand River near Riverview is more than twice that of the Boyne and Pine River, despite having a drainage area almost half the size. This relates to differences in the predominant soils and surficial geology found in these catchments.

Upon visual inspection, data availability and quality at the WSC and GRCA gauges are good, as shown in Figure 4.15 through Figure 4.18. Of note is that the majority of annual flow in these rural catchments occurs during the spring freshet. The streamflow time series along the Grand River exhibit an extreme flashy behavior with high streamflow values that are followed by almost no baseflow contributions to the hydrograph. The temporary nature of the Genivar gauges is reflected in the quality of the data collected which lacks continuity but provides a general impression of the catchment response to precipitation events (Figure 4.19 and Figure 4.20).

When addressing streamflow gauge data, temporal resolution is of extreme importance (Thompson, 2013). Processes and mechanisms that occur at a higher frequency can be obscured at the daily time scale. For example, this often occurs in flashy urban systems. However, undeveloped areas predominate in the model domain, consequently the PRMS and GSFLOW models, which will be calibrated to reported daily mean discharge, should adequately represent the hydraulic response within the study area.

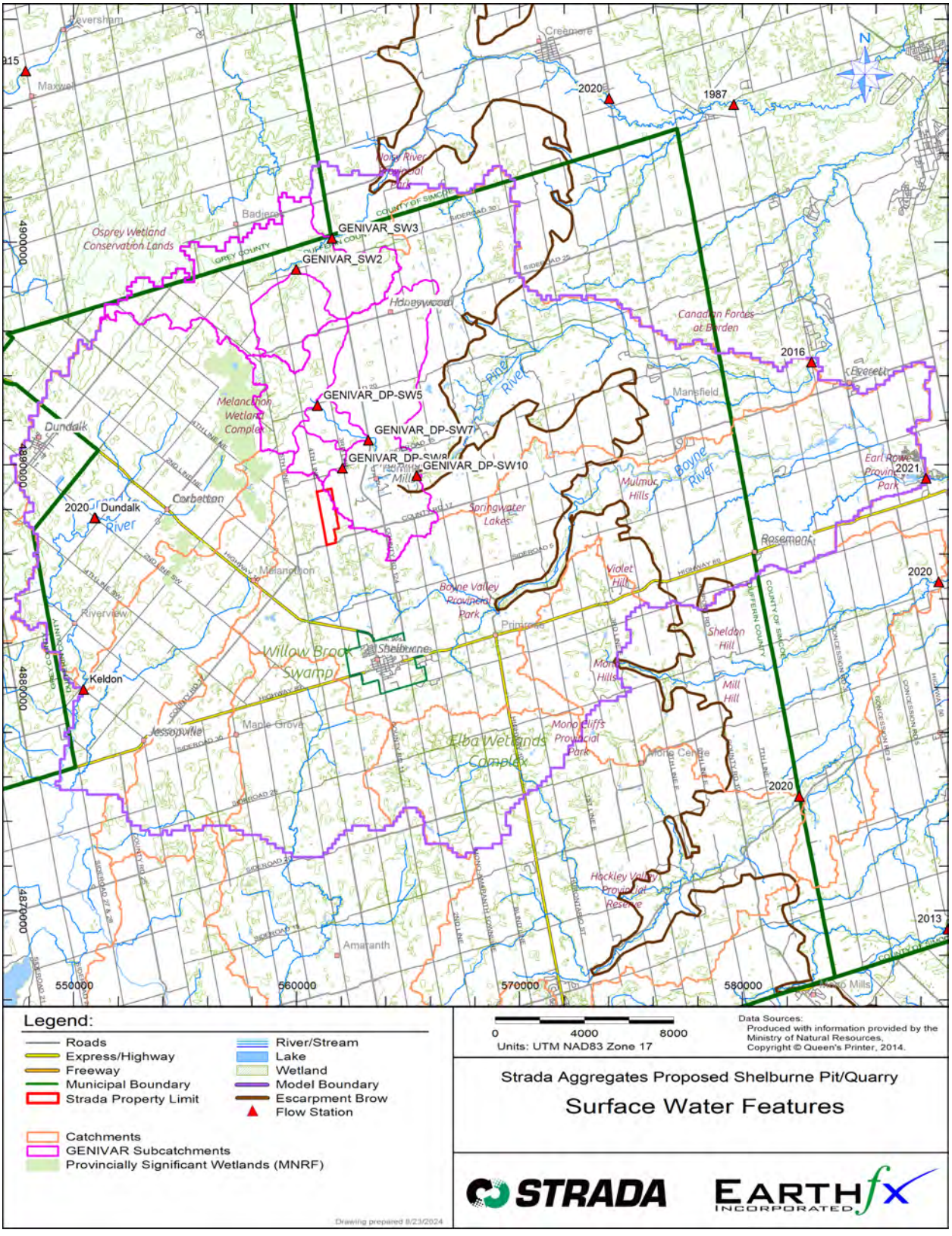


Figure 4.14: Surface water features.

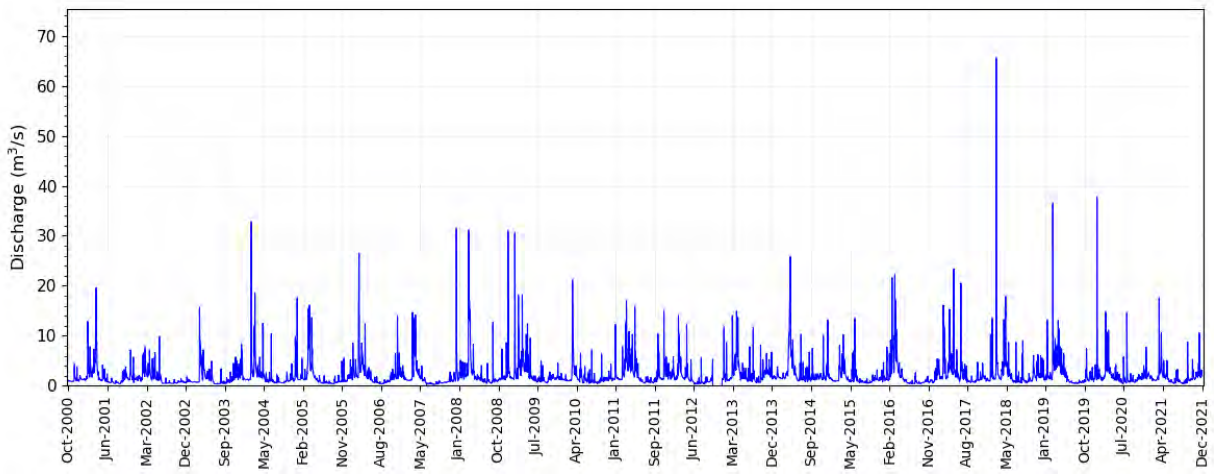


Figure 4.15: Mean daily discharge at Boyne River at Earl Rowe Park.

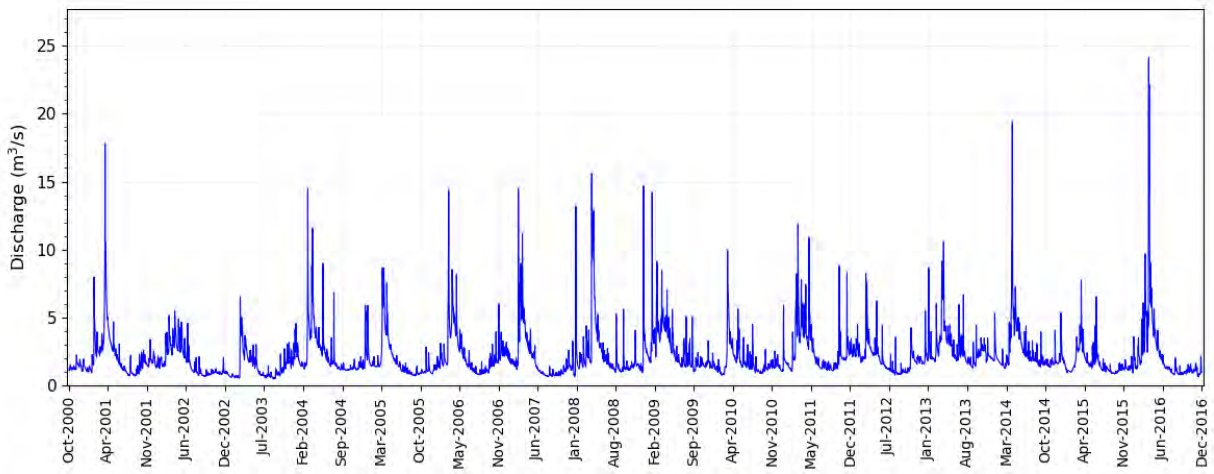


Figure 4.16: Mean daily discharge at Pine River near Everett.

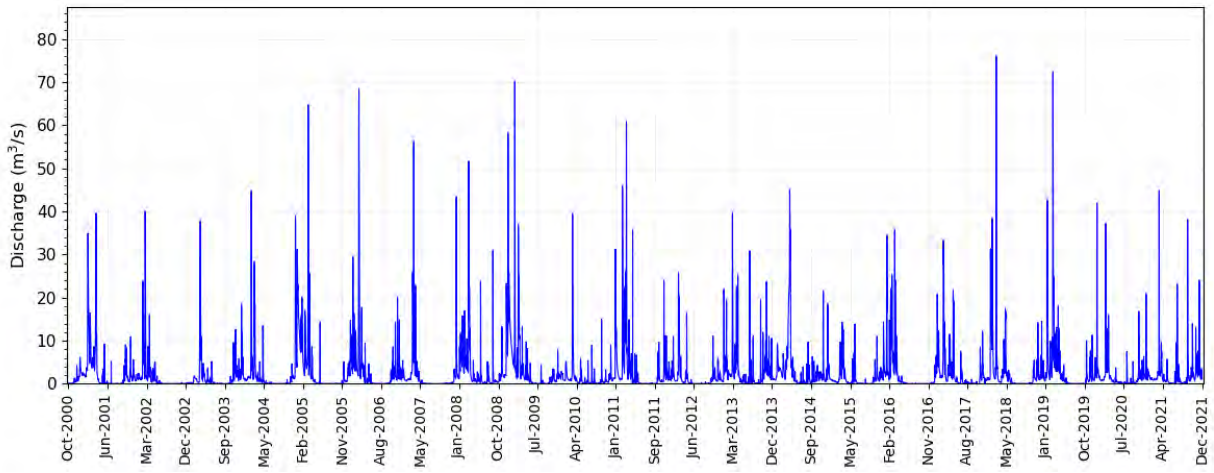


Figure 4.17: Mean daily discharge at Grand River near Riverview.

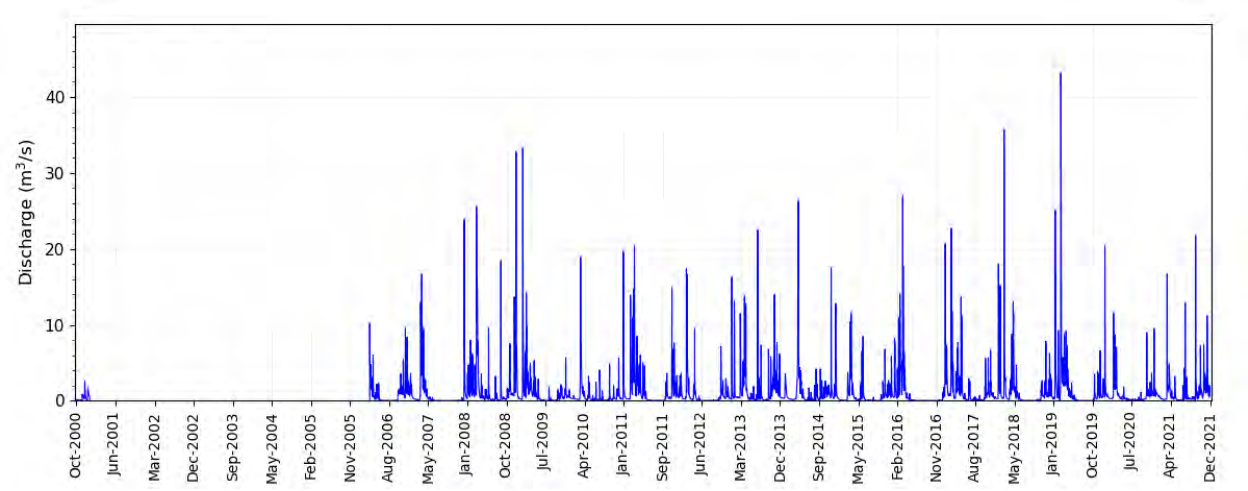


Figure 4.18: Mean daily discharge at Grand River near Dundalk.

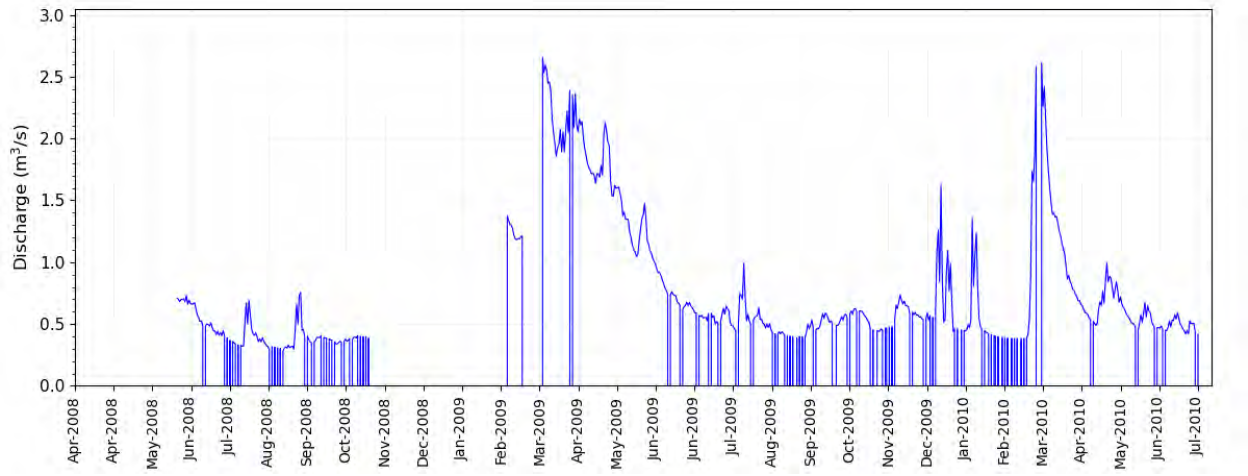


Figure 4.19: Mean daily discharge at Genivar's DP-SW10 gauge (Pine River subcatchment).

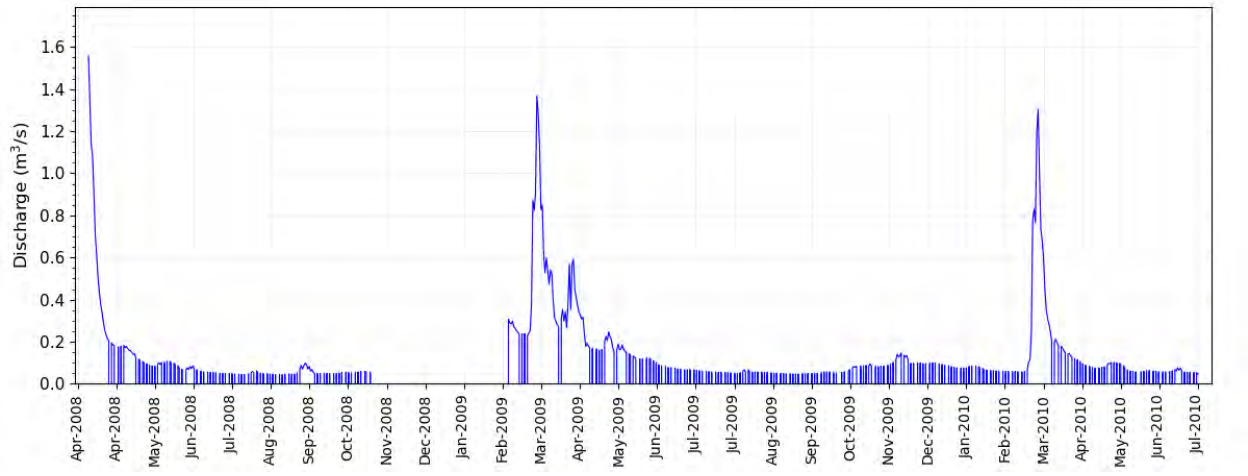


Figure 4.20: Mean daily discharge at Genivar's DP-SW7 gauge (Pine River subcatchment).

4.4.2 Baseflow

Hydrograph separation techniques were applied to the continuous flow data to split the two components of streamflow: (1) overland runoff and (2) baseflow. Baseflow is generally assumed to be primarily composed of groundwater discharge; however, it should be noted that the separation methods cannot distinguish between groundwater discharge and other relatively steady flows such as discharge from reservoirs and upstream wetlands which also contribute to discharge during low flow conditions.

Numerous techniques are available to estimate baseflow including curve processing and statistical techniques. Baseflow was estimated with the modified United Kingdom Institute of Hydrology (UKIH) smoothed minima method devised by National Water Research Institute and Meteorological Service of Canada (Piggott *et al.,* 2005). The modified UKIH method, has resolved two aspects of the conventional method that lead to less-than-optimal results:

1. the calculation of values of baseflow that exceed the corresponding values of streamflow; and,
2. the dependence of the calculated values on the origin of the five-day segmentation of the input streamflow data.

The latter aspect was corrected based on the suggestion of Piggott *et al.* (2005) where four additional passes (i.e., multi-pass) of the UKIH method are performed 1 to 4 days after the arbitrarily chosen origin. The modified approach was found suitable for areas of southern Ontario, where baseflow is primarily due to groundwater discharge.

Figure 4.21 through Figure 4.24 illustrates the estimated baseflow for the streamflow time series data from the calibration catchments. These estimates will also be used in the calibration process to compare against the simulated PRMS baseflow values.

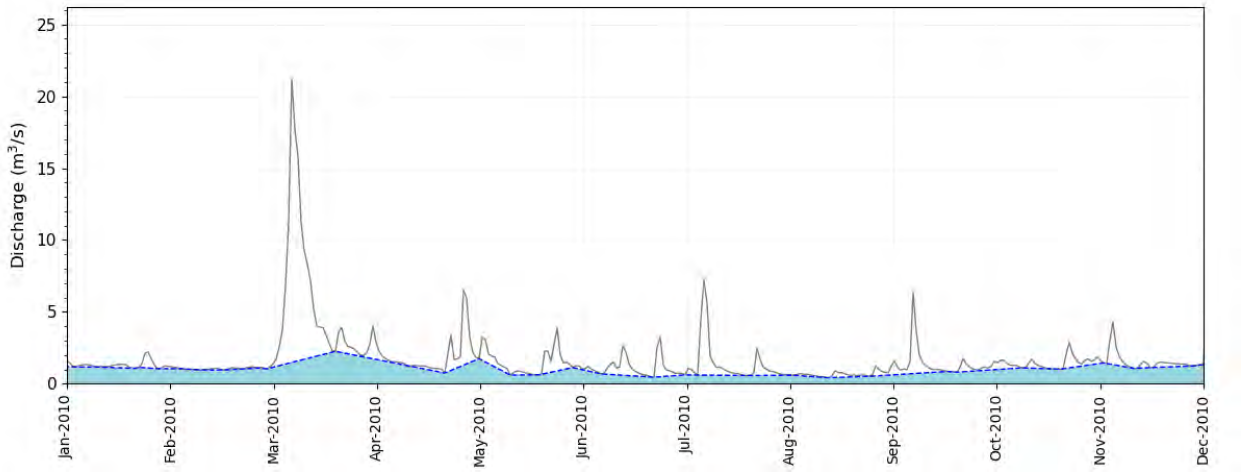


Figure 4.21: Estimated baseflow from daily discharge (2010) at Boyne River at Earl Rowe Park.

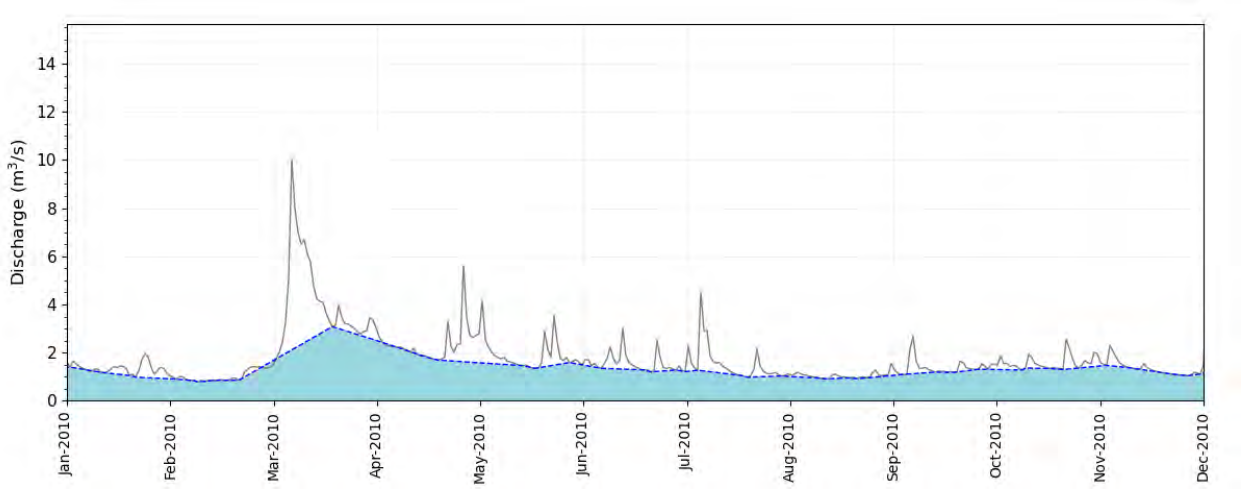


Figure 4.22: Estimated baseflow from daily discharge (2010) at Pine River near Everett.

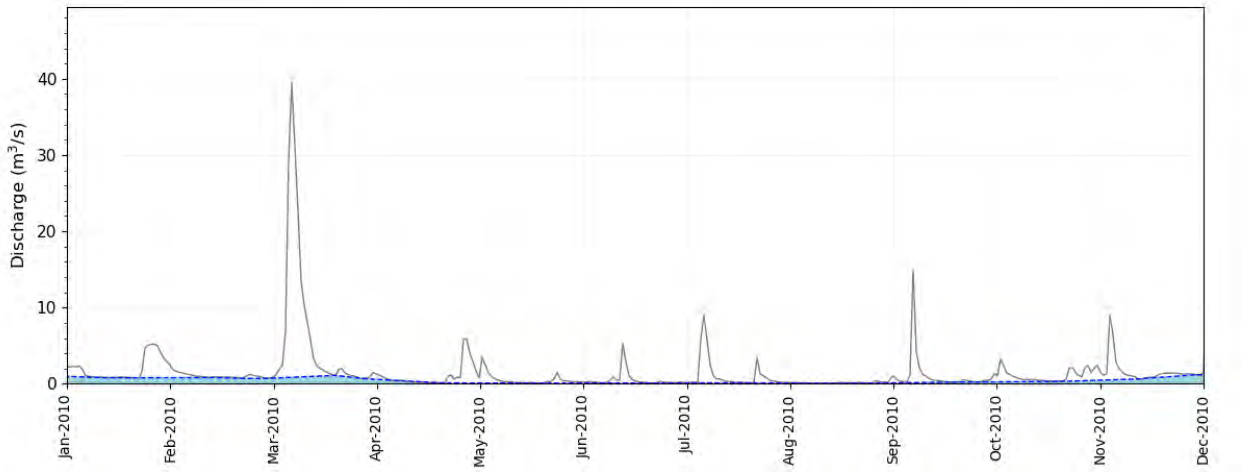


Figure 4.23: Estimated baseflow from daily discharge (2010) at Grand River near Riverview.

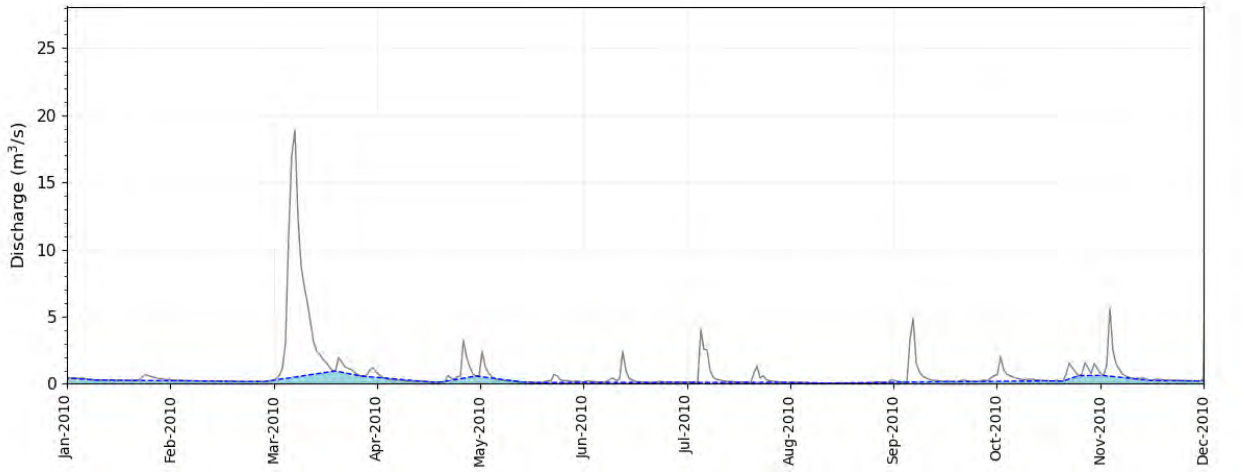


Figure 4.24: Estimated baseflow from daily discharge (2010) at Grand River near Dundalk.

4.4.3 Lakes

There are 869 waterbodies within the model domain of different shapes and sizes (Figure 4.25). The histogram in Figure 4.25 indicates that most lakes have areas smaller than 5 hectares (ha), and that 95% of the lakes have areas smaller than 1.06 ha. The largest lake is of 32.3 ha, and the smallest is of 80 m^2. The -surface and groundwater flow each treat lakes in a different, non-overlapping fashion. The PRMS model treats it as a land use feature, whereas the groundwater model (MODFLOW-NWT) represents a lake as a significant component of the routing process along the stream network. In MODFLOW-NWT, stage-volume, stage-area, and stage-discharge curves are provided for each lake. Inflows include direct precipitation (minus evaporation) and incoming streamflow as computed by the SFR Package. The integrated model (i.e., GSFLOW) offers the same treatment to lakes as MODFLOW-NWT.

A total of 56 lakes will be modelled explicitly with the MODFLOW-NWT and GSFLOW codes. These lakes are mostly located in the vicinity of the Strada site. Modelling the lake water balances will provide a better representation of the interaction between lakes and streams and between lakes and the underlying groundwater system in the vicinity of the proposed Strada Shelburne pit/quarry.

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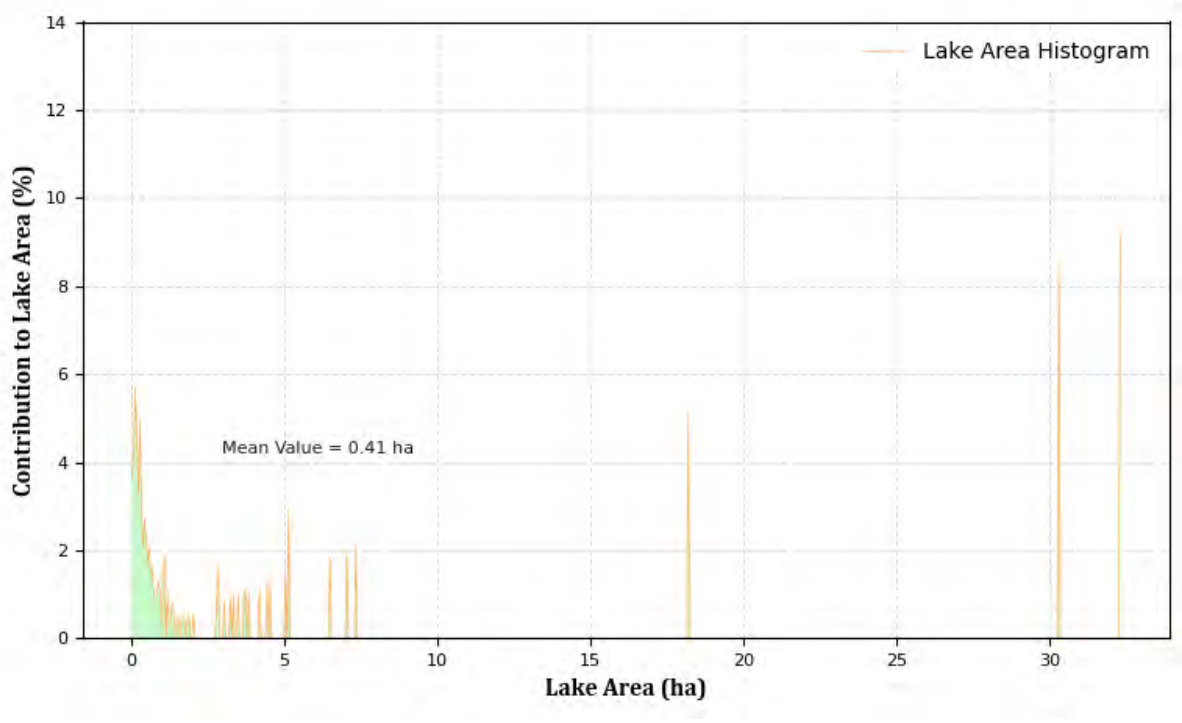


Figure 4.25: Histogram of lake areas present within the model domain.

5 Hydrogeologic Setting

5.1 *Water Level Data Sources*

The groundwater model produces results primarily in terms of simulated groundwater levels (heads) and changes in groundwater levels (drawdowns). Compilation of the observed groundwater levels was necessary to establish calibration targets for the steady-state and transient groundwater flow models and for estimating response to changes in pumping rates and to drought conditions. Water level data are available from four primary sources, as described below.

5.1.1 MECP WWIS Static Water Levels

Static water level data from wells in the MECP WWIS database provide insight into the regional groundwater levels and groundwater flow patterns in the study area (groundwater flows from higher to lower levels in a direction perpendicular to the contours of equal groundwater level). Well locations, predominantly for domestic or agricultural use, are shown in Figure 5.1. The static water levels represent a one-time measurement taken by the well driller when the well was constructed. Numerous biases and errors are known to exist in the water well record data. These are discussed further in Section 5.2.1. Assessment of the intrinsic error and variation in this data set is discussed in Kassenaar and Wexler (2006). Despite these limitations, the WWIS data set has good regional coverage.

A total of 4,730 static water levels were used in the characterization of groundwater patterns and for model calibration for this study. Wells are equally distributed below and above the Niagara Escarpment within this subset of the WWIS data. The primary focus of the study, however, is located above the Niagara Escarpment, at the headwaters of the Pine and Boyne River catchments.

5.1.2 Provincial Groundwater Monitoring Network

Transient groundwater level data were obtained from wells in the MECP Provincial Groundwater Monitoring Network (PGMN) wells. Three PGMN well clusters are found in the model domain and provide extremely useful information on natural seasonal and climactic variation in water levels. Locations are shown in Figure 5.1. Data, current to December 2019, were processed to identify and correct spikes and shifts in the data, reconcile the logger data with manual measurements (where appropriate), and generally prepare the data for use as transient model calibration targets. The closest PGMN well is located approximately 6 km west of the Strada property. Besides PGMN wells, transient data were also collected from the municipal wells network at the Town of Shelburne where aquifer testing and frequent monitoring has been conducted.

Table 5.1: PGMN well construction data.

Location ID	Aquifer Type	Aquifer Lithology	Easting (m)	Northing (m)	Ground Elev (masl)	Well Depth (m)	Screen Setting
W0000347-2	overburden	sandy cl, sand	555048	4889091	508.2	6.40	S 3.05-6.1
W0000347-3	bedrock	dolostone	555046	4889089	508.2	21.64	O 7.8-21.6
W0000421-1	bedrock	dolostone	553176	4877336	496.0	20.12	S 16.5-19.5
W0000505-1	overburden	sand	557901	4897462	516.7	14.6	S 12.16-15.0
W0000506-1	bedrock	limestone	557901	4897462	516.7	55.08	S 52.5-54.0
W0000507-1	bedrock	limestone	557901	4897462	516.7	77.38	S 76.0-77.4

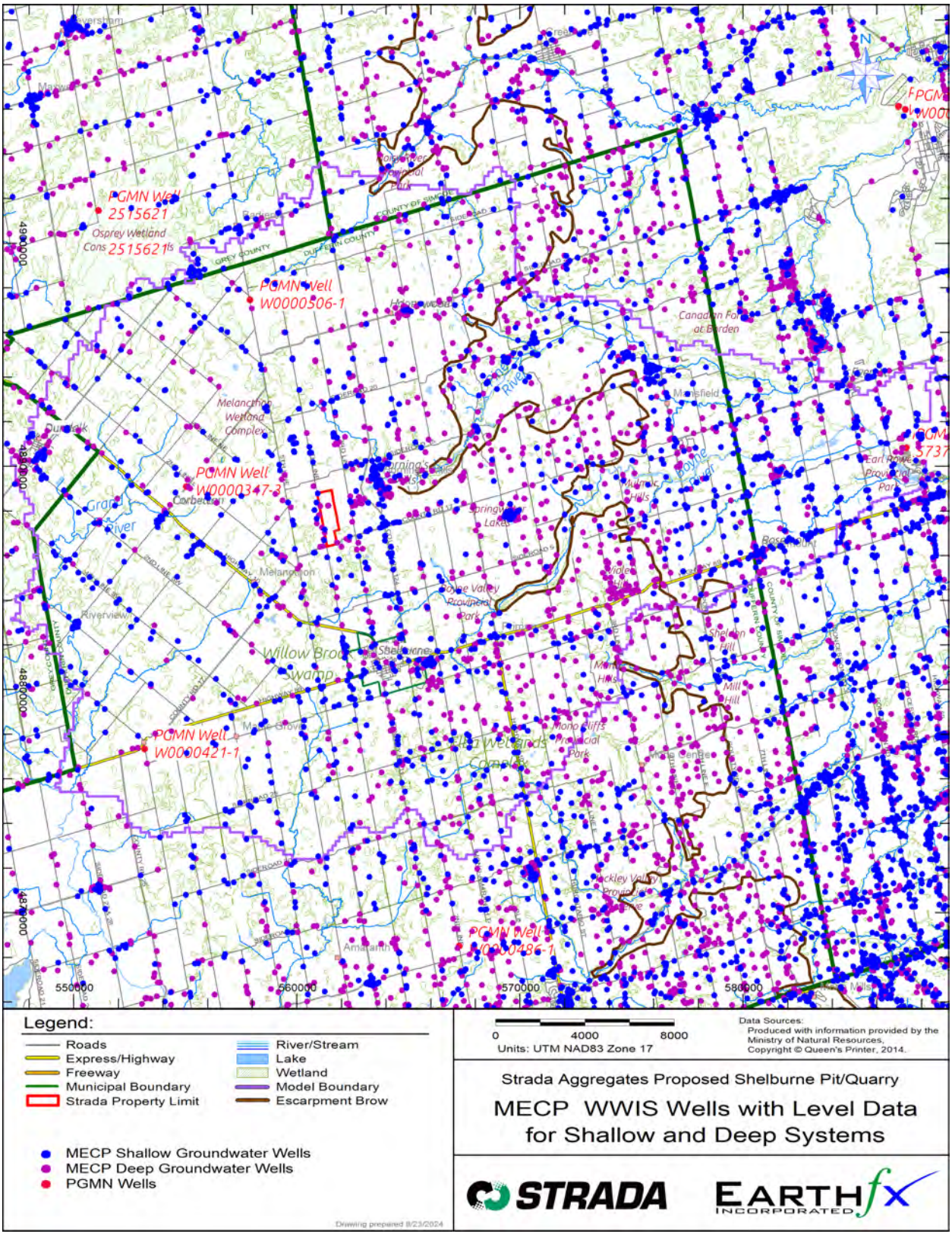


Figure 5.1: Location of MECP WWIS wells with static water level data for shallow and deep systems and PGMN wells with continuous groundwater level data.

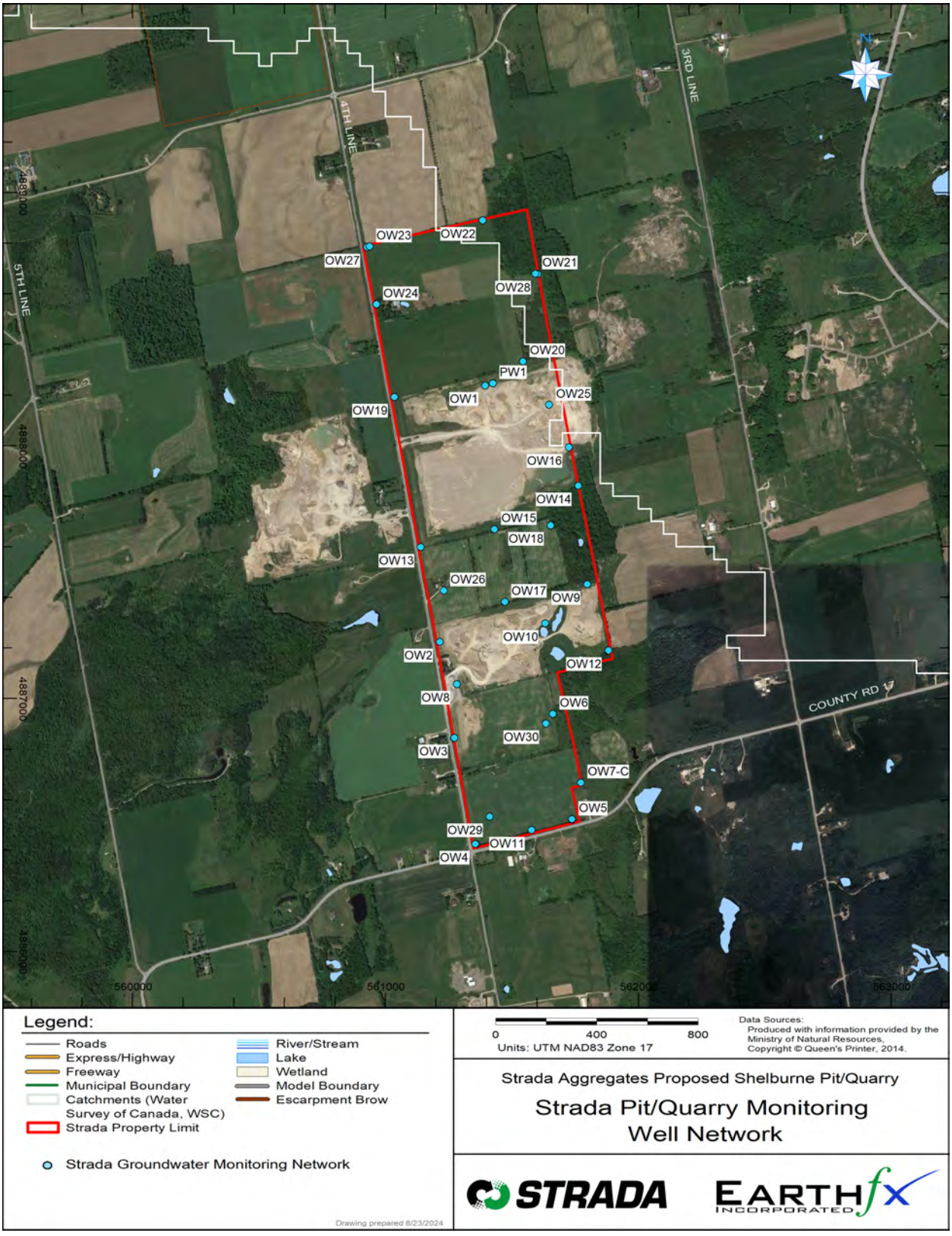


Figure 5.2: Location of wells in the Strada property groundwater monitoring network.

5.1.3 Strada Aggregates Monitoring Data

Strada Aggregates Inc. has been collecting water level data at and in the vicinity of their gravel mining operations located at their Shelburne property. Figure 5.2 shows the locations of the groundwater monitoring well network. Water level data include manual and datalogger measurements. The 49 monitoring locations provide comprehensive spatial coverage. In most cases, the data provide useful information on natural groundwater fluctuations. Well locations around the centre of the Strada property, where the active excavation of overburden materials has been ongoing since 2002, have likely been affected by the excavation and associated dewatering activities, but their data is useful for the purpose of understanding the local water level patterns and modeling. Long-term monitoring at variable distances from the centre of the site have also provided information on horizontal gradients (differences in water levels with respect to distance) across the property and vertical gradients (differences in heads with respect to depth) between shallow and intermediate aquifers.

5.2 *Regional Water Level Patterns*

Regional water level patterns were evaluated using the MECP WWIS static water level data, static water levels from other geotechnical and consultant wells, and average water levels from long-term water-level monitoring sites.

5.2.1 Data Screening

There are numerous problems that have been identified in the static water level data in drillers' logs submitted to the MECP and the data could not be used without some filtering. Sources of error include positional and depth measurement errors and questions as to whether static conditions were achieved prior to measurement. Seasonal and year-to-year water-level variations also introduce noise in the data which is very noticeable when analyzing clusters of water-level data. It is therefore uncertain whether a particular measurement in the data set is accurate and, even if accurate, whether it represents a reasonable measurement of an average water level at that point in time. The accuracy of maps produced from these data is similarly affected. However, the MECP WWIS data are the only data with sufficient spatial coverage to allow mapping of potentiometric surfaces over the entire study area and, it is important to note that, the water levels and the spatial trends observed in the mapped water level surfaces appear consistent and reasonable when obvious outliers are removed from the data.

The static water level data were analysed and the measurements were assigned to either the shallow or deep groundwater system based on the reported screened interval. The distribution of shallow and deep wells is presented in Figure 5.1. A shallow system designation was assigned to wells with a screen bottom at a depth of less than 20 m below ground surface (mbgs). Wells were assigned to the deep system if the top of the screen was greater than 20 mbgs. In general, the shallow groundwater system above the Niagara Escarpment is considered to correspond to the productive weathered bedrock/overburden interface and the water-bearing zones of the Guelph and Upper Eramosa formations (above the confining Lower Eramosa/Vinemount member), while the deeper system corresponds to the Goat Island/Gasport (Amabel) production zones.

It should be noted that, because of the discontinuous and non-uniform distribution of stratigraphic units across the site, the above categorization of units, as being of the shallow or deep system, is also subject to spatial variation. For example, in the eastern portion of the study area (above the Niagara

Escarpment), wells assigned to the deep system tend to reflect interstadial sand and gravel units atop glacial tills followed by coarse sands instead of the shallow bedrock. Despite the spatial variability, the approach taken here helped develop a reasonable representation of regional flow patterns and vertical gradients across the study area.

The water-level data were interpolated using a geostatistical technique known as “kriging” to determine general patterns of groundwater flow. Kriging is a weighted-averaging interpolation method that attempts to minimize variance and bias in the results while honouring the local values at the data points. Figure 5.3 through Figure 5.6 show the results of the kriging of the static water levels in the shallow and deep groundwater systems, respectively, at both regional and local scales. The variogram used in the kriging process of these two datasets required a nugget value of 3.5 and 18, which their squared root determine, in turn, the mean error in the measurements of groundwater levels at shallow and deep MECP datasets: 1.87 m and 4.25 m.

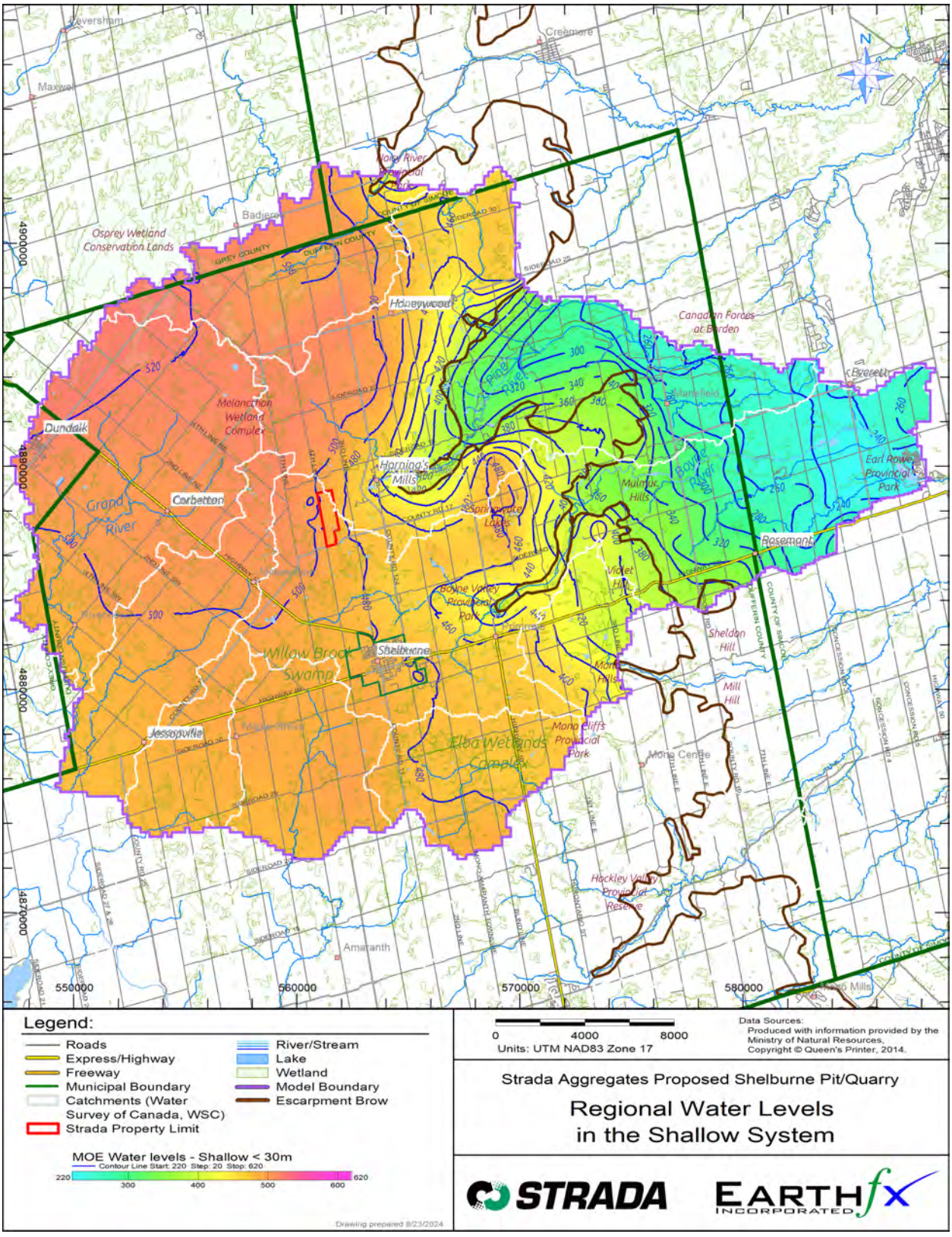


Figure 5.3: Interpolated water levels (masl) in the shallow groundwater system at the regional scale.

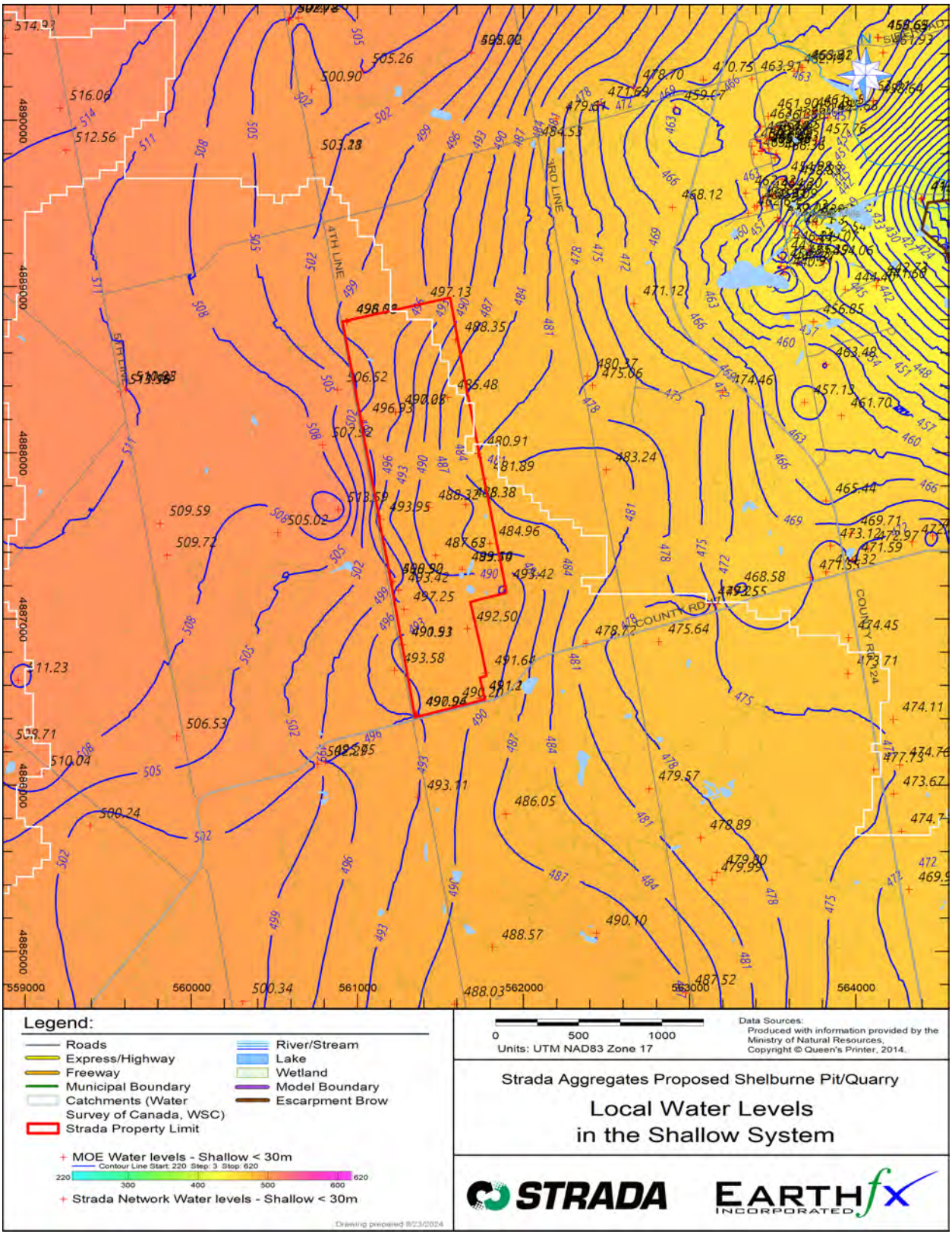


Figure 5.4: Interpolated water levels (masl) in the shallow groundwater system at the local scale.

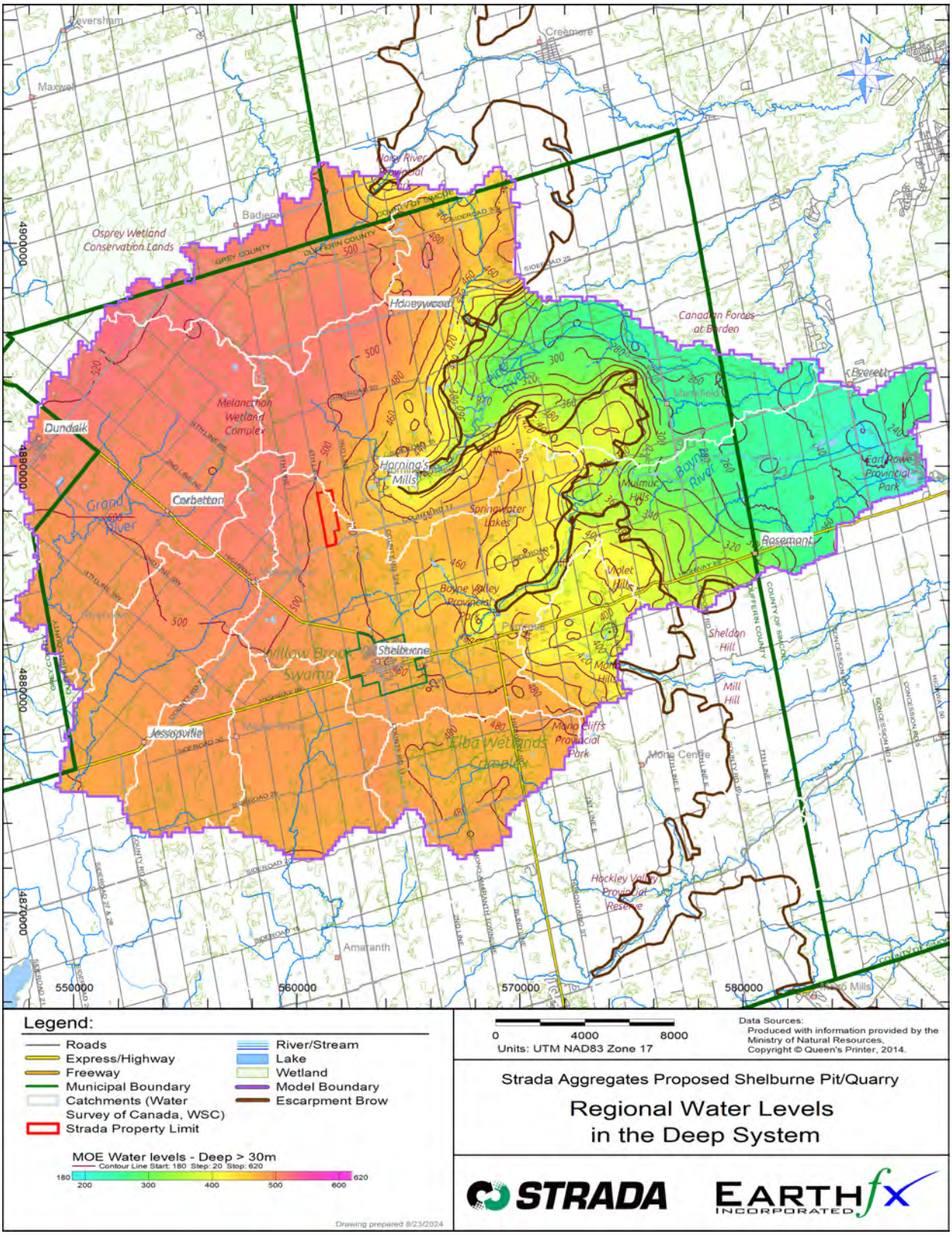


Figure 5.5: Interpolated water levels (masl) in the deep groundwater system.

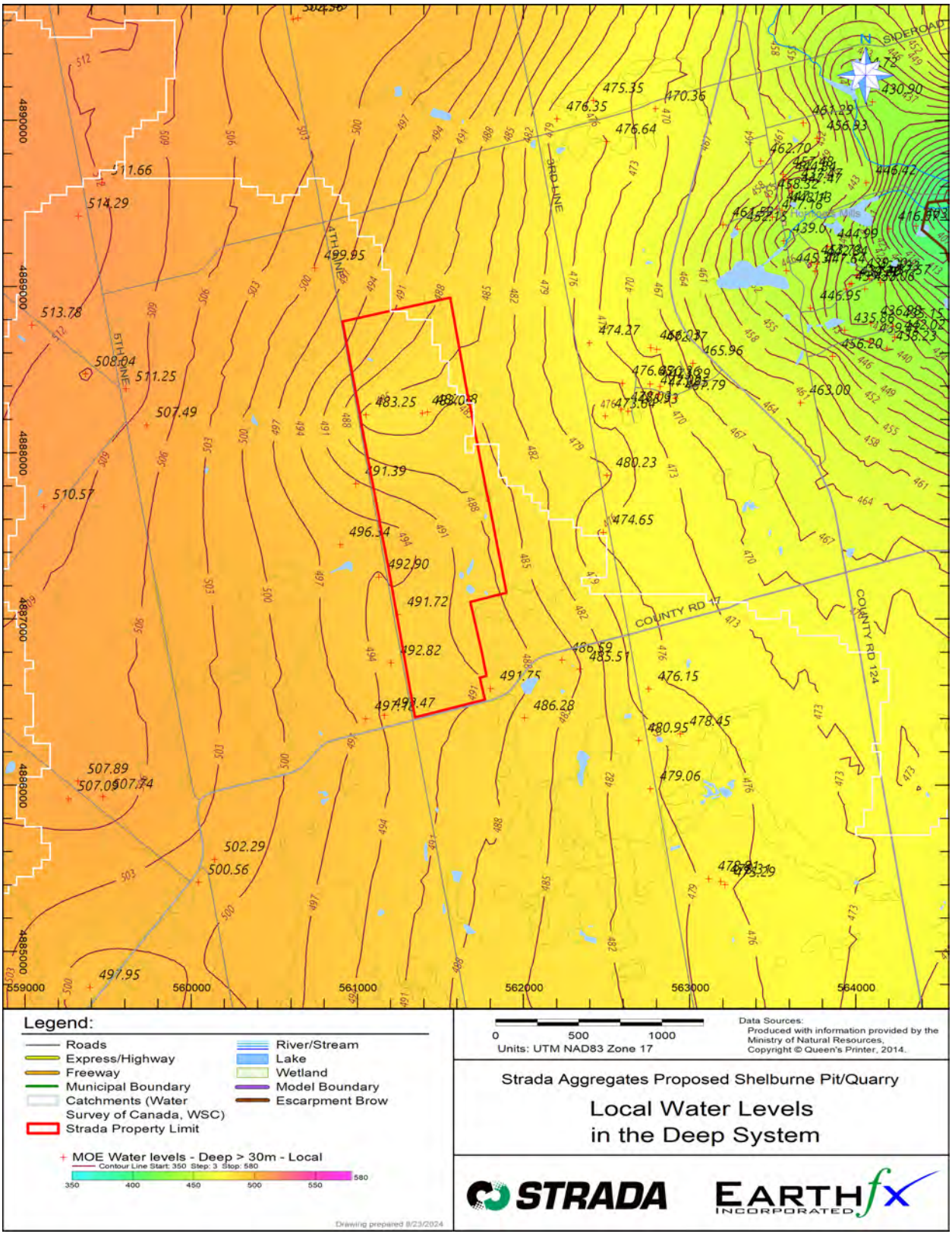


Figure 5.6: Interpolated water levels (masl) in the deep groundwater system at the local scale.

5.3 *Regional Trends*

A total of 1,459 water level observations were interpolated for the shallow system within the model grid. Available static water levels from MECP well records are sparse in some areas above and below the escarpment (Figure 5.1). An average of the recorded water levels at each MECP well was used to create these figures. The highest water level elevations in the shallow groundwater system, over 520 masl, were observed in the northwest portion of the study area in the vicinity of the Osprey Wetland Conservation area; lowest water levels in the shallow groundwater system above the Escarpment are approximately 380 masl. Lower water levels are found below the Niagara Escarpment with a transition zone occurring within the unconsolidated sediments that bury the brow of the escarpment. The change in water levels is steeper in the Pine River re-entrant than near the Boyne River re-entrant. The lowest water levels are observed at the eastern model boundary with values of 216 masl.

Water level contours indicate that regional groundwater flow patterns above the Niagara Escarpment are dominated by a southward trend on the western portion of the model area and by an eastward trend (toward the Niagara Escarpment) in the eastern portion of the area. The Strada property lies along the line between these two trends, with flow mostly towards the east across the site.

The interpolated water level map for the deep groundwater system used a total of 3,271 locations within the model grid. The highest water levels in the northwest of the study area exceeded 523 masl. The lowest water level above the escarpment was about 380 masl and about 200 masl near the Town of New Tecumseth below the Niagara Escarpment. The deep groundwater system has a similar, although more subdued, flow pattern (Figure 5.5) with southward regional flow to the west and eastward flow in the eastern part of the area above the Niagara Escarpment.

Sand and gravel mining operations are present along 4th Line north of County Rd. 17, including the Strada Aggregates property on the east and the Duivenvoorden Haulage Ltd. Site on the west. Ponds on the site and water use for aggregate washing may locally depress groundwater levels. The pond at the Duivenvoorden Property is maintained at about 511 masl and is located adjacent to the Melancthon Wetland Complex in the northwest. The pond at the Strada site had a water surface elevation of 503 masl.

5.4 *Local Trends*

The shallow potentiometric surface across the Strada site follows a northwesterly direction with a uniform slope towards the Niagara Escarpment where it reaches a sharp slope (Figure 5.4). The topography at and around the Strada site dictates that the surface water system is mostly within the Boyne River catchment. The shallow potentiometric surface departs from this assumption by directing groundwater flow to the Pine River catchment instead. South of the Strada property, the contours indicate that the groundwater flow follows a southwesterly direction towards the Pine River re-entrant.

The water levels in the deep system show a more variable flow pattern (Figure 5.6) compared to the shallow system. The number of wells shown in Figure 5.6 indicates that the bedrock system is the preferred source of groundwater supply in the study area. The impact of the historical excavation at the Strada pit/quarry is also captured by this averaged water level contours. A water elevation in the deep system of 485 masl extends flat around the centre of the Strada property. Extraction activities in the Duivenvoorden Haulage Ltd. site have also left a mark on the temporally averaged water levels.

5.5 *Transient Groundwater Levels*

Transient water levels provide information on the response of the groundwater system to changes in hydrologic forcings at both short and long temporal scales and within the different hydrostratigraphic units. A temporal analysis also looks into the celerity of the pressure response between aquifer units and provides insight into the storage properties of the aquifers and intervening aquitards. The vertical response, or the lack of it, through the hydrostratigraphic system, takes into account the intensity of the stress, the timing, and the celerity of the hydrologic forcings as it moves through the units.

The hydrologic forcings can be either naturally occurring, through changes in weather (e.g., storm events) or in climate (seasonal response, response to extreme wet and dry years, or long-term climate change)) for short- or long-term analysis, respectively, or artificially created by pumping wells for commercial, agricultural, domestic, or municipal water usage. Figure 5.7 shows the location of groundwater monitors with transient data in and around the Strada property. Groundwater monitoring started in the early 2000's at the Strada Aggregates site contributing to a database that spans nearly 20 years. Hydrographs for selected wells are shown in Figure 5.8. Different monitoring programs with different time spans are included in this time series.

5.5.1 Operational Record of Strada's PW1

The groundwater level record for production well PW1, located near the centre of the Strada site, provided data used in the transient calibration of the groundwater model. The PW1 time series spans from January 2008 to December 2012 and provides insight on seasonal changes in groundwater levels in addition to the water level fluctuations generated by daily pumping (Figure 5.9). Figure 5.9 shows the PW1 water level record for the year 2009, together with observations at neighbouring wells. Of note is the recovery of wells when pumps are shut down at the end of the day, for the weekend, and for longer periods. The pumping rate for PW1 during the period of transient analysis, which covered the first week of June, was 137 m^3/d. No monitoring location presented in Figure 5.9 exhibited a response to pumping, except for OW1 (34 m away).

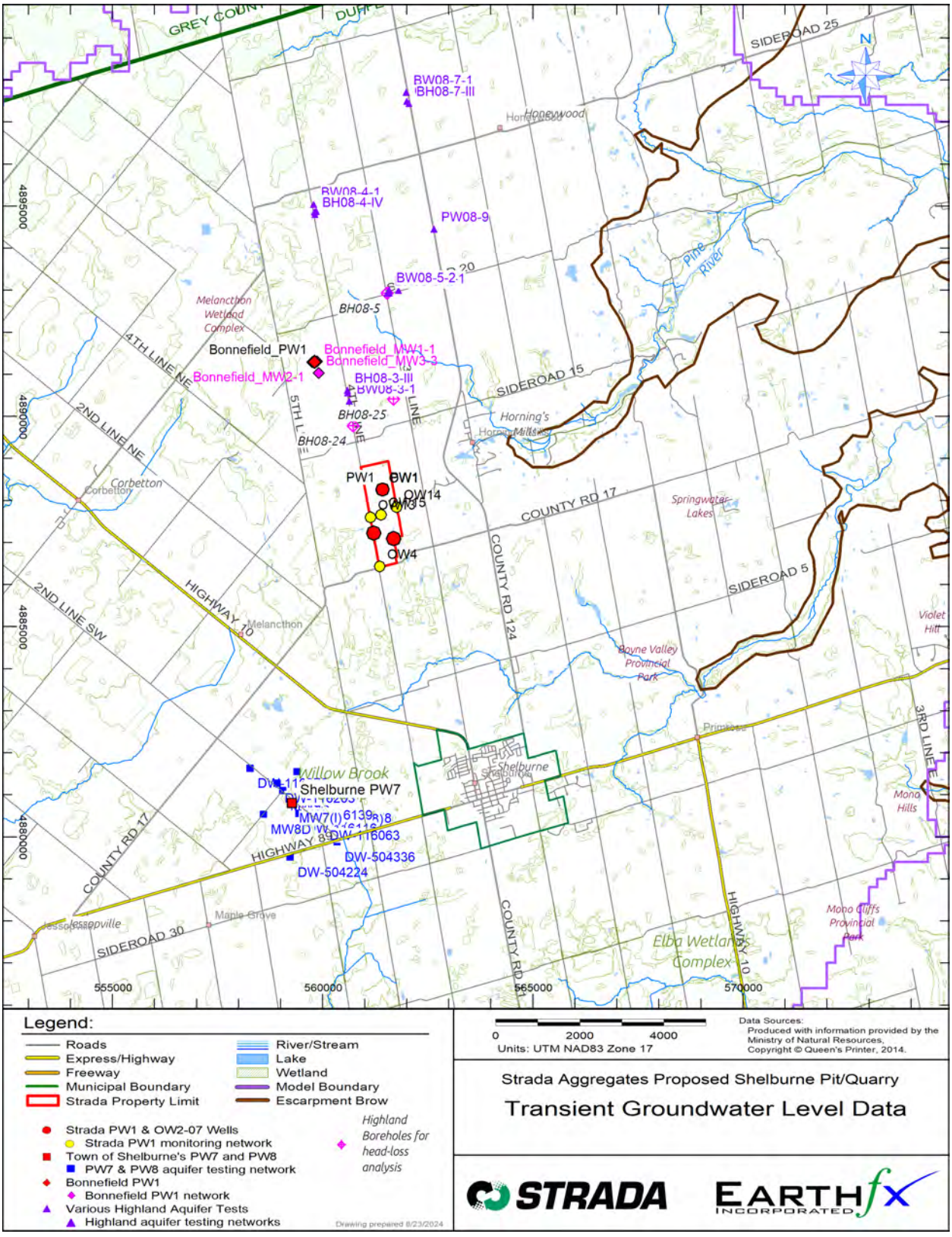


Figure 5.7: Locations of monitors with transient groundwater level data.

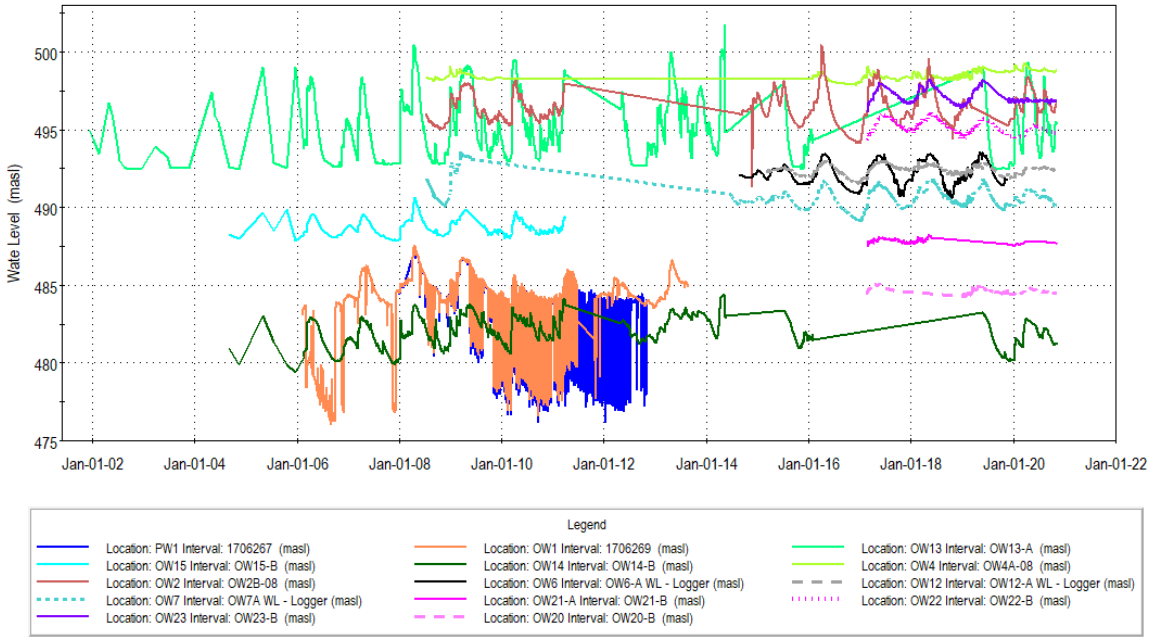


Figure 5.8: Hydrographs for select wells showing the transient groundwater level data collected within the Strada Aggregates site.

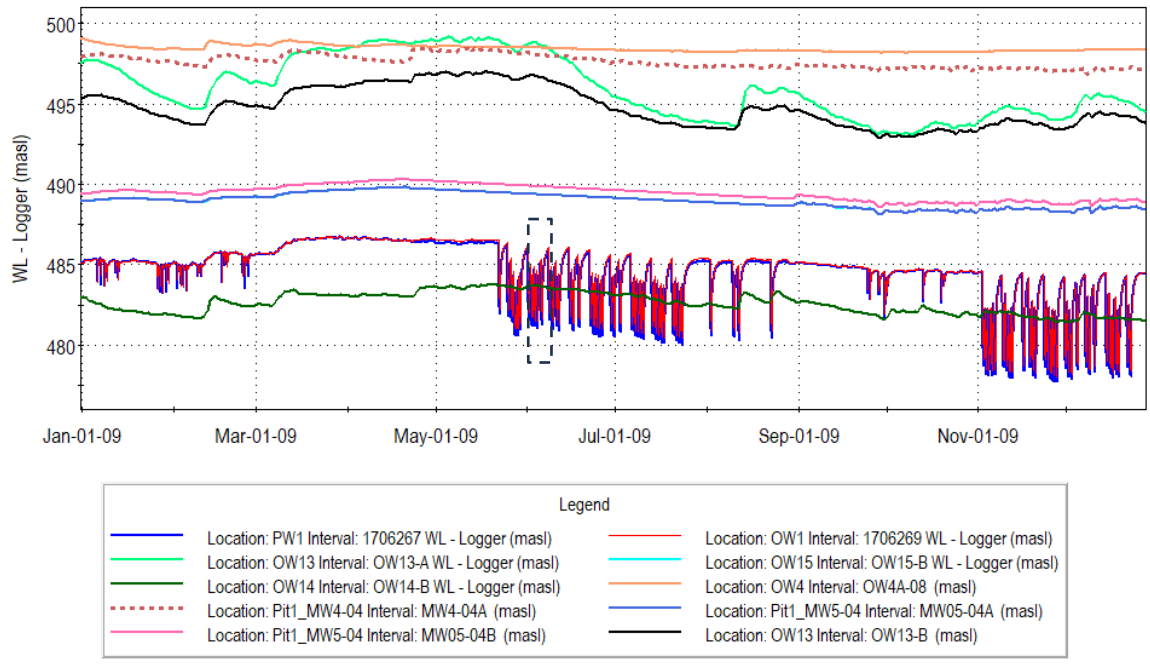


Figure 5.9: Water level record for PW1 at the Strada site and for neighbouring monitors used for transient modeling. Period of analysis for transient modeling is indicated by the dashed box.

Other monitors in Figure 5.9 responded to seasonal change and to storm events rather than to pumping at PW1. For example, water levels at OW13 rise before March, as in response to seasonal recharge and then dip at the end of June as groundwater discharge to streams ceases. The second closest monitoring location is at Pit1_MW4-04, at a distance of 190 m, screened on gravel and sand material just above the bedrock, and on the weathered bedrock. Water levels at this location show a very muted feedback to seasonal change but do not fluctuate in response to pumping at PW1. Observed drawdowns are the typical calibration targets for model calibration; however, a lack of response (no drawdown) can still be used as a calibration target, although to a limited extent.

5.5.2 Shelburne's PW7 & PW8 Aquifer Testing

Earthfx was retained in 2022 to update the wellhead protection areas (WHPAs) for the Town of Shelburne's wellfield (Earthfx, 2022). As part of that effort, a multi-level aquifer test was carried out for a period of 7 days with the deeper wells, Shelburne PW7 and PW8, pumping at maximum permitted capacity. The observed multi-level response and the results of a transient model simulation are presented in Figure 5.10. A significant head gradient across the Niagara Formation was observed at this location during pumping. Under normal operating conditions, the head loss between the Goat Island and the Gasport is approximately 10 m, but at maximum permitted capacity for both PW7 and PW8, the head loss grew an additional 23 m. During shut-off times the head loss recovered to half a metre. This great variability is representative of an aquitard with a significant number of fractures that during the periods of no stress heads equilibrate rapidly, and during stress conditions the effects of a leaky confined aquifer become evident.

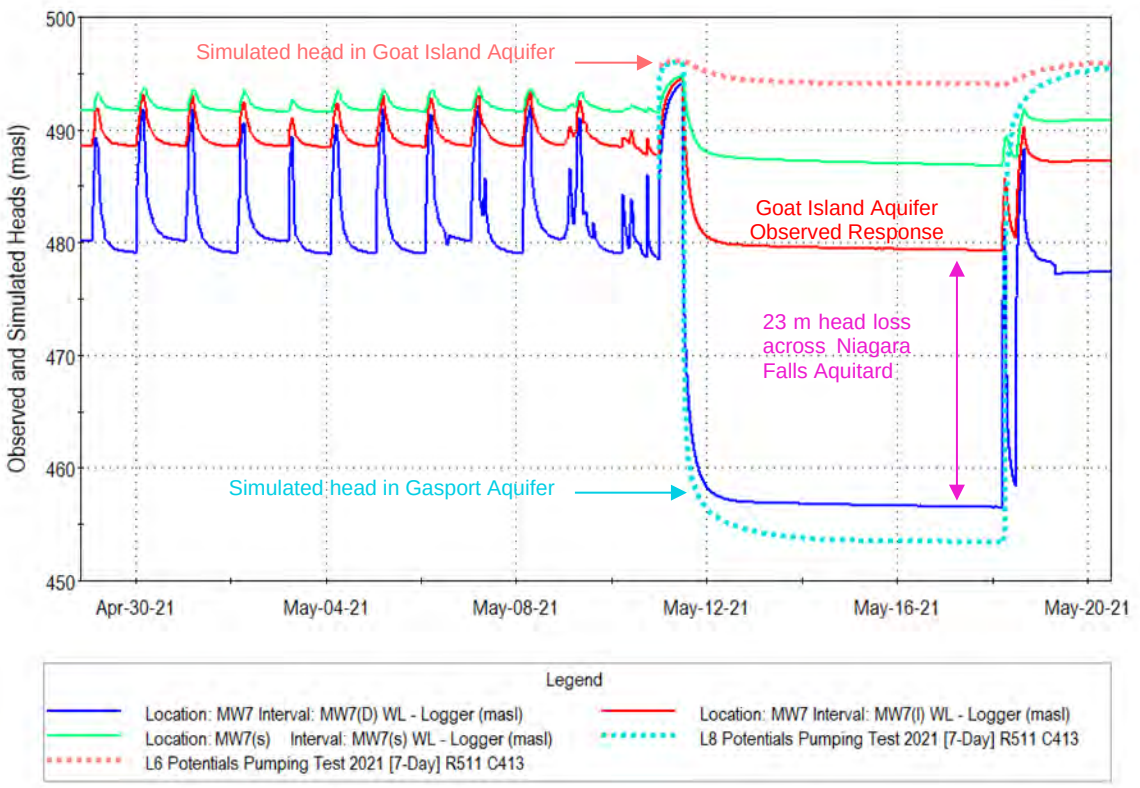


Figure 5.10: Observed and simulated heads during 7-day aquifer test in Shelburne PW7 and PW8 pumped at 1,633 m^3/d (Earthfx, 2022).

5.5.3 Strada's OW2-07 Aquifer Test

This aquifer test was performed at OW2-07 (formerly known as MW2-07) within the Strada property in May 2007 (Goffco Ltd., 2007). Well OW2-07 is 72 m deep open-hole well that intersects all the bedrock formations below the Tavistock till until the Cabot Head Formation. Figure 5.11 shows the response of the composite water levels from all the intersected bedrock units. A drawdown of approximately 40 m was observed after 130 minutes of pumping at 28 L/min with a submersible pump installed at 61 mbgs. This drawdown is indicative of an extremely tight hydrogeological unit, typically associated with an aquitard.

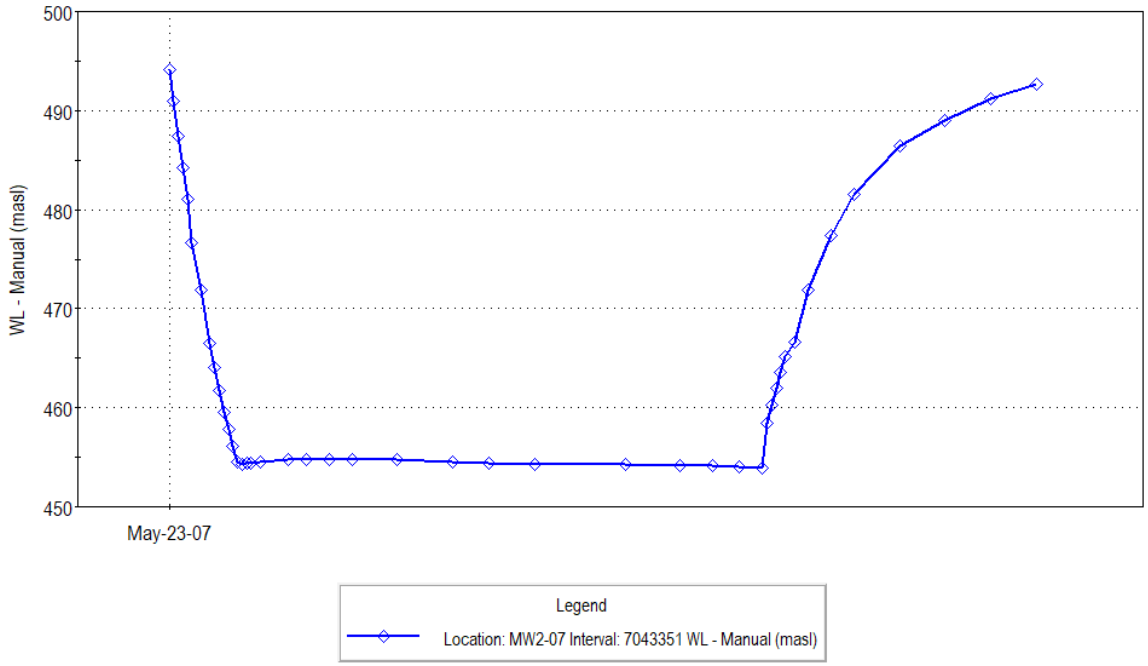


Figure 5.11: Recorded water levels during aquifer test at OW2-07.

5.5.4 PGMN Groundwater Wells

As stated previously, another source of transient data is provided by PGMN wells in the area. Their locations are presented in Figure 5.1. There are three PGMN wells close to the Strada property and they are spread from north to south in the western portion of the model area. Well construction data are provided in Table 5.1. The northernmost (W0000505 through W0000507) has three monitoring locations at different depths, with the deepest one screened in the Gasport Fm. The middle cluster (W0000347-2 and W0000347-3) has an overburden well and an open-hole to the shallow bedrock. The southernmost well is another shallow bedrock well. Water levels at the northern location indicate that the head loss between shallow, intermediate, and deep systems is a fraction of a metre.

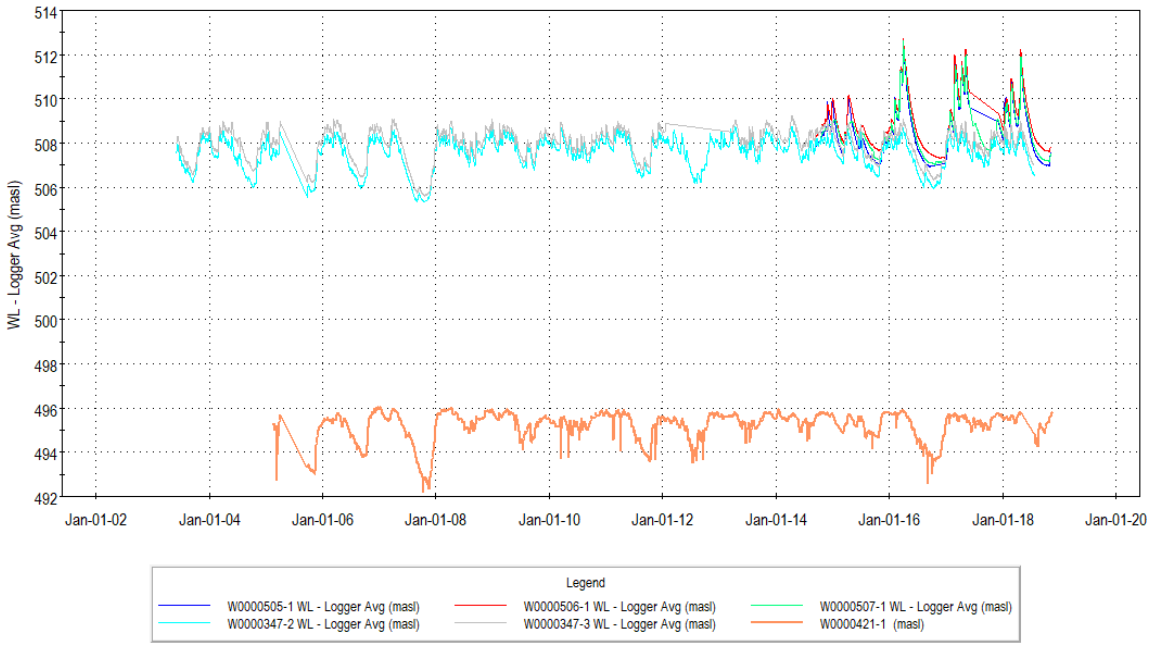


Figure 5.12: Transient groundwater levels measured at PGMN wells within the model area.

5.5.5 Bonnefield GP III PW1 Operation

The operation schedule of the agricultural Bonnefield PW1 well provides pertinent information on the groundwater system response to pumping (Figure 5.13) (Whitewater Hydrogeology, 2013). This well is located 2.5 km north of the Strada site (Figure 5.7). Water levels were also monitored at four neighboring sites during 2013. Bonnefield PW1 is an 88.4 m deep borehole. It was constructed as an open-hole well intersecting bedrock formations from the Guelph to the top of the shale. There are natural differences in head between the monitoring wells due to differences in location, depth, and well construction, however, all respond to pumping at PW1 to varying degrees. The drawdown response was simulated and used to assess the degree of local connectivity of the bedrock units.

Initial static levels on the time series of the monitoring locations were not available for this time period. They were extrapolated from another section of the time series where no active pumping was taken place. Considering that the major contribution of this dataset lies on the drawdown exerted during pumping at the monitoring locations, this extrapolation will not have an effect on the interpretation of the response.

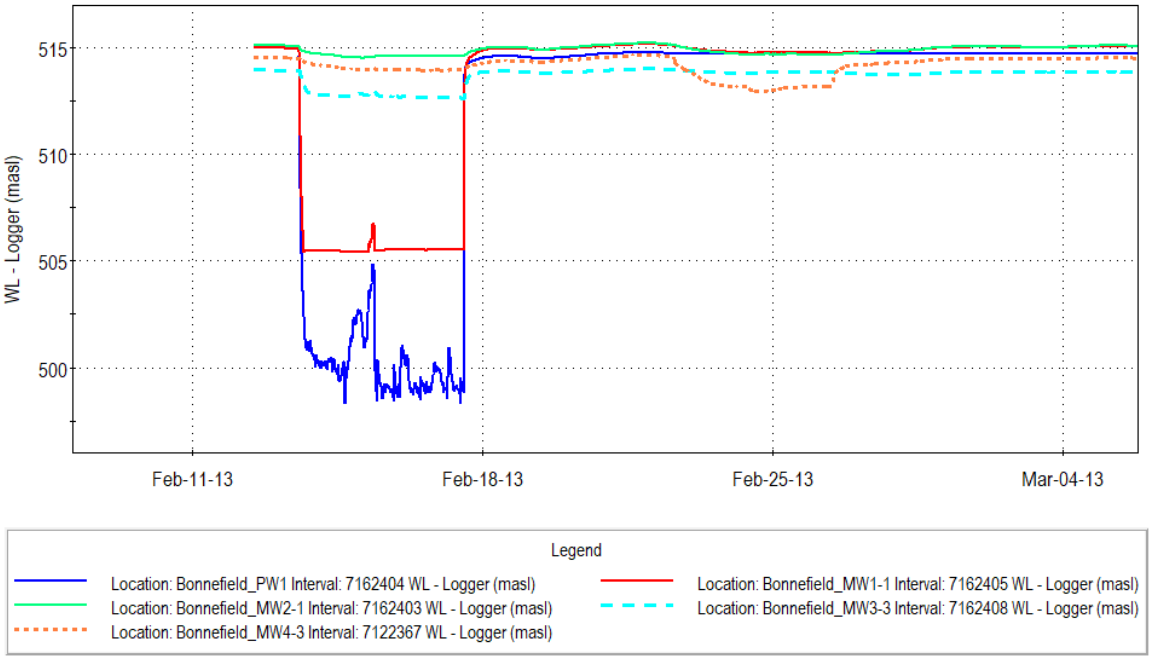


Figure 5.13: Groundwater levels during operation of Bonnefield PW1 at the pumped well and at neighboring monitoring locations.

5.5.6 Highland Transient Data of Interest

Several pumping tests were performed at different well clusters within the Highland Properties (Figure 5.7). Despite the tests being of short in duration, with some caveats in the way they were conducted, and with some of them are at a considerable distance from the Strada site, they still can provide some insights on the spatial variability in the hydraulic properties of the bedrock units. Table 5.2 presents a list of pumping tests that were analyzed in this study (Genivar Inc., 2011). These pumping tests were carried out during a three-week period in 2008, and their time series are plotted in Figure 5.14.

Table 5.2: Pumping tests performed at the Highland property.

Aquifer Test Location	Pumping Rate (L/min)	Date	Duration (hr)
PW08-3	13	9/22/2008	72
PW08-4	202	9/29/2008	71
PW08-5	83	4/21/2009	44
PW08-9	13	10/6/2008	1

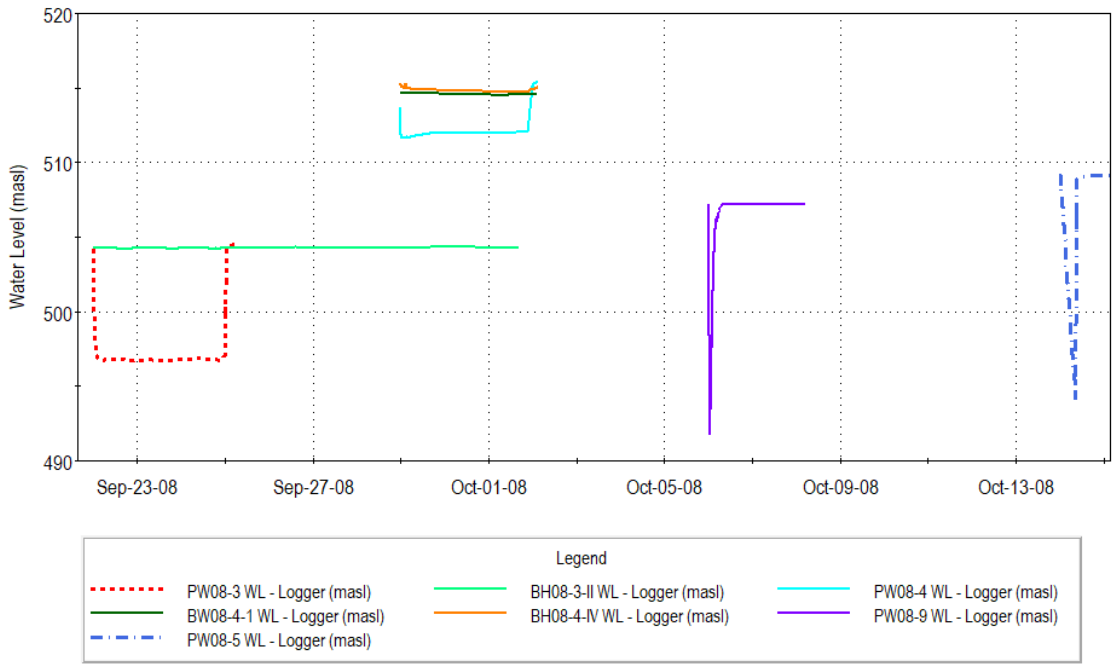


Figure 5.14: Transient groundwater levels collected from aquifer tests performed at the Highland properties.

Other transient data collected at the Highland properties are of relevance for the information they provide on head loss across the aquifer units (Figure 5.7). The multi-level time series at the boreholes BH08-5, BH08-24, and BH08-25 are presented in Figure 5.15 through Figure 5.17. In these figures, monitors labeled as I, II, and III refer to shallow, intermediate, and deep units, respectively. Monitors at these locations intersect different aquifer units:

- BH08-5: the Goat Island and Gasport units,
- BH08-24: intersects the till, weathered bedrock, and Gasport units, and
- BH08-25: intersects the overburden, Goat Island, and Gasport units.

These time series and spatial distribution offer an insight of the effect that proximity to the Niagara Escarpment has on the water levels. Upward groundwater heads are clearly seen in BH08-5 and BH08-25 where water levels in the confined Gasport remain elevated while the shallow water levels have dropped due to proximity to the Escarpment. While water levels in BH08-24 from three monitoring depths are intertwined at different snapshots in time, with no clear pattern.

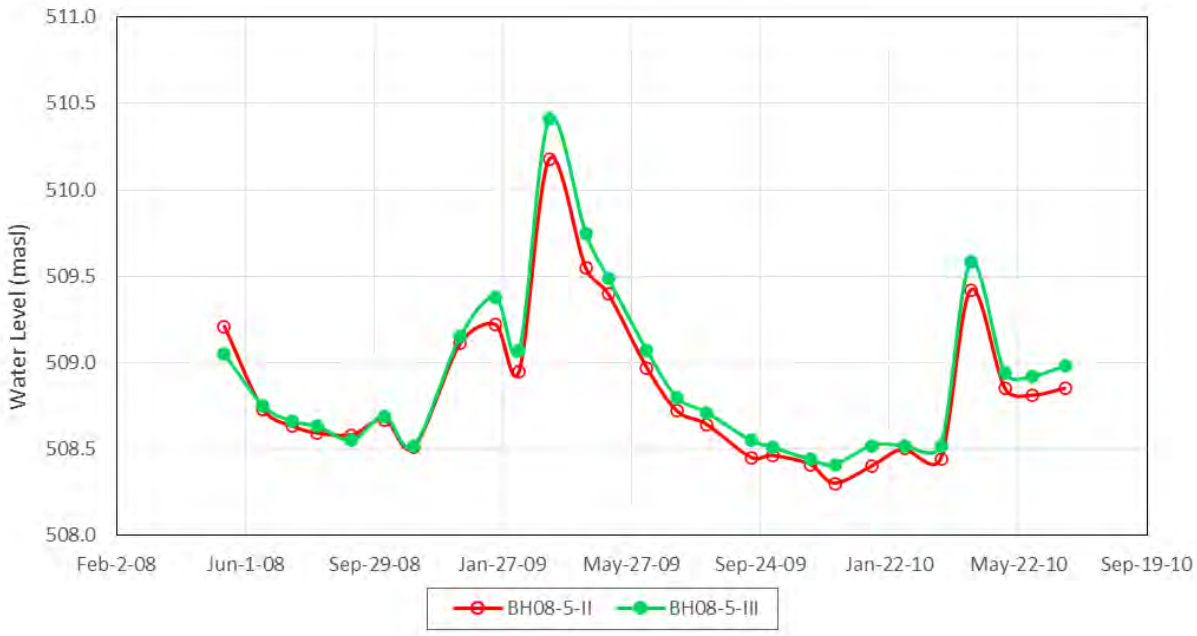


Figure 5.15: Water level time series at multi-level borehole BH08-5 at the Highland property.

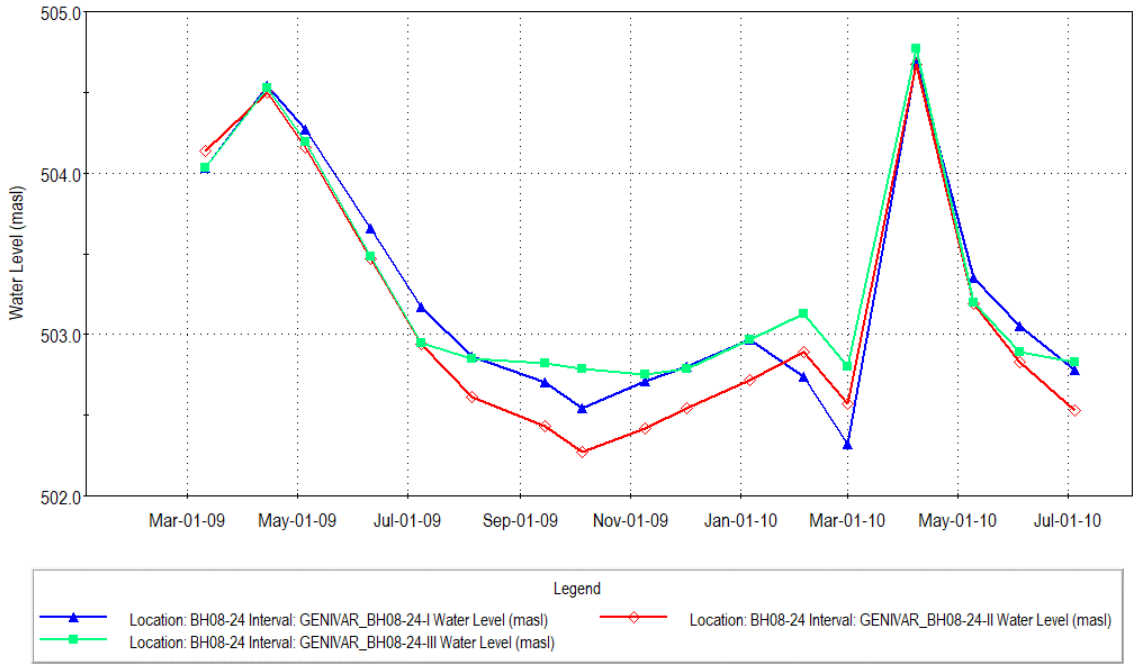


Figure 5.16: Water level time series at multi-level borehole BH08-24 at the Highland property.

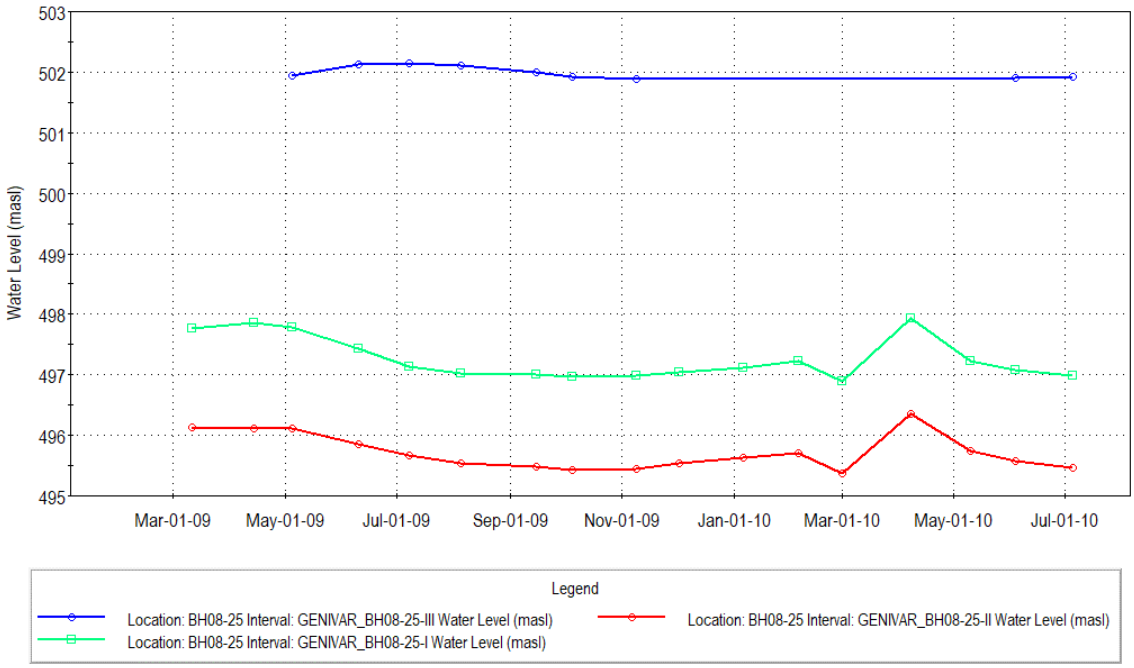


Figure 5.17: Water level time series at multi-level borehole BH08-25 at the Highland property.

6 Groundwater and Surface Water Takings

Quantifying the use of surface and groundwater within the study area is important for assessing the overall water balance. Municipal water use is, overall, a small component of the overall water demand in the study area but it needs to be considered along with other large permitted water takers and numerous distributed smaller water users.

Assessing water use is a complex task. The reporting of water use is somewhat sporadic and frequently inaccurate. The MECP Permitting and Water Taking Reporting Systems have undergone significant changes in recent years, in some cases making assessment of historic use more difficult because of changes in the permitting system. Actual use is frequently lower than the maximum permitted taking, and can vary on a seasonal basis. Finally, estimating the consumptive portion of the taking can be difficult, however general guidelines are available for estimating consumptive use by industry or type of taking (e.g., MNR, 2011).

6.1 *Permitted Takings*

Groundwater and surface water are extracted from the aquifers, streams, and lakes in the study area for communal water supply, agricultural use, commercial and industrial use, golf course irrigation, and private (domestic) water supply (Figure 6.1). Extraction of over 50,000 litres of water per day (L/d) from a surface or groundwater source requires a Permit to Take Water (PTTW) from the MECP. Permits are designated as surface water, groundwater, or both.

The locations of 20 permitted groundwater takings (not including quarry takings) from the 2012 PTTW database are presented in Figure 6.1, along with their maximum allowable daily takings. Permit location data, maximum permitted groundwater takings, and historical average takings for the calibration period (2007 to 2012) are listed in Table 6.1. Maximum rates in the study area range from 52 m^3/day to 50,406 m^3/day.

Actual water use rates are generally less than the permitted water takings. The Water Taking Reporting System (WTRS) database, maintained by the MECP, contains self-reported information on actual takings. Data for municipal wells are generally complete. Some known problems exist with the database for non-municipal pumping due to changing permit numbers, incomplete records, backlogs in the transcription of paper records, and non-compliance with reporting requirements. A subset of the WTRS data for 2007 to 2012 was used in this study due to the paucity and inconsistencies in the data prior to 2007. For takings where no historical reported rates could be found, it was conservatively assumed that pumping rates were at their maximum permitted daily value.

No provincial updated PTTW or WTRS data was made available for the Shelburne Source Water Protection update study (Earthfx, 2022). For example, some golf courses in the area are not listed.

Permits for pumping tests are not included in this analysis because they were likely issued on a temporary basis. In the case of expired permits, an effort was made to identify whether the permit was renewed under a different PTTW number; this was conducted by reviewing the Environmental Registry, maintained by the MECP, and by reviewing the WTRS database for on-going reporting beyond the stated permit expiration date. Expired permits that were found to be discontinued were not included in model simulations.

Table 6.1: Groundwater permitted takings for steady state calibration.

Permit Number	Well Name	Screen Depth (mbgs)	Easting	Northing	Water Use	Max. Permitted (m^3/d)
6653-A7BND2	Bonnefield GP III Inc. (PW1) (60/24)[1]	88.4	559810	4891295	Agricultural	3273
6653-A7BND2	Bonnefield GP III Inc. (PW2) (60/24)	89.9	559714	4891209	Agricultural	2304
4244-7NVLRZ	Home Farm #1 (D&C Vander Zaag Farms) (93/24)	63.7	562330	4894162	Agricultural	2937
0746-7NVMQ7	Ferguson Farm #1 of 3 (D&C Vander Zaag Farms) (93/24)	68.3 31.7 31.7	560811	4894742	Agricultural	2937
7114-9PELZR	Atkinson Farms (Dugout Pond 90/24)	42.7	559619	4896512	Agricultural	5237
2306-AK2N8H	D&G Ferguson Farms Ltd (Stewart Pond 60/20)	31.1	559642	4897046	Agricultural	2040
2773-9G2RXX	Gott Enterprises Inc PW2 and PW3	42.0 78.6	564663	4876678	Commercial	327
2773-9G2RXX	Gott Enterprises Inc PW4	42.9	564632	4876687	Commercial	327
0580-78PPS2	PW1 Strada Property	48.8	561426	4888258	Industrial	164
1814-7QVK7S	Shelburne PW1	23.5	564361	4880947	Municipal	1642
1814-7QVK7S	Shelburne PW3	18.6	563053	4881667	Municipal	1309
1814-7QVK7S	Shelburne PW5	23.5	562391	4880659	Municipal	982
1814-7QVK7S	Shelburne PW6	24.4	562395	4880659	Municipal	982
1814-7QVK7S	Shelburne PW7	86.5	559266	4880808	Municipal	1634
1814-7QVK7S	Shelburne PW8	86.6	559274	4880797	Municipal	1634
1554-9FDJ6A	Township of Mulmur PW1 (Mansfield Water Supply)	33.2	576808	4891253	Municipal	327
1554-9FDJ6A	Township of Mulmur PW2A (Mansfield Water Supply)	45.4	577009	4890641	Municipal	262
1554-9FDJ6A	Township of Mulmur PW3 (Mansfield Water Supply)	56.6	577735	4891325	Municipal	363
6567-8NWMQP	Hamlet of Rosemont PW1A	30.5	580926	4886101	Municipal	33
6567-8NWMQP	Hamlet of Rosemont PW3A	22.9	581229	4886411	Municipal	52

[1] (X/Y): indicates number of days allowed for pumping per year (X), and number of hours per day (Y)

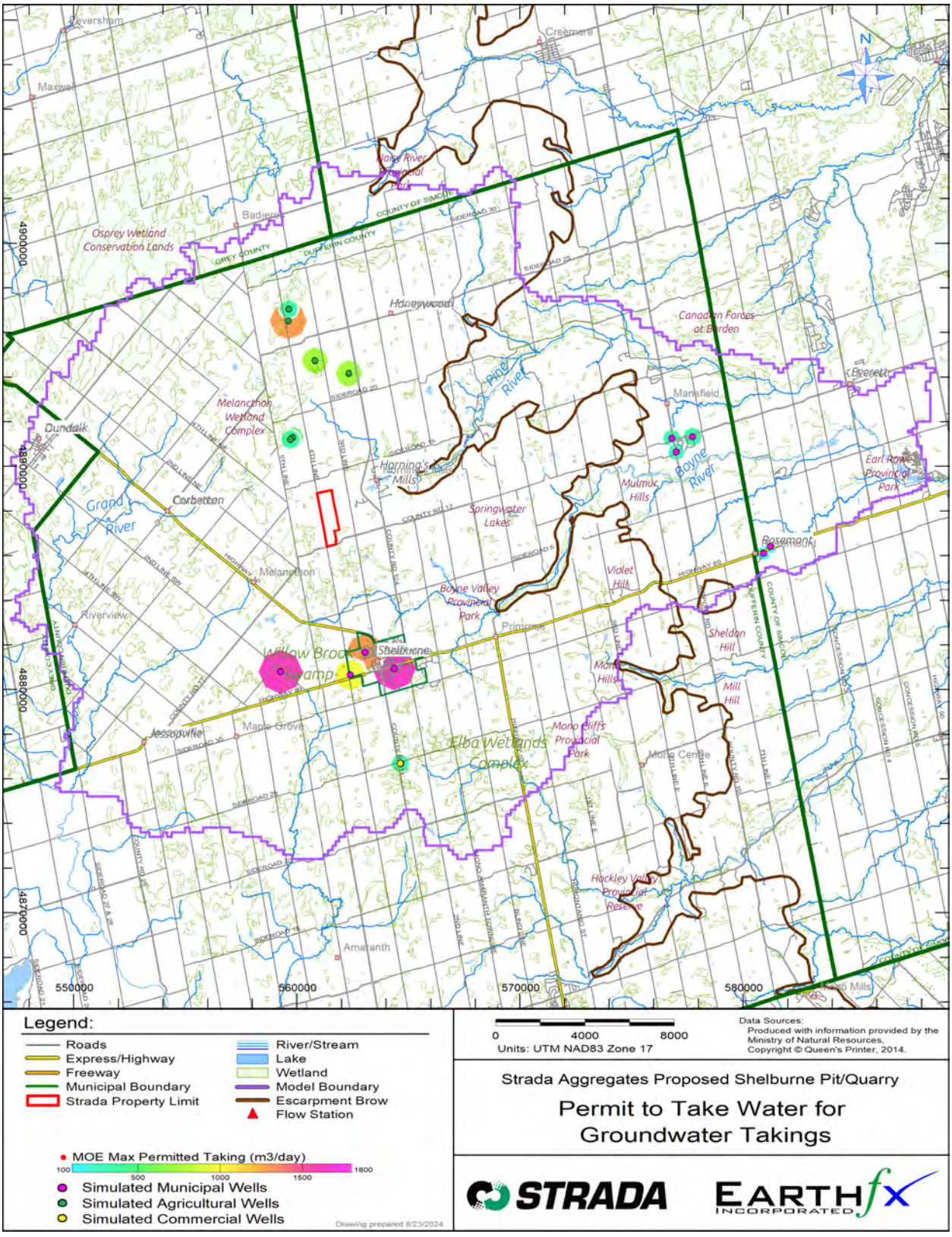


Figure 6.1: Maximum permitted takings of simulated groundwater wells and their water usage.

Withdrawals for permitted, non-municipal groundwater takings were assigned to the appropriate model layer based on the placement of the well screen (where known or reasonably estimated). The Water Budget and Water Quantity Risk Assessment Guide (MNR, 2011) provides consumptive use factors for different usage classes and sub-classes. Consumptive use was determined by multiplying the estimated takings by consumptive use factors that account for the return flow of water back to the aquifer from which they were extracted.

6.2 *Municipal Water Supply*

The wellfields for the Towns of Shelburne and Mulmur together with the Hamlet of Rosemont are included in the model area. The Town of Shelburne's production wells serve approximately 8,126 residents. Four existing supply wells are connected to three pump houses situated proximal to the East (PW1), North (PW3), and West (PW5 and PW6) wellfields. In 2012, a fifth well (PW7) was installed to address the Town's expected supply concerns and to secure a groundwater source with lower arsenic levels. Well PW8, located near PW7, was added in 2014. Both wells target the deeper Gasport aquifer unit, which is considered to have more desirable formation water chemistry than the shallower Guelph/fractured bedrock contact aquifers. The entire wellfield operates under MECP PTTW #1814-7QVK7S.

The Mansfield municipal water supply system consists of three production wells, PW1, PW2, and PW3 (R.J. Burnside & Associates Ltd, 2010a), permitted under MECP PTTW #1356-6NMMU3. They are located at the intersection of Airport Rd and Country Rd 17. Intermediate and deep aquifer units are used as water source for these wells, characterized by unconsolidated materials of gravel, sand, clay, and coarse sand. As of March 2023, this water supply system has approximately 153 service connections. It is owned by the Township of Mulmur and operated by Dufferin Water Co. Ltd (Dufferin Water Co. Ltd, 2023).

The Rosemont water supply system consists of two wells, PW1A and PW3A and services a population of approximately 280 people (R. J. Burnside & Associates Ltd, 2010b). The production wells are completed in the gray shale bedrock as open hole, and in the case of the PW3A, the shale is preceded by a sequence of sand and gravel with some clay. The shale intersected by these wells is that of the Queenston Formation. The Mansfield and Rosemont water supply systems are both located below the Escarpment.

6.3 *Agricultural and Commercial Water Usage*

The main agricultural water usage is located above the Niagara Escarpment, north of the Strada Property, and owned by Bonnefield GP III Inc. and D&Z Vander Zaag Farms Ltd. Their usage is limited to a fixed number of both days per year and hours per day. They can be used for 48 and 93 days in a year for a maximum of 15 and 24 hours per day, for the Bonnefield GP III Inc. and D&Z Vander Zaag Farms Ltd wells, respectively.

Gott Enterprises Inc. commercially bottles water under an MECP PTTW through three active wells. This company is located south from the Town of Shelburne at the intersection of County Rd 11 and Sideroad 25. They are permitted to take a maximum volume of 327 m^3/s throughout the year, 24 hour a day.

For the purpose of evaluating the impact of the agricultural wells under steady state conditions, their maximum pumping rate is factored by the number of days they are allowed to pump per year.

Commercial takings are included fully under steady state conditions as they are not limited by any time restrictions.

6.4 *Private Domestic Wells*

Domestic water supply in the study area was developed based on private wells and septic systems, except for the clusters of population found in the Towns of Shelburne and Mulmur, and the Hamlet of Rosemont. A total of 3,919 groundwater takings located within the model domain are listed in the MECP WWIS database. The locations of these private wells are presented in Figure 6.2. Drillers are supposed to provide accurate well locations but many well locations are estimated from the provided location sketches or have been assigned to the centroid of the indicated lot and concession. An unknown fraction of the wells may no longer in service, as the occurrence of reporting the decommissioning of private wells is infrequent.

Of particular interest are the wells in the immediate vicinity of the Strada site. Owners will be contacted to be part of both an initial survey of the conditions of the well and invited to participate in a monitoring network used to assess the long-term effects of the proposed excavation at the site. Figure 6.2 shows 1 km and 2 km buffers around the Strada property that include 51 and 179 MECP wells, respectively. The extent of the area likely to be affected by pit/quarry development will be determined through groundwater modelling and the results will be used to refine the list of wells to be included in the monitoring program.

6.5 *Surface Water Takings*

Several permitted surface water takings fall within the model domain. Those located above the Escarpment are mainly clustered along the Noisy River on the north portion of the model for agricultural purposes, except for the PTTW #7121-9Y7HP7, which is a surface and ground water permit sourced for commercial aquaculture purposes and is located at approximately 1 km northeast of the Strada property. The permit allows takings from a tributary of the Pine River, and includes a groundwater component that relates to the capture of spring water within the property.

PTTW #7121-9Y7HP7 is significant due to its proximity to the study area. Details regarding this permit are summarized as follows:

- Source ID: Pine River #1, is allowed to divert a maximum volume of 65.4 m^3/d, throughout the year.
- Source ID: Pine River #2, is allowed to divert a maximum volume of 215.7 m^3/d, throughout the year.
- Source ID: Newell Pond, for a pond with a fixed volume of 281 m^3/d equal to the sum of the maximum volumes captured from the Pine River.
- Source ID: Springs, is allowed to divert a maximum volume of 179 m^3/d, for 180 days of the year.

Surface water takings are to be considered in the transient calibration process of the integrated surface and ground water model for the study area.

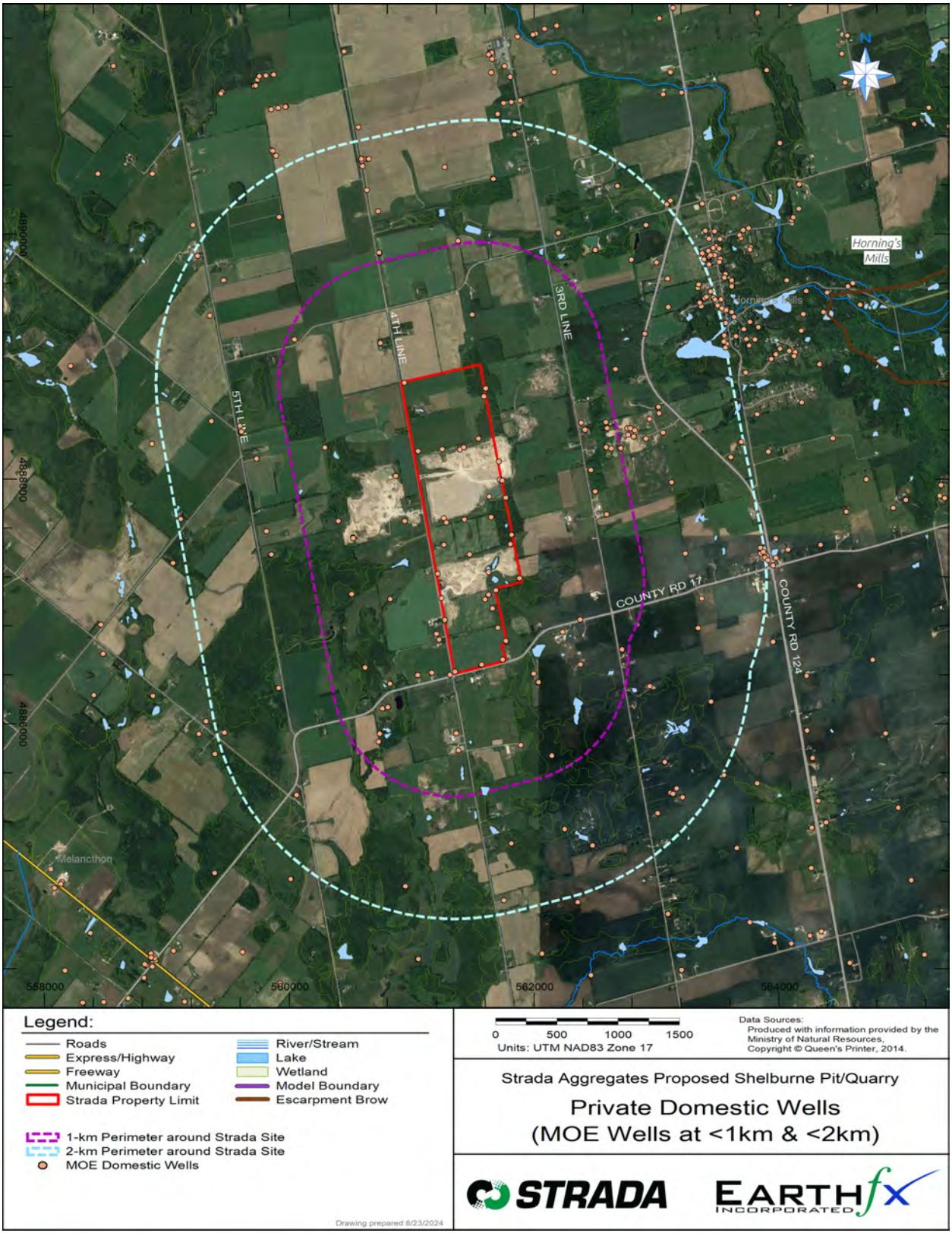


Figure 6.2: Private domestic wells within a 1-km and 2-km buffer around the Strada site.

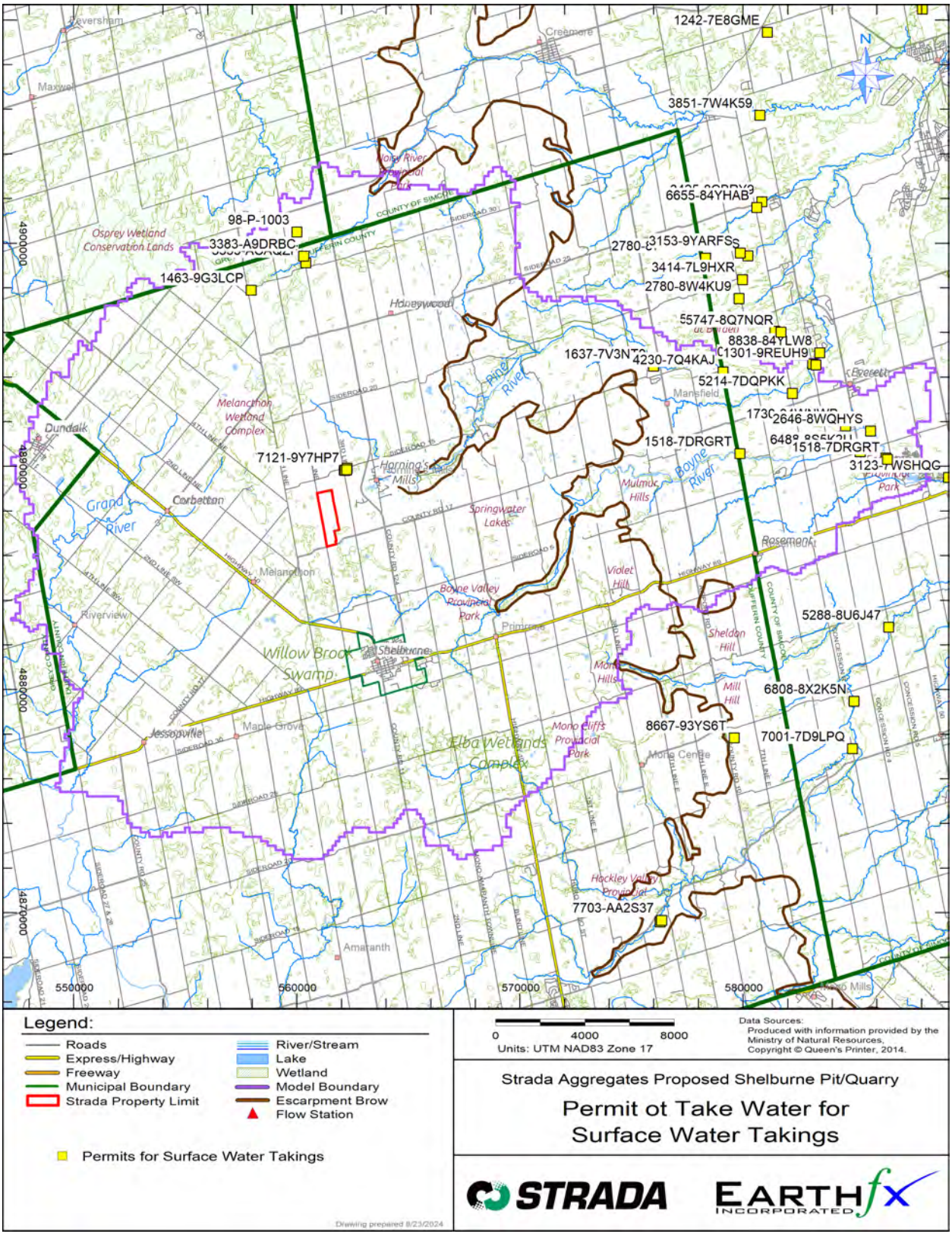


Figure 6.3: Surface water takings.

7 References

Banks, W.D. and Brunton F.R., 2017 Collaboration between Ontario Geological Survey, Consultants and Municipal staff results in discovery and development of a safe and sustainable bedrock groundwater supply for the Town of Shelburne, Southern Ontario, Canada, Presented at GeoOttawa, 2017

Brunton, F.R., 2008. Preliminary revisions to the Early Silurian stratigraphy of Niagara Escarpment: integration of sequence stratigraphy, sedimentology and hydrogeology to delineate hydrogeologic units; in Summary of Field Work and Other Activities 2008, Ontario Geological Survey, Open File Report 6226, p.31-1 to 31-18.

Brunton, F.R., 2009. Update of revisions to the Early Silurian Stratigraphy of the Niagara Escarpment: integration of sequence stratigraphy, sedimentology and hydrogeology to delineate hydrogeologic units; in Summary of Field Work and Other Activities 2009, Ontario Geological Survey, Open File Report 6240, p.25-1 to 25-20.

Brunton, F.R. and C. Brintnell, 2011. Final update of Early Silurian stratigraphy of the Niagara Escarpment and correlation with subsurface units across southwestern Ontario and the Great Lakes basin; in Summary of Field Work and Other Activities 2011, Ontario Geological Survey, Open File Report 6270, p.30-1 to 30-11.

Brunton, F.R. and C. Brintnell, 2020. Early Silurian Sequence Stratigraphy and Geological Controls on Karstic Bedrock Groundwater-Flow Zones, Niagara Escarpment Region and the Subsurface of Southwestern Ontario. Ontario Geological Survey Groundwater Resources Study 13.

Burwasser, G.J., 1974. Quaternary geology, Collingwood-Nottawasaga area, southern Ontario; Ontario Division of Mines, Preliminary map P0919, scale 1:50 000.

Chapman, L.J. and D.F. Putnam, 1984. The physiography of southern Ontario; Ontario Geological Survey, Special Volume 2, 270p.

Chapman, L.J. and D.F. Putnam, 2007. The physiography of southern Ontario; Ontario Geological Survey, Miscellaneous Release – Data 228, digital version of physiography maps.

Cowan, W.R., 1976. Quaternary Geology of the Orangeville area, southern Ontario; Ontario Division of Mines, Geoscience Report 141, 98p.

DWCo. (Dufferin Water Co.) Ltd., 2023, Mansfield water system – Annual Summary Report for 2022. Prepared for: the Township of Mulmur. 13 p.

Earthfx Incorporated, 2010a, Water Balance Analysis of the Lake Simcoe Basin using the Precipitation-Runoff Modelling System (PRMS): prepared for the South Georgian Bay - Lake Simcoe Source Protection Region, October 2010. 106 p.

Earthfx Incorporated, 2022, Updated wellhead protection area delineation, vulnerability scoring, and threats assessment for the Town of Shelburne, Ontario. Prepared for: S. Burnett and Associates, June, 2022. 309 p.

Earthfx Incorporated, 2024a. Proposed Strada Aggregates Shelburne Pit/Quarry Model Development and Calibration Report (Application Appendix D). October 2024, 148 p.

Earthfx Incorporated, 2024b. Proposed Strada Aggregates Shelburne Pit/Quarry Impact Assessment Report (Application Appendix E), October 2024, 242 p.

Environment and Climate Change Canada, 2021, High resolution deterministic precipitation analysis system (CaPA-HRDPA). https://collaboration.cmc.ec.gc.ca/cmc/cmoi/product_guide/docs/lib/technote_capa_hrdpa_e.pdf

GENIVAR Inc., 2011, The Highland Companies proposed Melancthon Quarry hydrogeologic and hydrologic assessment, Geographic Township of Melancthon, County of Dufferin, volumes 1 through 4. Prepared for: The Highland Companies, January, 2011.

Gerber, R.E., Boyce, J.I., Howard, K.W., 2001. Evaluation of heterogeneity and field scale groundwater flow regime in a leaky till aquitard. Hydrogeology Journal 9, 60-78.

GOFFCO Ltd, 2007, Report on a preliminary pumping test for monitoring well MW2-07 near the Shelburne Pit Lot12, Concession 3, Melancthon Township. June 28th, 2007. 14 p.

Golder Associates and Banks Groundwater Engineering, 2013, Long Term Well for Additional Water Supply Project, Environmental Assessment/Environmental Impact Statement: prepared for the Town of Shelburne, September 2013.

Gwyn, Q.H.J., 1975. Quaternary geology of the Dundalk area, southern Ontario; Ontario Division of Mines, Open File Report 5132, 138p.

Hargreaves, G.H. and Samani, Z.A., 1982, Estimating potential evapotranspiration. Journal of Irrigation and Drainage Engineering, 108, 223-230.

Hoffman, D. W. and Matthews B. C. 1964. Soil Survey of Dufferin County, Ontario. Repot Number 38. Ontario Agricultural College R. E. Wicklund Soil Research Institute

Janzen, Bob, 2018. An Overview of Bedrock and Quaternary Geological Interpretations in the Grand River watershed

Johnson, M.D., D.K. Armstrong, B.V. Sanford, P.G. Telford, and M.A. Rutka, 1992. Paleozoic and Mesozoic geology of Ontario; in Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 2, p. 907-1008.

Kassenaar, J.D.C. and Wexler, E.J., 2006, Groundwater modelling of the Oak Ridges Moraine area: YPDT-CAMC Technical Report #01-06: Available at http://www.ypdt-camc.ca.

Liberty, B.A., I.J. Bond, and P.G. Telford 1976a. Paleozoic geology of the Dundalk area; Ontario Geological Survey, Map 2340, scale 1:50 000.

Liberty, B.A., I.J. Bond, and P.G. Telford 1976b. Paleozoic geology of the Orangeville area; Ontario Geological Survey, Map 2339, scale 1:50 000.

Ministry of Natural Resources and Forestry (MNRF), 2019, Southern Ontario land resource information system (SOLRIS) version 3.0: Data Specifications, April 2019. 40 p.

Munn, Johnathan David, 2018. Measuring groundwater flow system variability in a fractured carbonate aquifer using fibre optic distributed temperature sensing. University of Guelph Ph.D. Thesis

Ontario Geological Survey 2010. Surficial geology of Southern Ontario; Ontario Geological Survey, Miscellaneous Release--Data 128-REV, ISBN 978-1-4435-2483-4. 8 p.

Ontario Geological Survey Aggregate Resources Inventory Paper 163—Revision 2, 2014. Aggregate Resources Inventory of Dufferin County Southern Ontario. Prepared by MacNaughton Hermsen Britton Clarkson Planning Limited, White LandScience, Robinson Consultants, D.J. Rowell and F.R. Brunton

Piggott, A.R., Moin, S., & Southam, C., 2005, A revised approach to the UKIH method for the calculation of baseflow, Hydrological Sciences Journal, 50:5, 920, DOI: 10.1623/ hysj.2005.50.5.911.

R.J. Burnside & Associates Limited, 2010a, Groundwater Vulnerability Analysis, Issues Evaluation and Threats Assessment, Township of Mulmur. 210 p.

R.J. Burnside & Associates Limited, 2010b, Groundwater Vulnerability Analysis, Issues Evaluation and Threats Assessment, Township of Adjala-Tosorontio. 257 p.

Thompson, P.J., 2013, Event Based Characterization of Hydrologic Change in Urbanizing Southern Ontario Watersheds via High Resolution Stream Gauge Data (Master's Thesis). University of Waterloo, Waterloo, ON, Canada.

Torrance, J.K. 2009. The Honeywood Soil Series and Potato Production in Dufferin County, Ontario

Whitewater Hydrogeology, 2013, Category 3 PTTW Application: 3191574 Nova Scotia (Downey Farms). Prepared for the Ministry of the Environment, Environmental Assessment and Approvals Branch, 2 St. Claire Avenue West, Floor 12A Toronto ON

Appendix D: Model Development and Calibration Report

Strada Aggregates Proposed Strada Pit/Quarry

Appendix D
Model Development and Calibration Report

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October, 2024

Proposed Strada Aggregates
Shelburne Pit/Quarry

Appendix D
Model Development and Calibration Report

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Proposed Strada Aggregates Shelburne Pit/Quarry Model Calibration Report

1 Introduction

1.1 *Background*

Strada Aggregates is seeking a license to operate a pit/quarry at the site of their Shelburne pit, located at 437159 4th Line, Shelburne, Ontario.

To assess the potential impacts of pit/quarry development on groundwater and surface water resources, an understanding of groundwater flow through the underlying overburden and fractured rock environment is required. This is developed through the collection of field data and the development of a site conceptual model. Once a sufficient level of understanding has been developed, the conceptual representation of the fractured bedrock is translated into a mathematical model for the purpose of impact assessment.

1.2 *Objectives*

The purpose of this investigation is to meet the requirements of the Ontario Ministry of Natural Resources (MNR) Level 1/Level 2 Hydrogeological Investigation. This includes:

- Field characterization of the current hydrogeologic conditions at the proposed pit/quarry site;
  - Appendix A and B: Field Program Methodology and Results

- Evaluation of the current hydrogeologic and hydrologic conditions through data interpretation, conceptual interpretation and the development of a groundwater/surface water model of the site; See:
  - Appendix C: Conceptual Model Report (Earthfx, 2024a)
  - Appendix D: Model Development and Calibration (this report)
  - Appendix E: Impact Assessment (Earthfx, 2024b)

The purpose of this “Appendix D: Model Development and Calibration Report” is to present a description of the data and assumptions used to build and calibrate numerical surface water and ground water model of the proposed pit/quarry development. More detailed analysis of the data is presented in this Appendix D: Model Development and Calibration. The effect of pit/quarry development are presented in Appendix E (Earthfx, 2024b).

1.3 *Stream, Wetland, Pond and Lake Model Representations*

The graphical presentation and use of the term “ditches”, “wetlands”, “ponds”, “lakes”, “rivers” and “streams” on figures and in the text of this report refers to features that are represented in the numerical model. These terms do not imply that the feature is considered an officially classified hydrologic feature

by the regulatory agencies (including MNR). For example, in some figures presented below, stream segments (blue lines) are shown on the maps to represent streams, roadside ditches and surface drainage swales in the model. These lines represent overland runoff drainage pathways mapped from the digital elevation model (DEM), but they may not correspond to MNR mapped (and classified) streams. The MNR does not classify roadside ditches, for example.

Similarly, there are model representations and discussions of dugouts, wetlands, ponds and lakes that represent depressions in the DEM, but they may not correspond to an MNR mapped wetland or water body. For example, man-made ditches and ponds are simulated and assessed but not considered key hydrologic features or key natural heritage features.

A set of Priority Natural Features (hereafter referred to as NAT complexes) were identified by NRSI as part of their impact assessment (NRSI, 2024, Section 1.1). These “natural features” (wetlands) are discussed in Section 1.3 of Appendix E (Earthfx, 2024b). While wetlands of all classes are identified on the basemap legend, NAT wetlands are labelled as NAT-XX on the maps, hydrographs and water budget bar charts.

Another example is the numerical model representation of subsurface karst conduits (personal communications with peer reviewer, Map dated April 8, 2010). The subsurface portion of the stream conduit is, in some figures, interpreted and illustrated as a dashed blue or orange line, but that does not imply that the feature exists on surface and is a MNR classified stream. In these cases, the model is representing the routing of water through an inferred subsurface conduit.

1.4 *Maps and Model Datum*

In late September, 2023 the Province of Ontario released detailed LiDAR ground elevation survey data covering the entire Strada study area (CGVD2013 Datum). This datum was used for the model ground surface representation. Map projection is UTM NAD 83 Zone 17. Basemap information is provided by the Ministry of Natural Resources and may be Copyright, 2014 Queen’s Printer. The accuracy of basemap information reflects the various government data sources and should not be used for purposes beyond this impact assessment. For example, the Town of Honeywood is incorrectly located in the government data source that was provided. Similarly, Water Survey of Canada (WSC) surely have inconsistencies with most recent information. Also note that the new LiDAR information is more accurate than the stream mapping provided by the government. It is beyond the scope of this project to correct the government source.

Map figures in this report have been prepared as high-resolution images suitable for detailed on-screen review, zoom and analysis. Figures are presented in a portrait letter orientation to allow consistent scrolling without page size and orientation changes. All figures are hyper-linked to the text discussion to facilitate switching between the text and figures.

Model row and column numbers refer to the grid described in Section 4.3.

1.5 *Map and Hydrograph Legend Abbreviations*

Throughout this report some abbreviations are use to improve readability and prevent legends and figure captions from becoming too long. This report includes terminology that are highly advanced in surface water and groundwater modeling and analysis. The report should only be reviewed by experts with suitable experience and knowledge of these techniques.

Model Row and Column numbers:
In the transient analysis (Section 4.10.4) accompanying model row and column numbers on maps and hydrographs refer to the model grid cells as described in Section 4.3 of Appendix D. The row and column are a more precise description of the model result, that any fellow modeler appreciates.

Model Layer Number:
The results from model layers are presented in an abbreviated form as:

- "L1" for Model Layer 1 (Shallow overburden across the entire model area)
- "L4" for Model Layer 4 (Guelph Eramosa formation *above the escarpment*)
- "L6" for Model Layer 6 (Gasport Formation *above the escarpment*)

Model layers are discussed in more detail in Section 4.3. Note that model layers above and below the escarpment represent different geologic units, so the reporting of the layer number is necessary.

2 Integrated Model Development Approach

2.1 *Introduction*

Hydrologic (surface water flow) and groundwater flow models are often applied to estimate and help mitigate the effects of quarry development on nearby features (e.g., streams and wetlands) as well as to better predict and manage inflows into the quarry. Typically, the hydrologic and groundwater models are developed separately, with the groundwater flow model run for steady-state (i.e., long-term equilibrium) conditions. A more advanced approach is the use of integrated groundwater and surface water models (Figure 3.1), which can assess the changes to both the surface water and groundwater systems on a transient (time-dependent) basis. This section presents an overview of the integrated modelling approach and addresses the following:

1. How is the movement of water between the surface and groundwater systems (dynamic feedback) represented in the integrated model?
2. What are the benefits and possible disadvantages of integrated modelling as it applies to the objectives of this study and the unique features of the study area?

The overview describes how each of the sub-model components are developed, pre-calibrated, and then coupled. This section is intended to help the reader better understand the technical details presented in subsequent discussions of model results.

2.1.1 Integrated Modelling

An integrated flow model represents the entire hydrologic cycle in a comprehensive, complete, and coupled manner. The hydrologic cycle includes:

- Hydrologic processes (e.g., precipitation, interception, snow accumulation and melt, overland runoff, infiltration, interflow, evapotranspiration (ET), and groundwater recharge and discharge)
- Hydraulic processes (e.g., streamflow in channels, and wetland and lake water balances
- Groundwater processes (i.e., saturated and unsaturated subsurface flow)

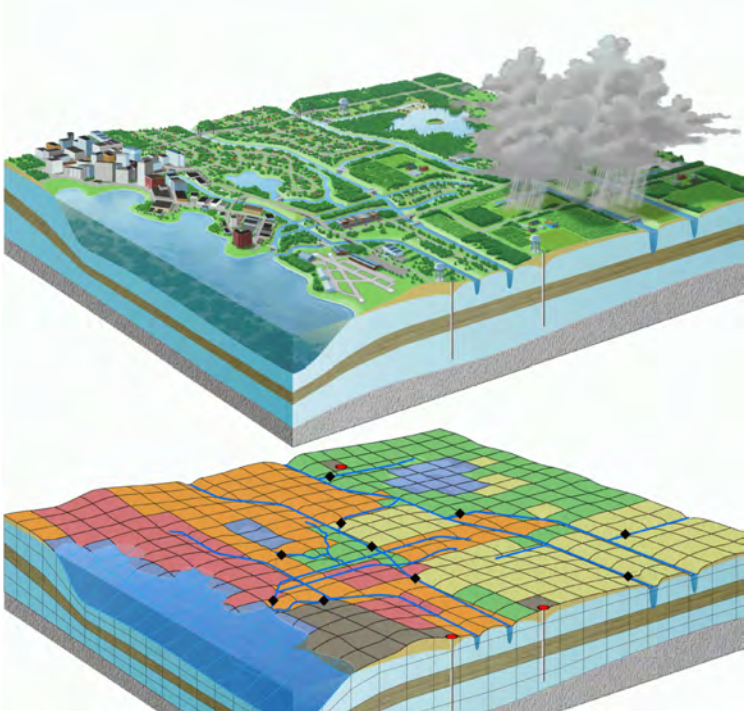


Figure 3.1: Integrated numerical representation of the surface and subsurface using a cell-based approach (USGS Image).

A comprehensive and complete representation of the hydrologic cycle is one in which the overall water budget is tracked through both the surface water and groundwater systems and where water cannot be created or lost. The term “integrated” denotes that the transfer of water between the surface water and groundwater domains is simulated and that key feedback mechanisms are represented. Integrated models determine the flows in the groundwater and surface water systems at the same point in time by solving the governing equations simultaneously or in an iterative manner.

An integrated approach provides additional benefits that are related to the development and calibration of the model. When surface water and groundwater models are developed separately, simplifying assumptions must be made in each model to account for processes that occur in the other model domain. For example, groundwater recharge must be independently estimated in the surface water hydrology domain and then applied to a groundwater model. Similarly, in surface water models, the complex groundwater system that supplies baseflow is often represented as simple linear reservoir, groundwater flow across the catchment surface water boundaries is rarely considered. Finally, there are many processes, such as rejected recharge (when groundwater levels are high), that have complex dynamic feedback between the systems.

2.2 *USGS GSFLOW Overview*

The USGS GSFLOW code (Markstrom *et al.*, 2008) was used in developing the integrated groundwater/surface water model for the area surrounding the proposed Quarry. GSFLOW is an open-source, well-documented code and has been used to investigate groundwater/surface water interaction in a number of recent peer-reviewed studies (e.g., Huntington and Niswonger, 2012; Hunt *et al.*, 2013; Ely and Kahle, 2012; Tanvir Hassan *et al.*, 2014; and Niswonger *et al.*, 2014). Earthfx has applied the code to a number of nearby watersheds as part of advanced water-budget studies for the Ontario Source Water Protection program.

GSFLOW was developed from two widely-recognized USGS submodels: The Precipitation Runoff Modelling System, PRMS (Leavesly *et al.*, 1986), and the modular groundwater flow model MODFLOW-NWT (Niswonger *et al.*, 2011). The MODFLOW-NWT code has three key process modules: the UZF unsaturated flow module (Niswonger *et al.*, 2006), the SFR2 streamflow routing module (Niswonger and Prudic, 2005), and the LAK3 lake module (Merritt and Konikow, 2000). The different processes and submodels in GSFLOW are listed in Table 2.1 and are shown schematically in Figure 2.2. The submodels include numerical representations of the physical system and the processes that occur within each submodel domain.

Table 2.1: Processes and GSFLOW submodels.

Zone	Process Component	GSFLOW Submodel
1	Hydrology – Soil Water Processes	PRMS Hydrologic Submodel
2	Streamflow	SFR2 module for MODFLOW
	Lakes, and Wetlands	LAK3 module for MODFLOW
3	Unsaturated Flow	UZF module for MODFLOW
	Groundwater flow	MODFLOW-NWT Groundwater Submodel

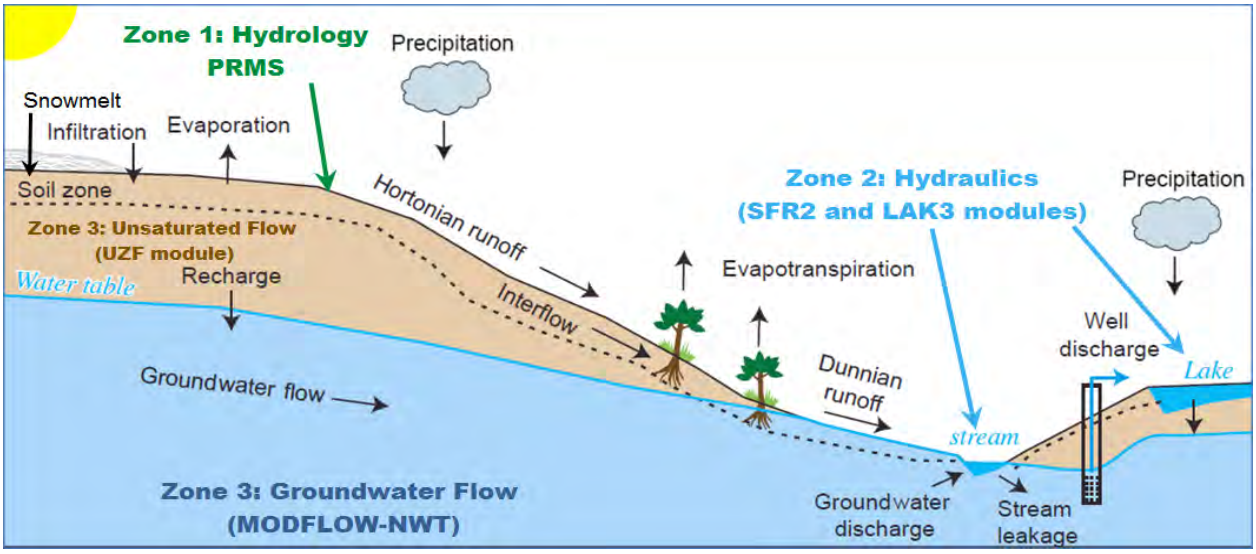


Figure 2.2: Schematic diagram of the GSFLOW process regions.

2.2.1 Spatial Representation

The MODFLOW groundwater flow submodel in GSFLOW is a fully-distributed model, meaning that groundwater processes are simulated using a cell-based representation of the study area. The PRMS hydrology sub-model is also run in a fully-distributed manner, with each cell having unique physical properties. Cells are assigned spatially variable soil and land cover properties as part of model construction. During a simulation, cells receive spatially-variable inputs, such as daily rainfall, snowfall, temperature, and solar radiation. Overland runoff and interflow are routed across cells to the receiving streams or lakes through a topographically-driven cascade flow network.

The spatial representation in GSFLOW is particularly flexible. Three different grid resolutions can be used for the climate, surface hydrology, and subsurface groundwater processes, respectively (Figure 2.3). This allows for different levels of refinement in each of the three regions to meet the accuracy requirements associated with those processes. The grids in this study share a common origin and, although they have different cell spacing, are generally aligned so that MODFLOW cells can contain integer multiples of PRMS cells.

Topography, soil properties, and land use vary widely across the study area, so a fine resolution was used to represent local-scale natural features and anthropogenic modifications such as the quarry, agricultural land use, and urban development (Figure 2.3). Sub-cell hydrologic processes are also represented, where each cell in the PRMS submodel is divided into pervious (grass or soil) and impervious (roads, parking lots, buildings) zones (Figure 2.3, right side enlargement), with different processes, storage properties, and interactions simulated in each sub-cell zone.

Rivers and streams in GSFLOW are represented as a network of one-dimensional line elements with open-channel flow routing through the network. The water storage associated with small wetlands are represented in the PRMS soil zone, while larger wetlands and lakes are represented with the LAK3 module. Deep lakes and excavations can be incised into one or more groundwater layers.

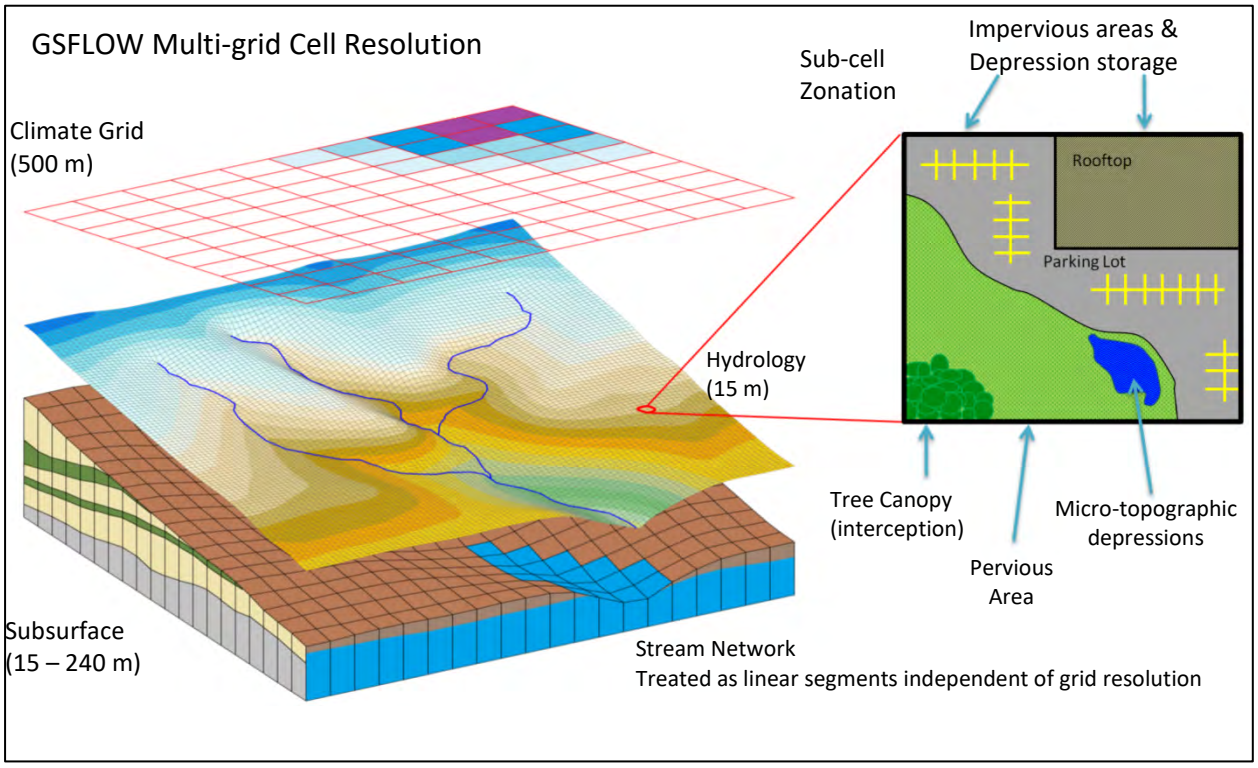


Figure 2.3: Different grid resolutions are available for each process region within GSFLOW.

Groundwater flow processes in MODFLOW can be represented with a variable cell size grid. In this study, the grid was locally refined to better represent the quarry excavation, nearby wetlands and streams and groundwater drawdowns.

Finally, climate inputs, such as rain, snow, and temperature data are available on a wider geographic distribution. GSFLOW allows a separate coarser grid resolution for the interpolation of climate data between stations to represent spatially-variable temperature and precipitation.

2.2.2 PRMS Submodel Soil Zone Processes

The PRMS submodel represents the vegetative canopy, pervious and impervious surfaces, and the soil zone as a series of reservoirs with finite capacity. The reservoirs are filled and depleted by different hydrologic processes and discharge to one or more reservoirs when the capacity is exceeded. For example, vegetation intercepts rainfall at rates dependent on the plant type and percent of vegetative cover under winter and summer conditions. Intercepted water is subject to evaporation (Figure 2.4). Water in excess of canopy interception capacity is passed to the land surface reservoir or to the snow pack (if present) as "throughfall" (or net precipitation). Net precipitation that falls on impervious soils can fill the depression storage reservoir and is subject to evaporation. Water in excess of depression storage is routed as Hortonian overland runoff through the Cascade Flow module in PRMS and, if it does not re-infiltrate along the pathway, it passes from PRMS to SFR2 or the LAK3 modules and is then routed through the stream/lake network.

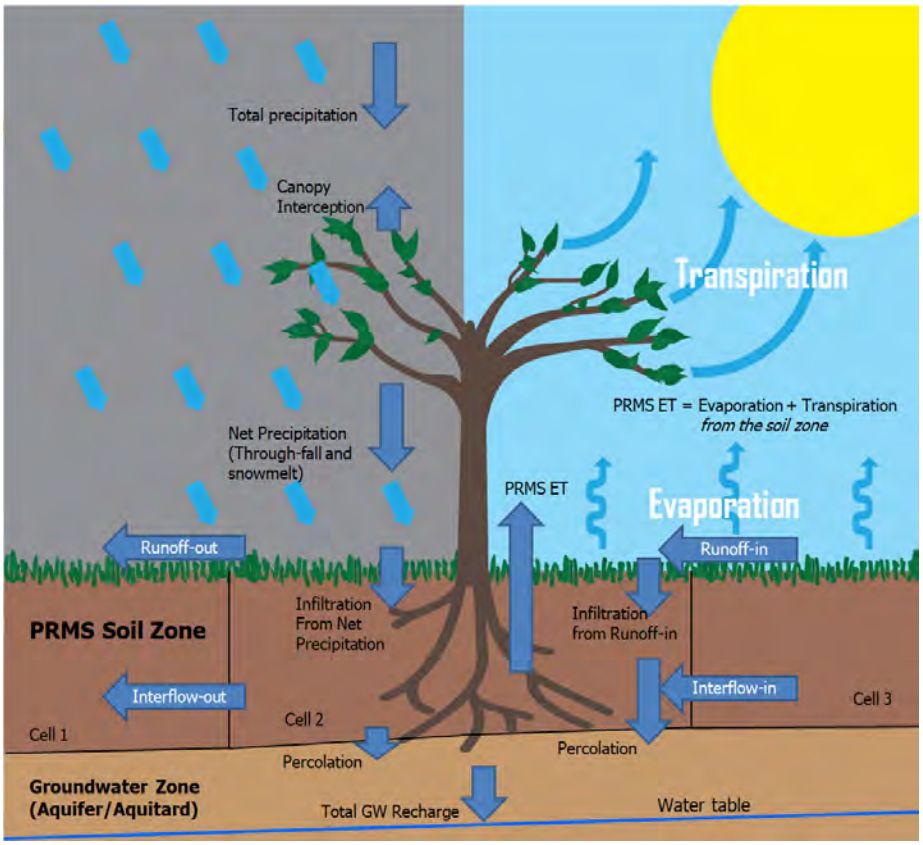


Figure 2.4: PRMS Soil Zone Processes

In a similar manner, net precipitation on pervious soils can infiltrate into the soil zone. If the infiltration capacity is exceeded, the water is discharged as Hortonian runoff and routed downslope to other cells and ultimately to the stream/lake network. Where infiltrating water fills the soil zone reservoir it is subject to evapotranspiration. Excess water above field capacity is partitioned between interflow and gravity drainage. Interflow is routed to downslope cells along the cascade network. Gravity drainage is directed to the unsaturated zone represented with the UZF module. Water is returned to the soil zone as rejected recharge if the percolation capacity is exceeded, otherwise, the water moves downward to the saturated zone as groundwater recharge. Excess water in the soil zone (above saturation) and any rain falling on the cell is discharged to the cascade network as Dunnian overland runoff.

2.2.3 GSFLOW Process and Region Integration

A key aspect of the integrated model is the representation of processes that move water between the three main model domains, as shown in Figure 2.5. The next sections provide a brief description of the key inter-region processes.

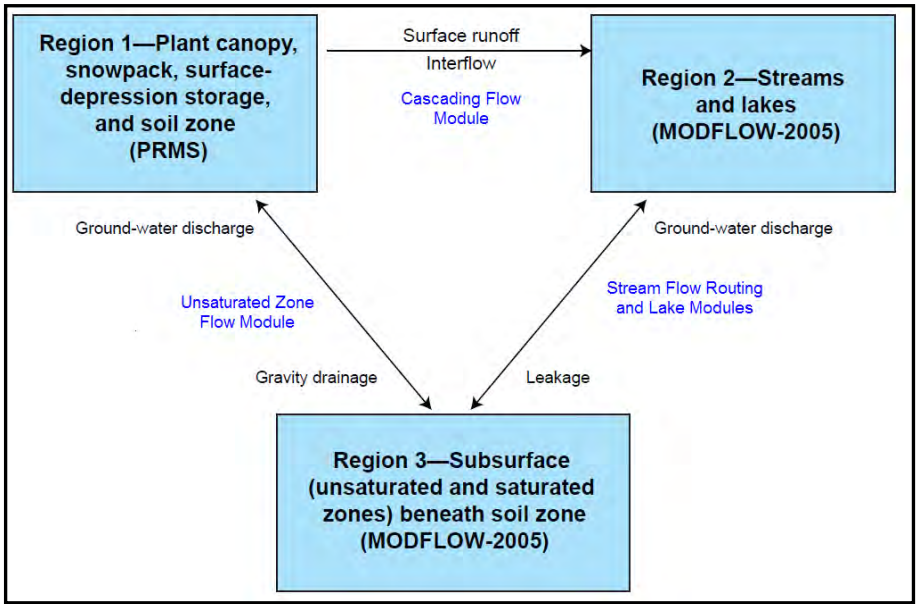


Figure 2.5: Processes moving water between GSFLOW regions.

MODFLOW-NWT simulates the saturated flow system that moves groundwater from recharge areas to points of discharge to streams, lakes, wetlands, and wells. Groundwater can discharge to the soil zone when the water table rises to intersect the base of the soil zone. Discharging groundwater is passed from MODFLOW to PRMS through the UZF module and is added to the soil zone reservoir. Groundwater discharge to the soil zone in low-lying areas often fills the soil zone reservoir and then discharges as Dunnian runoff.

2.2.4 Groundwater/Surface Water Feedback

Rejected Recharge and Contributing Area: The portion of the model area where direct feedback from the groundwater system occurs can change with seasonal fluctuations in the water table or in response to rainfall events. The portion of the watershed where the water table is near-surface and contributes to Dunnian runoff (rejected recharge) has been referred to as the "contributing area" (Dickinson and Whiteley, 1970). Figure 2.6 is a schematic illustrating the change in the contributing area due to the shift in the position of the water table between spring and summer. Rainfall and snowmelt events generate more runoff during the spring because the "contributing area" is larger and saturation excess (Dunnian runoff) is more prevalent.

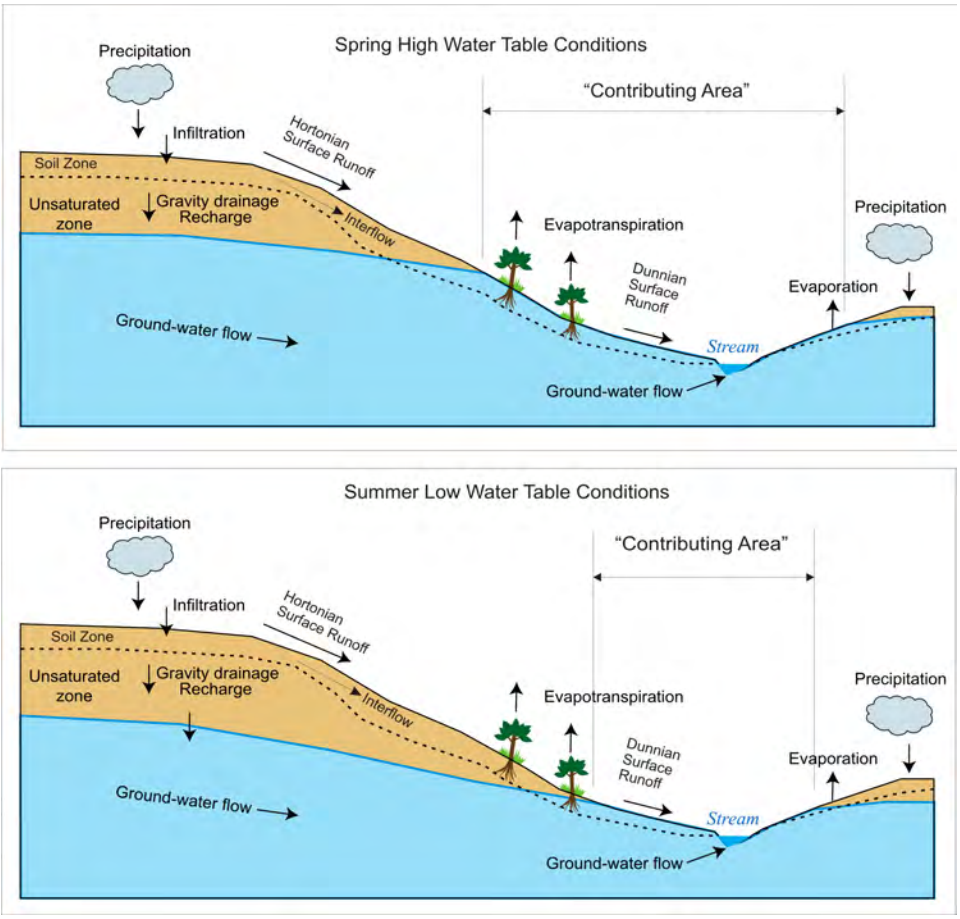


Figure 2.6: Changes in the spring and summer position of the water table increasing Dunnian runoff and the size of the "Contributing Area" (from Markstrom *et al.*, 2008).

Stream/aquifer interaction occurs in the hyporheic zone where water is exchanged between the stream and the groundwater system. This exchange is represented in the GSFLOW model as head-dependent discharge or leakage (Figure 2.7) with the assumption that the rate of water movement between the aquifer system and the stream is proportional to (1) the difference between the head in the aquifer and the stream stage, and (2) the permeability of the intervening streambed. The exchange of water can occur in either direction. Flow across the streambed is presumed to be independent of the water table position when the water table falls below the streambed bottom (Harbaugh, 2005). Similar exchange can occur between a lake and the underlying aquifer across the lakebed materials as lake levels, and groundwater heads change over time.

Often, only the exchange of water across the streambed is represented in separate groundwater models. Studies with the GSFLOW model have shown that considerable amounts of water are exchanged as groundwater discharge to the soil zone in riparian area, which subsequently emerges as Dunnian overland runoff. It should also be noted that groundwater discharge across the streambed is locally suppressed or even reversed as stream stage temporarily rises after precipitation or snowmelt events (Freeze and Cherry, 1979). Groundwater then seeps back out to the stream as the stage subsides (bank storage). While the representation of the groundwater discharge to streams in GSFLOW is more physically correct, it is sometimes more difficult to separate the surface water and groundwater components of discharge to streams in an integrated model.

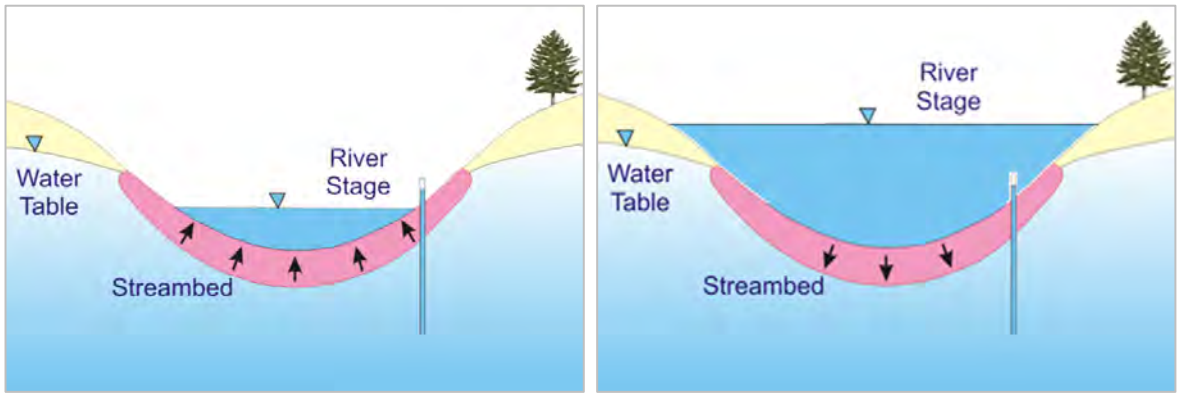


Figure 2.7: Head-dependant groundwater discharge to streams (l) and leakage from streams (r).

2.2.5 Temporal Discretization and Submodel Coupling

During a GSFLOW simulation, each submodel receives a set of daily inputs (e.g., daily climate data for PRMS and daily recharge and pumping rates for MODFLOW). The PRMS submodel calculates a new water balance for each cell in response to the climate inputs and passes updated estimates of groundwater recharge, overland runoff to streams, and residual ET demand to the MODFLOW submodel. In turn, the MODFLOW submodel solves the groundwater flow equations to compute new groundwater levels and the resulting changes in storage, groundwater ET, and groundwater discharge to the soil zone, lakes, and streams. Surface water flows, based on inputs including direct precipitation, evaporation, overland runoff, and groundwater gains or losses, are routed downstream and new stage values in lakes and streams are calculated using the SFR2 and LAK3 modules. The process is repeated in an iterative manner until the exchange of water calculated by the two submodels converges. The final soil water balance, groundwater recharge rates, change in discharge to streams, streamflow, lake stage, groundwater heads (including the updated water table position) are then computed and saved and the model progresses to the next day. A schematic showing the iterative computations executed as the model progresses through time is presented in Figure 2.8.

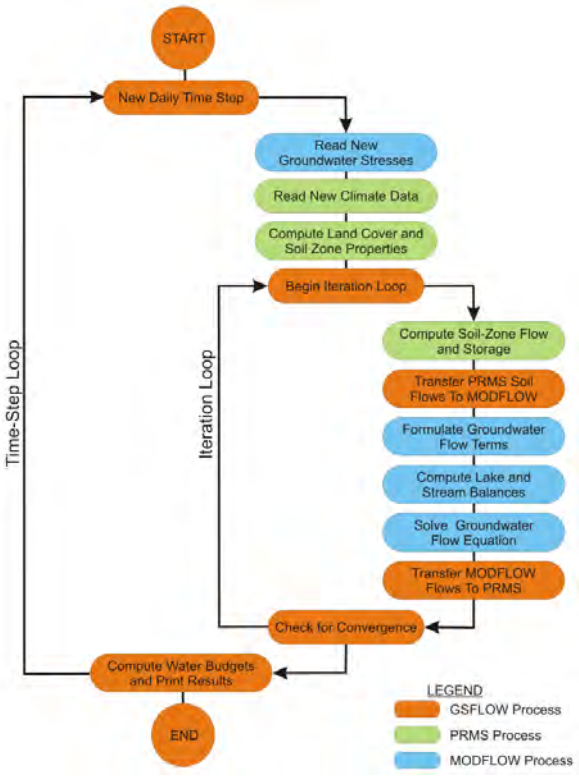


Figure 2.8: Computational sequence for an integrated PRMS/MODFLOW simulation in GSFLOW (modified from Markstrom *et al.* (2008)).

2.3 *GSFLOW Model Development and Calibration Process*

Developing an integrated watershed model is more complicated than building an independent hydrologic model or groundwater model. However, many of the basic model development steps and procedures are similar. Model development begins with the collection of available data. The next steps, as documented, include describing and assessing the features and critical processes active in the study area. Information on the topographic, physiographic, hydrologic, geologic, and hydrogeologic settings is synthesized and used to formulate conceptual models of the soil zone, surface water flow system (lakes, wetlands, and streams), stratigraphy, and hydrostratigraphy.

With data compilation and conceptualization completed, the next step involves converting the conceptual model and data into input data and parameter values for the PRMS and MODFLOW submodels. This translation is described in PRMS and MODFLOW model development chapters. For this study, the submodels were tested, "pre-calibrated" independently, and then combined in the GSFLOW framework.

It is important to note that the overall process of data assimilation, conceptual model development, and integrated model calibration is also iterative. Analysis of preliminary model results often pointed to gaps in the previous analyses. The gaps were addressed by obtaining additional data or re-evaluating the data analysis and assumptions made in the conceptualization phases. Model parameters, as well as the underlying conceptual geologic model, were revised several times during the study as our understanding of the study area grew.

3 PRMS Hydrologic Model Development

This section of the report describes the development and calibration of the PRMS hydrologic model.

3.1 *Introduction*

Hydrological processes were simulated using the USGS Precipitation-Runoff Modeling System (PRMS) code. The PRMS code is well documented in Leavesley *et al.* (1983) and Markstrom *et al.* (2008). The PRMS version used in this study is provided as a submodel in the USGS integrated surface water/groundwater code GSFLOW. PRMS can run in a stand-alone mode or in a fully-integrated manner in which the PRMS model is linked to the MODFLOW-NWT groundwater model.

The following section starts with a brief description of the PRMS model, followed by a summary of the climate inputs required to drive the model, an outline of the parameterization process employed in this study, and a brief discussion of the hydrologic calibration.

3.2 *Model Description*

PRMS is an open-source code for calculating all components of the hydrologic cycle at a watershed, subwatershed, or cell-based scale. PRMS is a modular, deterministic, physically-based, fully-distributed model developed to evaluate the impacts of various combinations of precipitation, climate, topography, soil type, and land cover on streamflow and groundwater recharge.

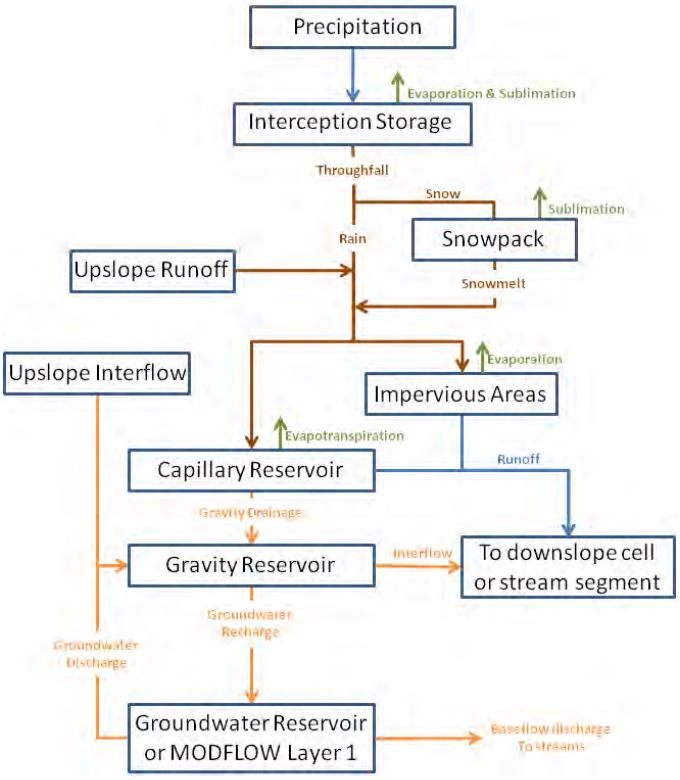


Figure 3.1: PRMS hydrologic processes

A flow chart describing the operation of the PRMS code is shown in Figure 3.1. A more complete description of the program code and underlying theory can be found in Leavesley *et al.* (1983), Markstrom *et al.* (2008), and Markstrom *et al.* (2015). In brief, the PRMS model tracks volumes of water in multiple storage reservoirs within each cell. These include interception storage, depression storage, snowpack storage, capillary soil moisture zone storage, gravity soil moisture zone storage (water in excess of field capacity), preferential flow storage, and groundwater.

To use PRMS as a fully-distributed model, the study area is first subdivided into a grid of small cells, each representing a small part of the overall water budget. Each cell is then assigned representative values to characterize slope, slope aspect, elevation, vegetation type, soil type, land use, and surficial geology; such that every cell within the model domain can have a unique set of properties.

Precipitation and Interception: As can be seen in Figure 3.1, the water balance computation is initiated with daily precipitation. Daily climate data (i.e., precipitation and minimum/maximum temperature) are assigned to each cell based on data from nearby climate stations. Precipitation can

be provided in the form of rain or snow or the model can determine the mix of rain and snow from total precipitation and air temperature. Daily solar radiation values are also assigned to each cell; these values are adjusted by PRMS for cell slope and aspect.

The model then computes interception by vegetation. The amount intercepted depends on vegetation type, precipitation type (rain, snow, or mixed), and winter/summer vegetation cover density. If interception storage capacity is exceeded, the surplus is allowed to fall through onto the snowpack, if present, or directly onto the ground surface (a process termed throughfall). Water is removed from interception storage by evaporation.

Snowpack: A snow accumulation/melting sub-model is used in PRMS to represent snowpack processes. Snow accumulation and subsequent melting is a key source of spring runoff and groundwater recharge in the spring. Rain-on-snow events and sudden warming can also trigger large runoff events mid-winter. A two-layer, energy-balance model, shown schematically in Figure 3.2, is used to compute snowpack depth, pack density, change in albedo, temperature, sublimation, and snowmelt on a daily basis using maximum and minimum air temperature, solar radiation, and precipitation data. The linear, energy-balance snowpack model is combined with an areal snow depletion curve to simulate the sub-cell spatial distribution of snowmelt at shallow snowpack depths (DeWalle and Rango, 2008).

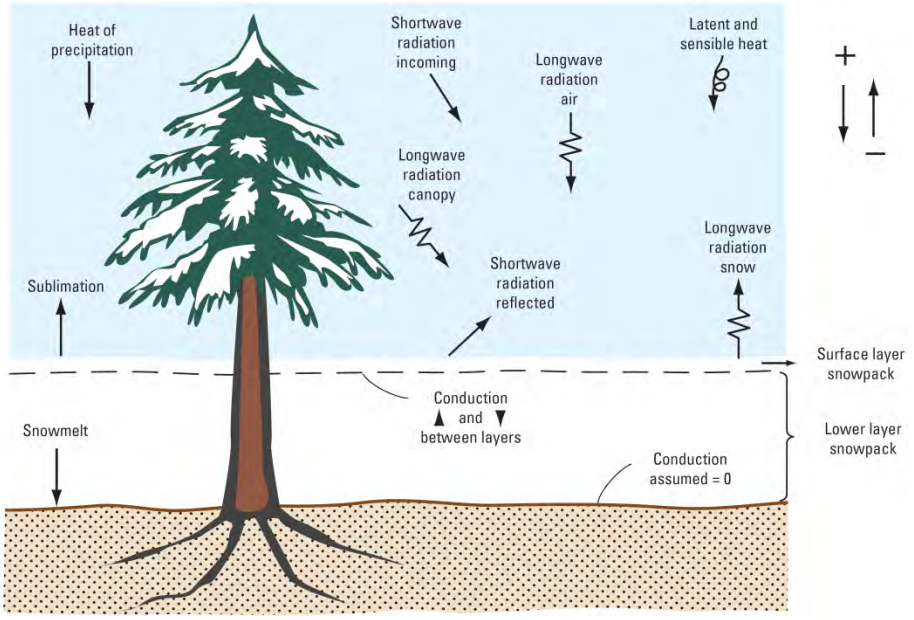


Figure 3.2: PRMS two-layer snowpack conceptualization and the components of the snowpack energy balance, accumulation, snowmelt, and sublimation algorithms (from Markstrom *et al.*, 2015).

On days with precipitation, the PRMS code first determines whether a snowpack exists. If the temperature is below a user-defined base temperature (T_b), all throughfall is added to the snowpack as new snow. If the temperature is higher than T_b, the throughfall is added as rain to the snowpack and is used to raise the temperature of the snowpack through sensible and latent heat exchange. If the energy input is high enough and the snowpack has become isothermal, all or part of the snowpack can melt. The snowpack can also melt or refreeze based on air temperature change and is also subject to sublimation. Snowmelt is allowed to infiltrate the soil (in permeable areas) up to a maximum daily amount and any excess is added to the overland (Hortonian) runoff for the cell.

Snowpack depth and water equivalency of the snowpack are measurable parameters in the field that are compared to their simulated counterparts during calibration. Measurements for these parameters are locally available as snow course data collected around weather stations.

Hortonian Runoff: Each cell can contain both pervious and impervious surfaces; a daily water balance is computed independently for each area type. For impervious areas, the model computes the capture of precipitation and snowmelt by depression storage. When depression storage capacity is exceeded, the surplus is added to the overland (Hortonian) runoff. Water is removed from the depression storage reservoir in each cell by evaporation.

Throughfall (in the absence of a snowpack) and snowmelt on pervious surfaces are partitioned between infiltration and Hortonian runoff. The original PRMS code included a "contributing area" method to partition flows (Dickinson and Whiteley, 1970). Because the contributing area method was originally intended to account for Dunnian (saturation excess) runoff, Earthfx added a module based on the Natural Resources Conservation Service (NRCS) Curve Number (CN) method. In the CN method, infiltration is computed based on the retention characteristics of different combinations of soils, cover type, land use, and antecedent moisture conditions. Water not infiltrating the soil surface is added to Hortonian overland runoff.

Soil Zone Processes: The soil zone in PRMS is split into two main conceptual reservoirs: the capillary reservoir and the gravity drainage reservoir (Figure 3.3). Water infiltrating into the soil zone in pervious areas enters the capillary reservoir where it is retained against gravity drainage as long as the moisture content is less than field capacity. The capillary reservoir volume is estimated as the field capacity minus the wilting point multiplied by the soil zone thickness. Evapotranspiration (ET) can remove water from the capillary reservoir (shown schematically in Figure 3.3).

The PRMS model has several methods for calculating potential evapotranspiration (PET). The modified Jensen-Haise method (Jensen and Haise, 1963) was used in this study to estimate daily PET and only requires values for daily temperature, incoming global solar radiation, and two other user-specified parameters. Actual evapotranspiration (AET) depends on available water and is assumed to follow a hierarchy whereby ET is first extracted from interception storage and then depression storage on impervious areas. Any unmet PET demand is extracted from the capillary reservoir.

A two-layer root zone is used in PRMS. Water is first extracted from the upper zone which is subject to soil evaporation and transpiration. The amount extracted depends on the type of soil, vegetation type, vegetation cover density, and the ratio of available water currently in the soil zone to its maximum available water-holding capacity (field capacity). Remaining ET demand is extracted as transpiration from the lower zone at a rate also dependent on soil, vegetation, and available water and determined by the evaporation extinction rate value in PRMS. Porosity, field capacity, and wilting point properties of the soil define the plant-available water (i.e., PAW). When linked to GSFLOW, remaining PET demand is passed from PRMS to MODFLOW where it can be extracted as groundwater ET from the saturated zone (i.e., GWET) at a rate dependent on depth to the water table.

Interflow, Gravity Drainage, and Dunnian Flow: Excess soil moisture (i.e., water above field capacity) is transferred to the gravity reservoir. Water leaves the gravity reservoir as either interflow or gravity drainage. Interflow is given priority and occurs at a rate proportional to the volume in storage (first-order rate). Gravity drainage occurs at a specified maximum daily seepage rate in PRMS. Water in excess of the amount that can be passed as interflow or gravity drainage is retained in the soil zone and the moisture content may build up over time to reach saturation. If saturation is exceeded, any additional rain or upslope runoff entering the cell will run off as saturation-excess Dunnian flow.

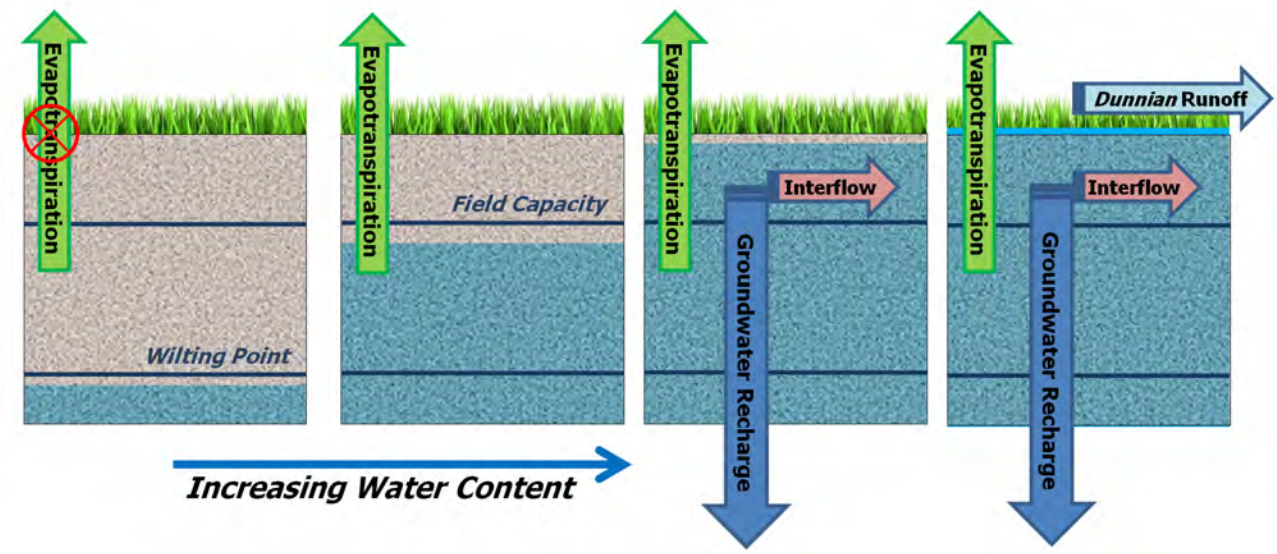


Figure 3.3: Influence of soil zone moisture on recharge, interflow, and runoff processes.

Groundwater Recharge: The maximum daily seepage rate controls the volume of water that is allowed to percolate from the soil zone to recharge the groundwater system. Rates are assigned based on a factor multiplying the estimated saturated vertical hydraulic conductivity of the surficial soils. In PRMS-only simulations, percolating water enters a linear groundwater reservoir associated with each cell. Discharge to streams from the groundwater reservoirs (baseflow) occurs at a rate dependent on the volume of water entering the groundwater reservoir. The groundwater discharge coefficient was selected to best match recession rates observed in streamflow records.

Cascade Flow: Overland runoff and interflow are routed between cells along a cascade flow network based on basin topography. The cascade directs outflows from each upslope cell as run-on to downslope cells. Hortonian overland runoff is added to snowmelt and net precipitation in the downslope cell where it can re-infiltrate or contribute to the runoff to the next cell. Interflow and Dunnian runoff from upstream cells are added directly to the capillary zone of the downstream cell where it can contribute to interflow, groundwater recharge, or additional Dunnian runoff. Overland runoff and interflow that does not re-infiltrate eventually reaches a stream or lake. Accumulation of runoff from upstream cells creates a generally dendritic flow network with enhanced runoff to streams, infiltration, and groundwater recharge in the downslope areas. ET is also enhanced in these areas because more water is available in the soil zone during the summer months.

3.3 *PRMS Model Construction*

The model area overlaps seven Water Survey of Canada (WSC) catchments and completely encompasses three of these catchments. Four subbasins within these catchments are explicitly calibrated to measured streamflow values in gauges from both Environment Canada (EC) and the Grand River Conservation Authority (GRCA). The streamflow stations Pine River near Everett and Boyne River at Earl Rowe Park are maintained by GRCA whereas the stations at the Grand River near Dundalk and the Grand River near Riverview are operated by the GRCA. Additional streamflow measurements were collected from temporary gauges put in placed by the Highland Companies for the proposed Melancthon Quarry for the period 2007-2011. The boundaries of the gauged and calibrated catchments are presented in Figure 3.4. The PRMS model area has the same extension as the groundwater model.

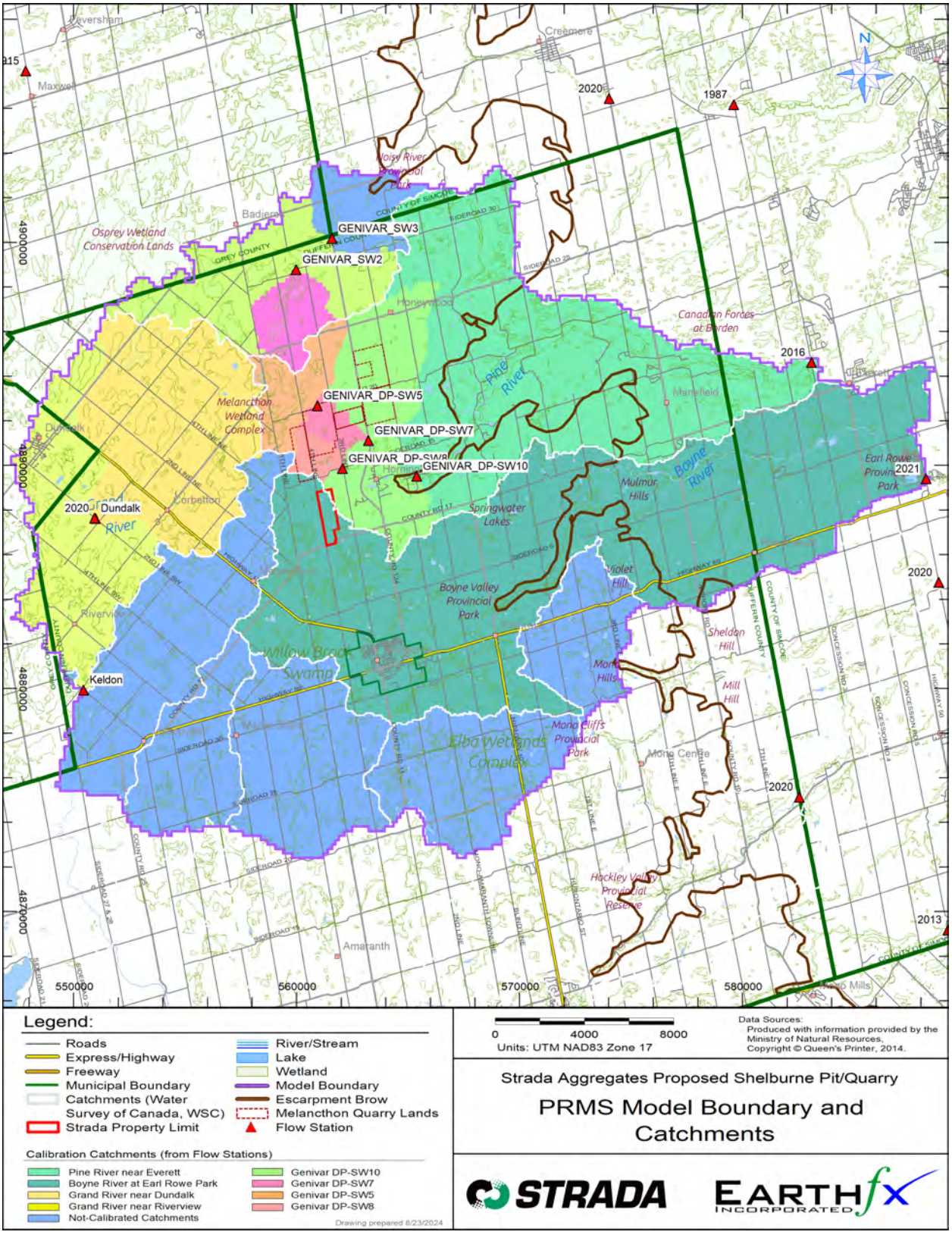


Figure 3.4: PRMS model boundary and catchments.

The eastern catchments comprised by the Pine River and Boyne River discharge below the Escarpment, whereas the streamflow stations on the western portion of the model area are part of the Grand River watershed and are entirely located above the Escarpment.

Spatial Discretization: The study area was subdivided using a uniform grid with square cells of varying length on a side ranging from 12.5 m to 200 m. The entire model area was represented by 180,724 active model cells covering 788 km². This grid resolution matches the one used by the MODFLOW-NWT groundwater model. Cells located outside of the PRMS model boundaries were designated as inactive and were not included in the water balance computations. The hydrologic processes computed by PRMS were aggregated over 18 catchments for generating hydrographs and computing subbasin water budgets.

Temporal Discretization: The PRMS model runs on a daily time step. Daily streamflow values generated by the PRMS model are assumed to represent average daily streamflow.

PRMS modules: The PRMS code uses a number of modules to analyze the various components of the hydrological process. Separate modules provide different methods of treatment for each process. Several of these modules are essential and are needed for all PRMS simulations. The following is a list of the most relevant modules used in this project:

- *temp_module* and *precip_module*: These modules define how temperature and precipitation data are assigned to each PRMS cell. Earthfx developed a module to create and assign gridded climate data (defined on a separate climate grid) to model cells. Recent versions of PRMS now contain a similar gridded climate data module.
- *solrad_module*: This module specifies the equation used to infill missing solar radiation data. The *ccsolrad* module was selected to compute shortwave radiation using a relation between sky cover and the daily range in air temperature.
- *transp_module*: This module determines the active transpiration method to apply during a particular time step. The *transp_tindex* method was selected and uses the temperature index method.
- *et_module*: This module specifies the method used to compute potential evapotranspiration. The *potet_jh* method was selected to compute PET using the Jensen-Haise formulation.
- *srunoff_module*: This module specifies the method used to partition runoff and infiltration. Earthfx developed a module to apply curve number (CN) method with CN values based on land use and soil type classifications and it was used in this project.
- *soilzone*: This module incorporates a suite of parameters to compute inflows and outflows from soil zone of each cell. The Strada PRMS model also incorporates the depression-storage reservoir module (released in recent PRMS versions) for pervious soils. Storage associated with ponds with areas smaller 1 hectare was accounted for using this depression storage module.

3.4 *Parameter Assignment*

Initial estimates of model parameters were assigned based on available data and were updated during the model calibration process. For parsimony, consistent assumptions and parameter values were applied across the study area, where possible. Model parameters fall into five key groups, including:

- topography-related parameters;
- land-cover related parameters;

- soil parameters derived from soils mapping;
- recharge parameters derived from surficial geology mapping; and,
- other parameters related to hydrological processes, such as snowmelt.

VIEWLOG 5.0 (Kassenaar, 2013) was used to help create, view, re-sample, and/or interpolate most gridded data sets (such as land surface elevations) and to assign parameters using lookups for tabulated values and cell-based indices. Additional data sets were created using VL-GSFLOW, a pre-processor written by Earthfx to generate input data for use in PRMS and GSFLOW simulations. VIEWLOG aided in visualizing and graphing model results and in preparing report figures.

3.4.1 Topography-related Properties

Topography for the model area is based on provincial LiDAR elevation data release in September 2023. Topography used in the PRMS model is shown for the PRMS model area in Figure 3.5. Three distinct zones can be distinguished in the study area based on their approximate elevation ranges: the zone above the Niagara Escarpment, extending from elevation 420 to 520 masl; the Niagara Escarpment zone, ranging in elevation from 300 to 420 masl; and the zone below the Niagara Escarpment, which ranges between 230 and 300 masl. The zone above the Niagara Escarpment is the largest of the three zones.

Slope and slope aspect values were calculated from the DEM coverage. Slope is shown in Figure 3.6 and highlights the steep slopes in the Niagara Escarpment zone and gentler slopes elsewhere. Milder slopes dominate in the zone above the Niagara Escarpment.

The soil-water balance is computed in the PRMS model on a cell-by-cell basis. Each cell has unique properties and is influenced by the processes in upslope cells, so cell response is much more complex than in simple hydrologic response unit models. Cells are connected through the runoff process, where Hortonian runoff and interflow from a particular cell can run on to a neighbouring cell along the topographically-driven cascade flow network. Terrain analysis techniques were applied to the DEM to create the cascade overland/interflow flow routing network. An 8-direction steepest-descent method was selected because it generates an efficient many-to-one cascade network. An example of the cascade flow network, along with the resampled land surface topography, is presented in Figure 3.7. The cascade pathline goes from cell to cell until a stream, lake, or a closed depression (referred to in PRMS literature as a “swale”) is encountered.

Most PRMS swales identified when generating the cascade network were true depressions. However, some “swales” occurred due to incomplete mapping of streams and drainage features, the presence of storm sewers and other infrastructure that drain the swales in urban areas, inconsistencies in the DEM, or problems caused by upscaling the DEM to the model grid. These false swales can create problems for the PRMS model, for example, where a long cascade pathway terminates without reaching a stream or other natural discharge point. While there are automated routines that can infill holes or otherwise “correct” the DEM and remove all closed depression swales, the codes can also remove real depressions such as the hummocky topography that is common in glaciated terrain. Accordingly, we iteratively generated the cascade network, visually inspected each swale, and then resolved as many of the mapping issues as possible by finding the lowest elevation pathway out of the swale, where appropriate. A final pass was completed whereby unresolved false swales were manually rerouted to the nearest cell with a lower elevation point that led to a true cascade endpoint. The final cascade network (light grey lines), swales, and the rerouted links (dark blue arrows), are shown in Figure 3.7.

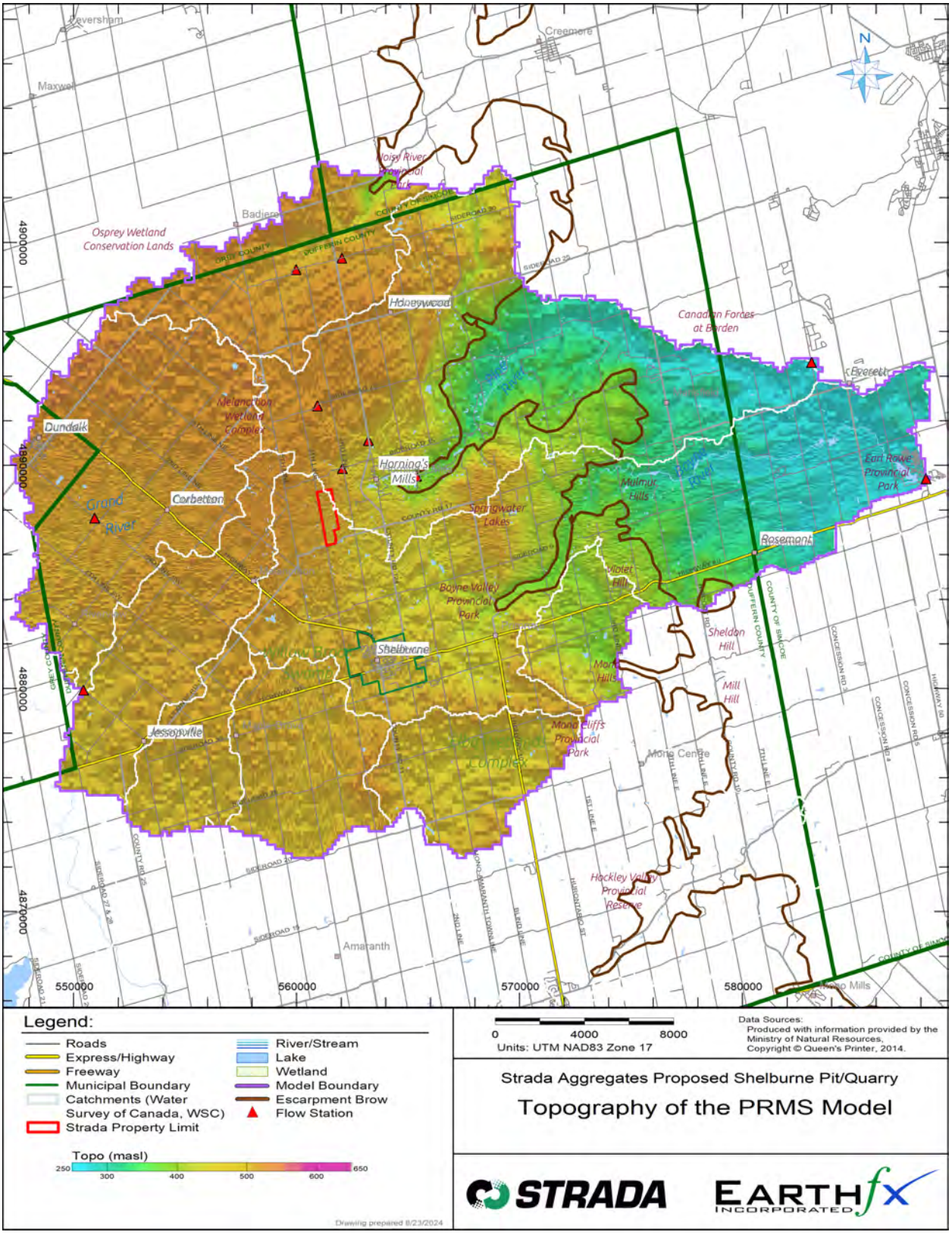


Figure 3.5: PRMS model topography.

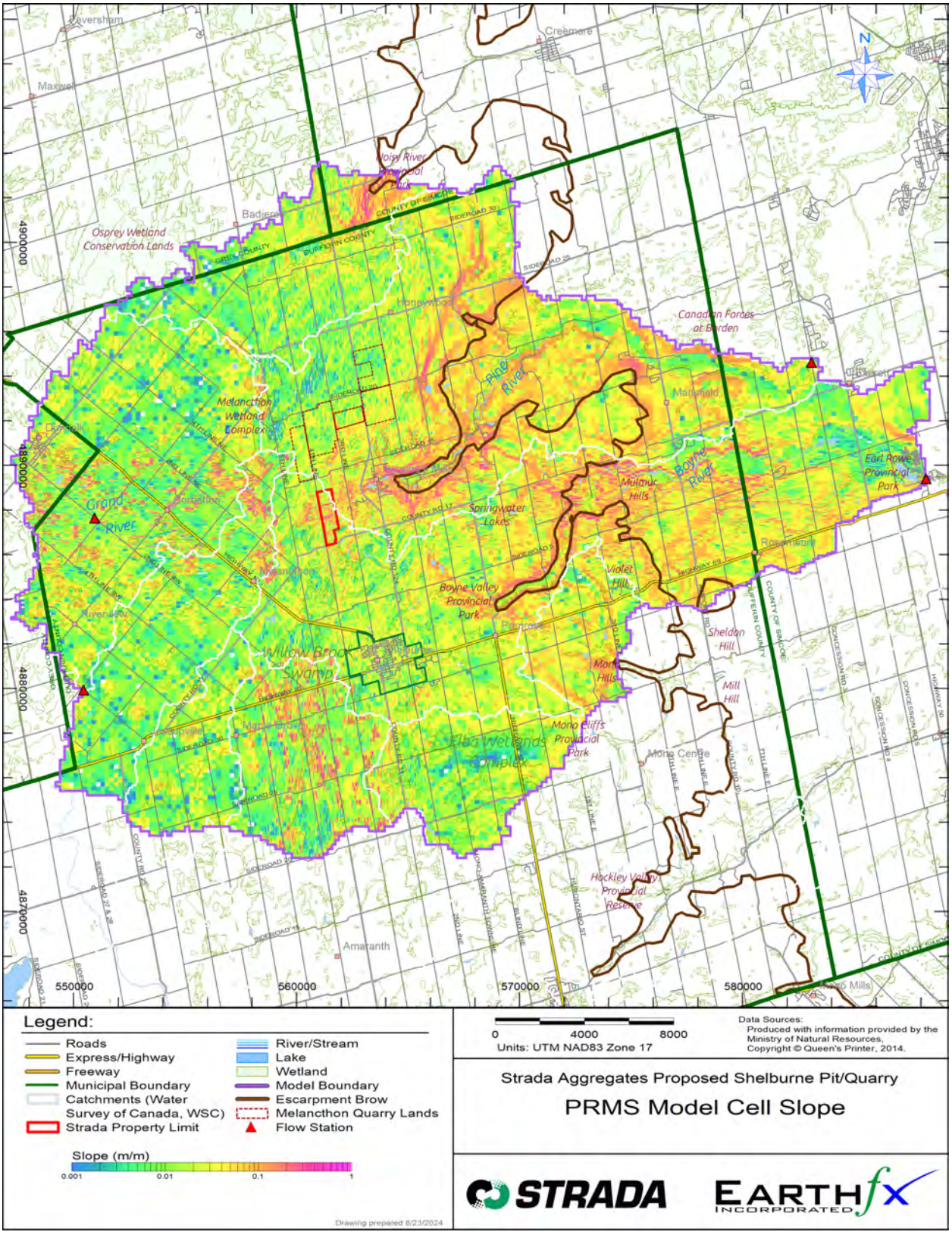


Figure 3.6: PRMS model cell slope.

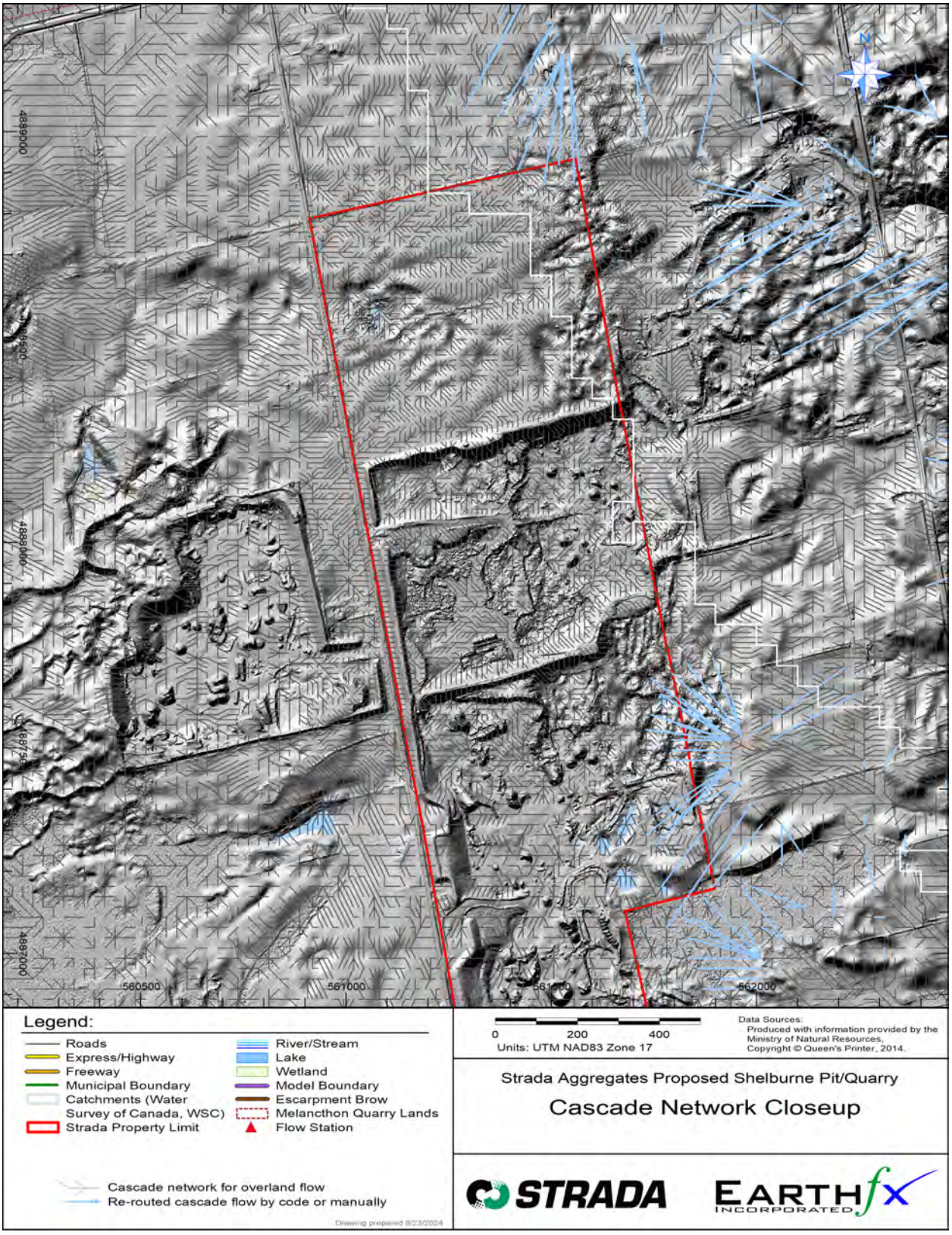


Figure 3.7: Close-up of the cascade network near the northern portion of the Strada site.

3.4.2 Surficial Geology and Soil Properties

Soil properties have a significant influence on hydrological processes because they control the amount of water that can infiltrate and be transmitted to the water table as well as the amount of water that runs off or is lost to actual ET. Soil water-holding capacity in the capillary and gravity reservoirs were calculated in VL-GSFLOW as functions of soil zone thickness, porosity (n), field capacity (fc), and wilting point (wp), which were all distributed from soil survey classes. Specific parameters in PRMS that define the water-holding capacity include: the soil saturation threshold, initial and maximum soil moisture, and initial and maximum storage of water for soil recharge zone. Parameters that controlled the partitioning of flow between interflow and percolation to the water table were also specified as soil-type properties.

The surficial geology map developed by the Ministry of Northern Development and Mines (MNDM, 2012) was used to distribute hydrological properties of surficial materials over the model area (Figure 3.8). These properties were assigned to cells using tabulated look-up values. The surficial geology, their respective soil type, and depositional environment are listed in Table 3.1. Surficial geology was used as the primary guidance for assigning the bulk of the soil properties, given the more descriptive nature of the surficial geology and its greater number of categories.

The agricultural soil texture map developed by Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) was also used to assign hydrological input parameters (Figure 3.9). The older 1964 Soil Survey of Dufferin County document and map (Hoffman and Matthews, 1964) was also reviewed, as was a report by Torrance, 2009, on the Honeywood Soil Series. Specifically, the CN soil type number, needed to properly assign SCS curve numbers, was assigned based on the drainage condition of the soils. The breakdown of the soil texture categories found in the calibration catchments and in the entire area is presented in Table 3.2.

Loamy soils are present west and north of the Strada site and extending well beyond the Town of Honeywood where a better-drained loamy soil variant can be found (i.e., Honeywood loam) than the original wind-blown loess base material. In this area, the surficial geology classification within the loamy soil area is more diverse, as it is underlain by Tavistock and Catfish Creek tills, to the west and north of the Strada site, and with interstadial deposits of outwash, bog deposits, and river alluvium to the northeast.

Soils surrounding the Melancthon Wetland Complex, located northwest of the Strada property, are predominantly sandy loam, fine sandy loam, loam, and organics, which are underlain by glacial outwash, bog deposits, river alluvium, and ice-contact stratified deposits. These soil texture classes also surround the immediate vicinity of the Strada property overlaying primarily ice-contact stratified and bog deposits. These deposits are characterized by sands and gravel with some till and silt and they extend as far as the Niagara Escarpment brow to the east of the property, followed by glaciofluvial outwash (sand and gravel) and glacial-outwash (gravel) deposits below the Niagara Escarpment and within the re-entrants.

A close-up of the surficial geologic features around the project site is shown in Figure 3.10. It also includes the estimated location of high recharge areas identified in the field (information provided by Hunter & Associates) that might be related to presence of a localized Karst environment. A lookup/assignment algorithm in VIEWLOG 5.0 (Kassenaar, 2013) was used to distribute soil-type related parameters to the PRMS model cells. Given the more descriptive nature of the surficial geology and its greater number of categories, the surficial geology coverage was felt to be more appropriate for spatially distributing values to model parameters. The distribution of vertical groundwater seepage rates, as assigned using the lookup procedure, is shown in Figure 3.11, as an example of a spatially-distributed soil-based parameter.

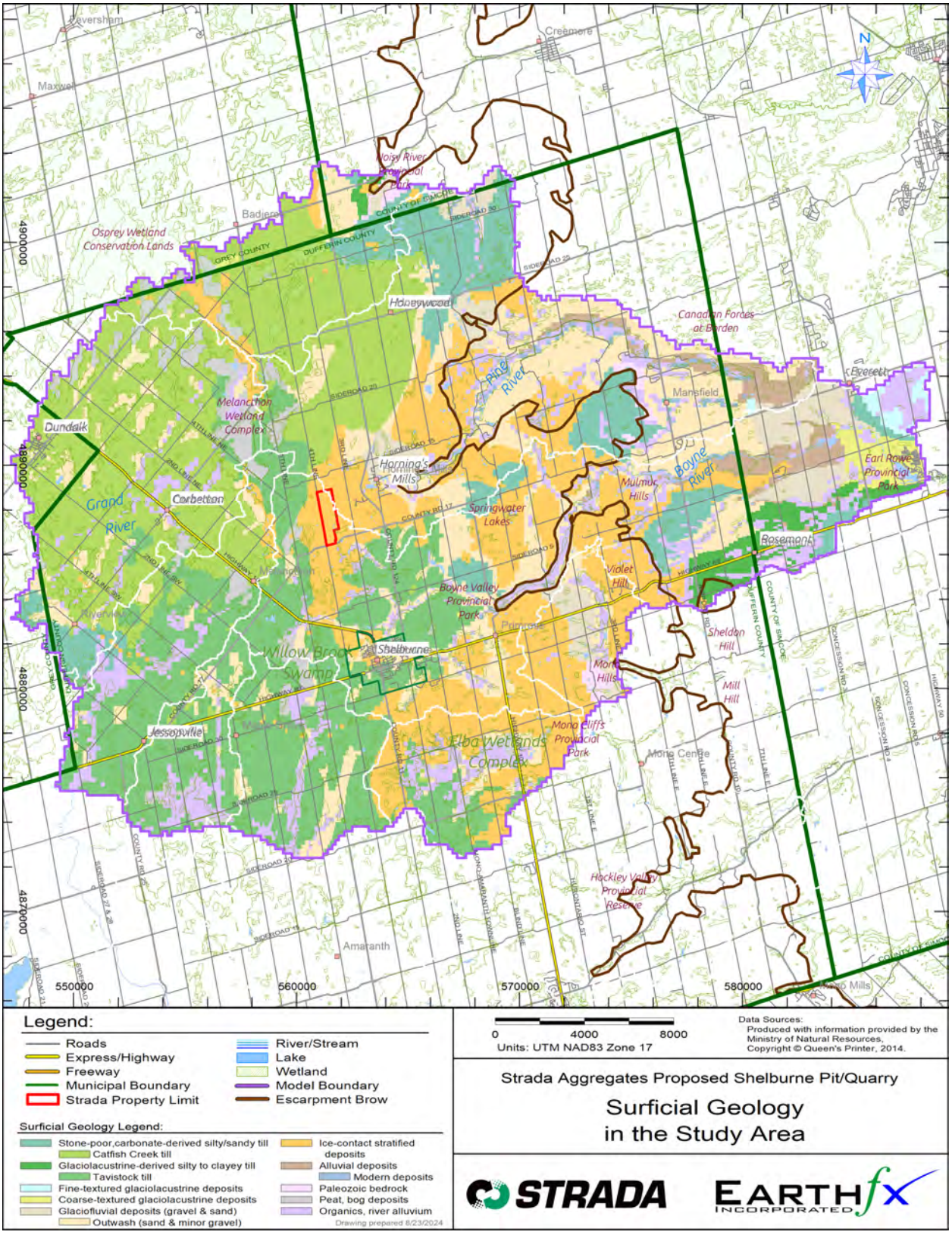


Figure 3.8: Quaternary geology (OGS, 2010).

Table 3.1: Geologic and soil material parameters used in final calibration.

Index	Surficial Geology	% Area	Soil Type	CN Soil Type	Porosity (n)	Field Capacity (fc)	Soil Depth (mm)	Evap. Extinction Depth Storage (mm)	Depres. Storage Seepage Rate (frac/d)
Paleozoic Bedrock									
151	Limy mudrock and clastic sedimentary rock	0.4%	2	2	0.35	0.15	356	50	1.5E-02
150	Various (Bedrock,Sandstone, dolostone, shale)	0.1%	2	2	0.35	0.15	356	50	1.5E-02
Stone-poor, carbonate-derived silty to sandy till									
210	Sandy silt to Sand till (Glacial deposits)	20.4%	3	1	0.35	0.2	51	75	5.0E-02
212	Catfish Creek till	1.1%	3	2	0.35	0.2	584	75	4.0E-02
219	Newmarket till (Sandy silt till)	8.4%	3	1	0.35	0.2	203	75	2.0E-03
Glaciolacustrine-derived silty to clayey till									
254	Tavistock till	9.0%	3	1	0.35	0.2	483	75	1.0E-04
265	Glacial deposits (Wildfield/Kettleby Till)	2.3%	3	1	0.35	0.2	254	75	5.0E-04
Ice-contact stratified deposits									
300	Sand and gravel including some till or silt	19.2%	1	4	0.4	0.17	635	50	8.0E-02
Glaciofluvial deposits									
400	Gravel and gravelly sand	3.0%	1	4	0.4	0.1	762	50	1.2E-01
410	Sand, minor gravel (Glaciofluvial outwash)	17.8%	1	4	0.4	0.15	559	50	1.5E-01
420	Glacial-outwash Gravel	1.3%	1	4	0.35	0.1	356	50	7.0E-02
Fine-textured glaciolacustrine deposits									
511	Mainly silt and clay (Glaciolacustrine)	0.6%	3	1	0.35	0.15	356	125	7.0E-02
Coarse-texture glaciolacustrine deposits									
630	Mainly fine to very fine sand (Glaciolacustrine)	1.4%	1	4	0.35	0.15	356	50	1.0E-02
Alluvial deposits									
900	Gravel, sand, silt, clay; 1-8m thick	2.8%	1	4	0.35	0.15	356	50	1.0E-02
Modern alluvial deposits									
1400	Fine sand in sand dunes (wind-blown)	0.0%	1	4	0.4	0.17	356	50	2.5E-02
1600	Gravel, sand, silt, clay, muck	0.7%	2	1	0.35	0.15	356	50	4.0E-02
Organic deposits									
1700	Peat, Muck, And Marl (Bog Deposits)	2.5%	3	2	0.75	0.5	203	50	4.0E-02
9999	Organics and river alluvium	8.9%	2	3	0.38	0.18	406	63	1.0E-02

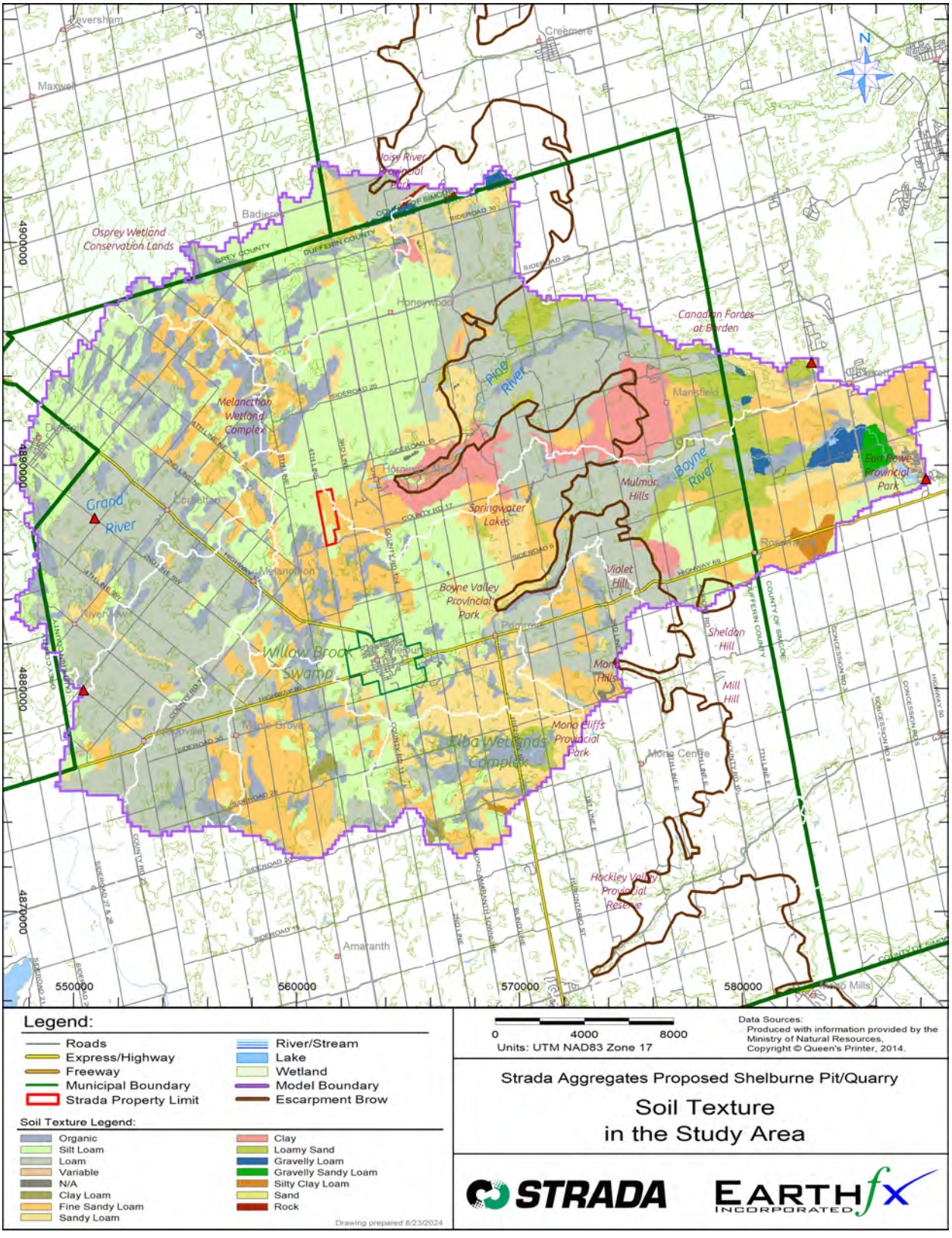


Figure 3.9: Soil texture.

Table 3.2: Coverage of soil texture among calibration catchments and the entire model area, in percentage.

Map Id	Texture	CN Soil Type	Boyne River at Earl Rowe Park (%)	Pine River near Everett (%)	Grand River near Dundalk (%)	Grand River near Riverview (%)	Entire Model Area (%)
ORG	Organic	1	6.8	4.2	*26.4*	13.9	10.4
SIL	Silty Loam	2	*26.5*	22.7	23.8	28.4	18.8
L	Loam	3	17.9	*33.4*	*26.3*	*52.8*	*26.8*
VAR	Variable	3	0.4	0.3			0.4
Blank	N/A	1	0.1	0.1			3.5
CL	Clay Loam	1					0.2
FSL	Fine Sandy Loam	2	19.9	8.0	21.4	2.2	12.3
SL	Sandy Loam	3	15.8	9.3	2.0	2.6	10.8
C	Clay	1	1.8	12.6			2.1
LS	Loamy Sand	3	6.6	8.6	0.1		12.0
GL	Gravelly Loam	3	1.6	0.8			0.7
GSL	Gravelly Sandy Loam	4	1.1				0.2
SICL	Silty Clay Loam	2	1.3				1.6
S	Sand	4					0.0
R	Rock	1		0.1			0.1

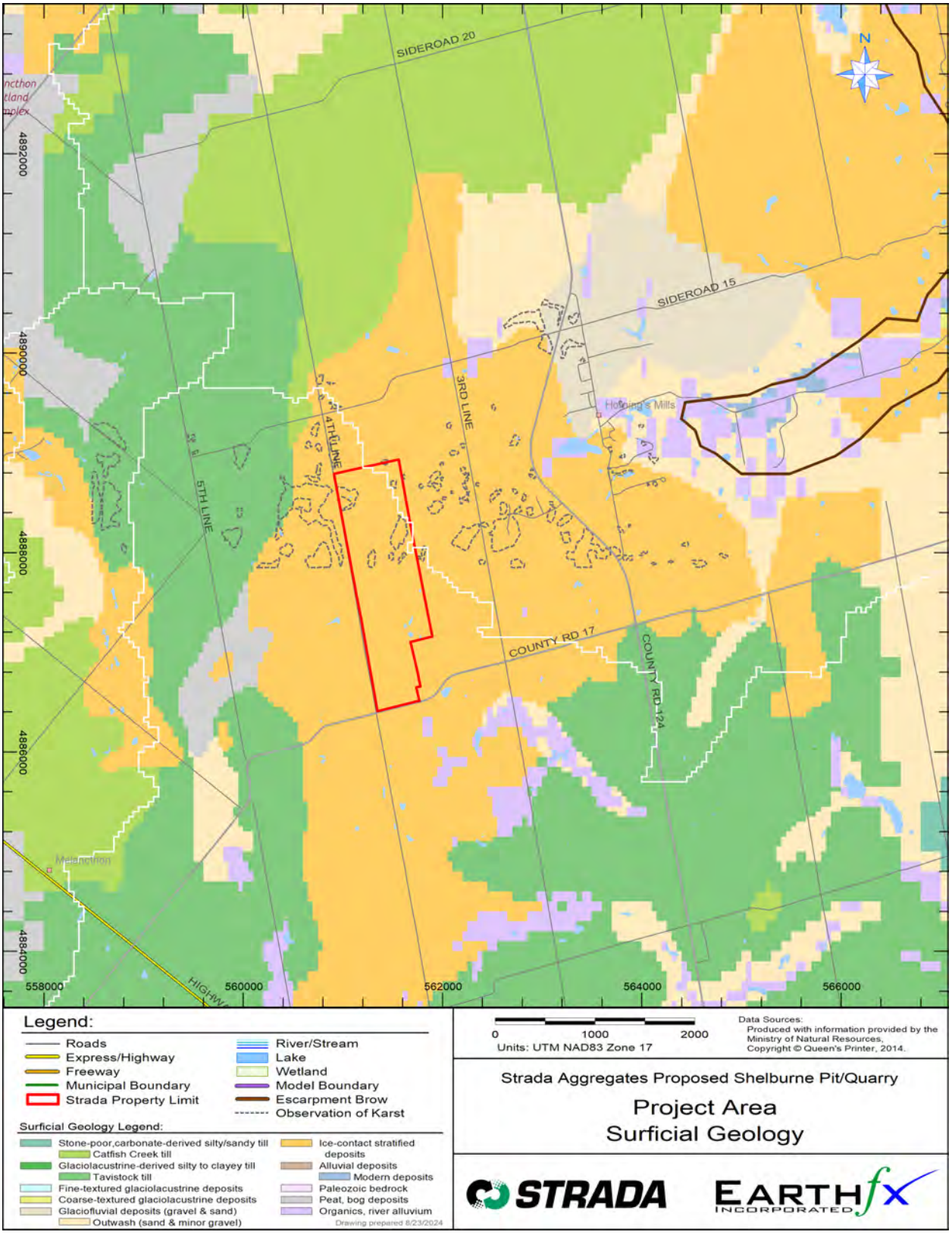


Figure 3.10: Quaternary geology in the project area.

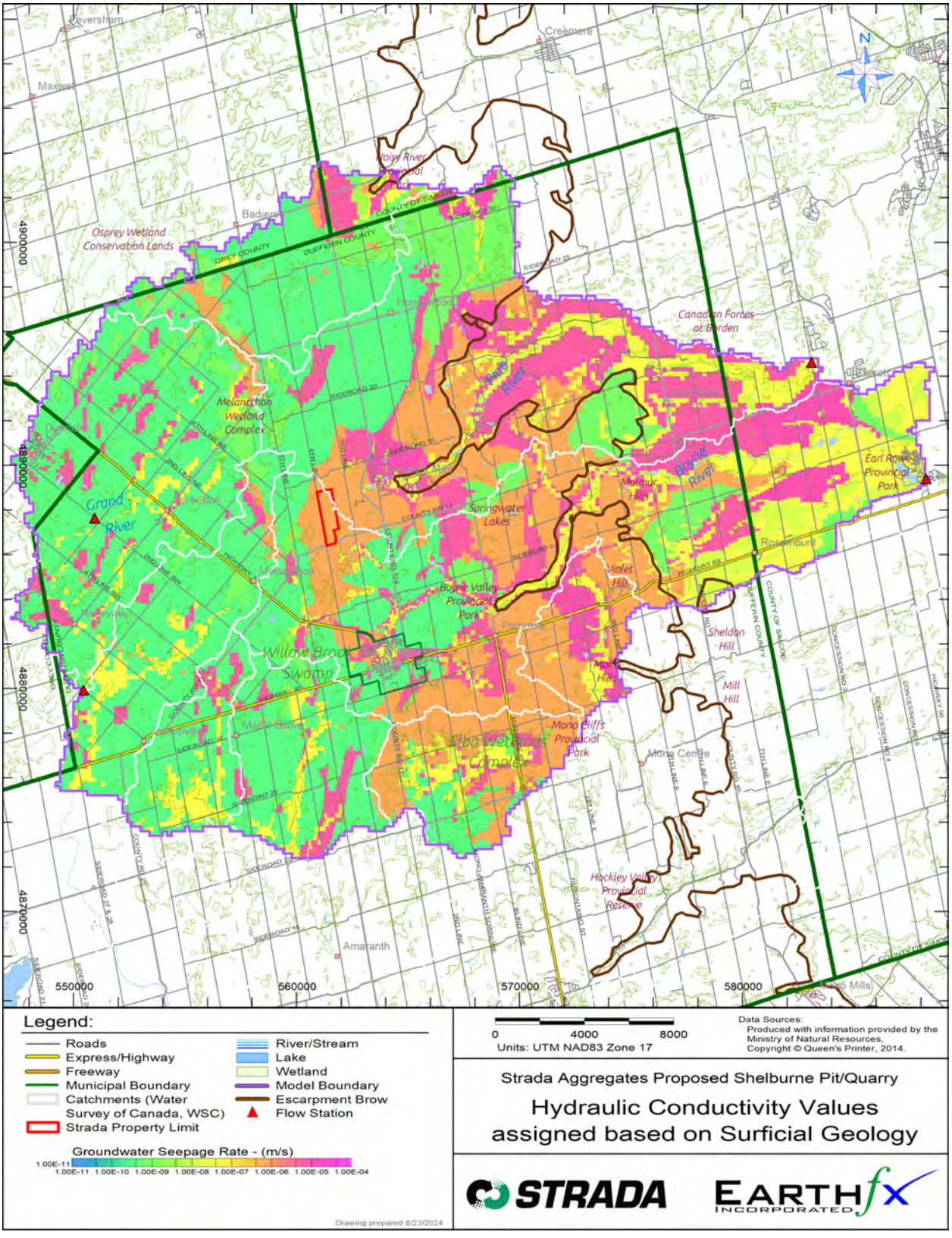


Figure 3.11: Surficial soil vertical hydraulic conductivity.

3.4.3 Land Use-related Properties

Land use and land cover strongly influence hydrologic response, especially in a fully distributed model such as PRMS. SOLRIS v3.0 was the first source of land use data considered for the study area. However, the percentage of land use labeled as 'undifferentiated' (37%) within the model area was too great to ignore. Therefore, this unknown characterization was diminished by complementing it with the Grand River Conservation Authority's (GRCA) land cover classification from the year 1999. The 'undifferentiated' category overlapped pasture, forage, and bare agricultural fields of the GRCA land use coverage, which are land use categories non-existent in the SOLRIS dataset. They were then incorporated as a single land use category named 'Pasture/Forage/Bare Agricultural Fields' with the SOLRIS code of 251 as they all share similar hydrological features.

The resulting land use coverage for the study area spans the time period between 1999 and 2015, which elapses the period chosen for hydrological analysis (see Section 3.6.1). The distribution of land use classes is summarized in Figure 3.12.

The dataset was indexed and sampled to the PRMS grid (Figure 3.13). The land use data was broken down into 18 categories that were the baseline to distribute hydrologic properties. An underlying assumption was that the hydrologic properties for a particular land-use class (e.g., "Row crop") were the same in one part of the model area as another. Hydrologic properties included:

- percent imperviousness–- the fraction of the cell area assumed to be impervious;
- depression storage–- the amount of water retained over impervious areas;
- vegetation index – dominant vegetation type (bare, grass, shrub, or trees) in the cell;
- vegetative cover density–- the fraction of pervious area covered by vegetation and/or tree canopy. Two values are provided: one for the growing season and one for winter;
- interception storage–- the amount of precipitation retained on vegetative surfaces and/or tree canopy. Three values are provided: interception storage for summer rain, winter rain, and winter snow. Effective interception capacity is the product of vegetative cover density and interception storage.
- soil zone and extinction depth thickness – Soil zone thickness is used (along with porosity, field capacity and wilting point) in calculating the size of the capillary and gravity reservoirs. Extinction depth fixes the size of the upper root zone for ET.

Figure 3.14 provides a more detailed view of the land use around the project area.

The land use lookup table used to assign properties for the model area is provided in Table 3.3. After close inspection of the consolidated land use distribution from two data sources, the assumption of consistent property values across the study area was perceived to be reasonable for most land use classes. The 'undifferentiated' land use category in the SOLRIS v3.0 coverage was reduced from 37% to 24.4% (compared to earlier coverages), and the model parameters for this category were assumed to be similar to treed swamp and pasture lands, as the coverage overlays a wide range of undeveloped lands with comparable features. Figure 3.15 shows the percent impervious cover assigned to the consolidated land use.

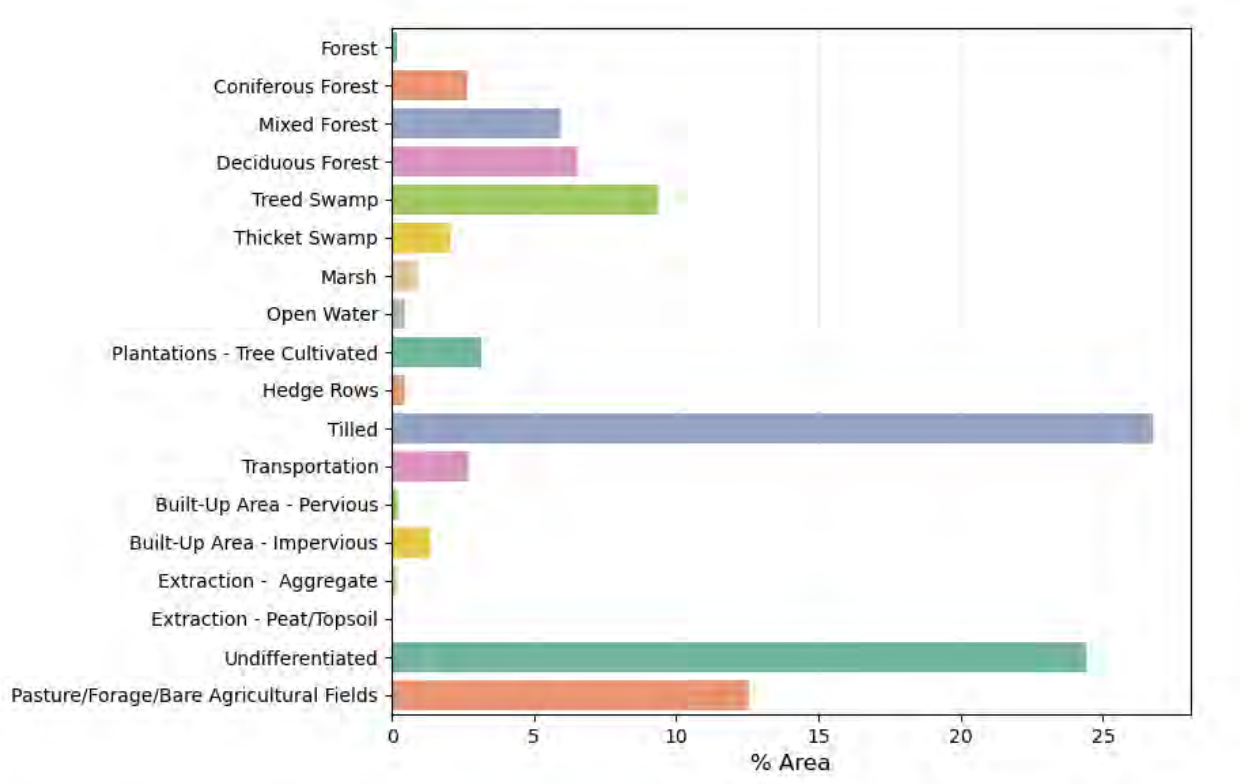


Figure 3.12. Land use breakdown in the model area.

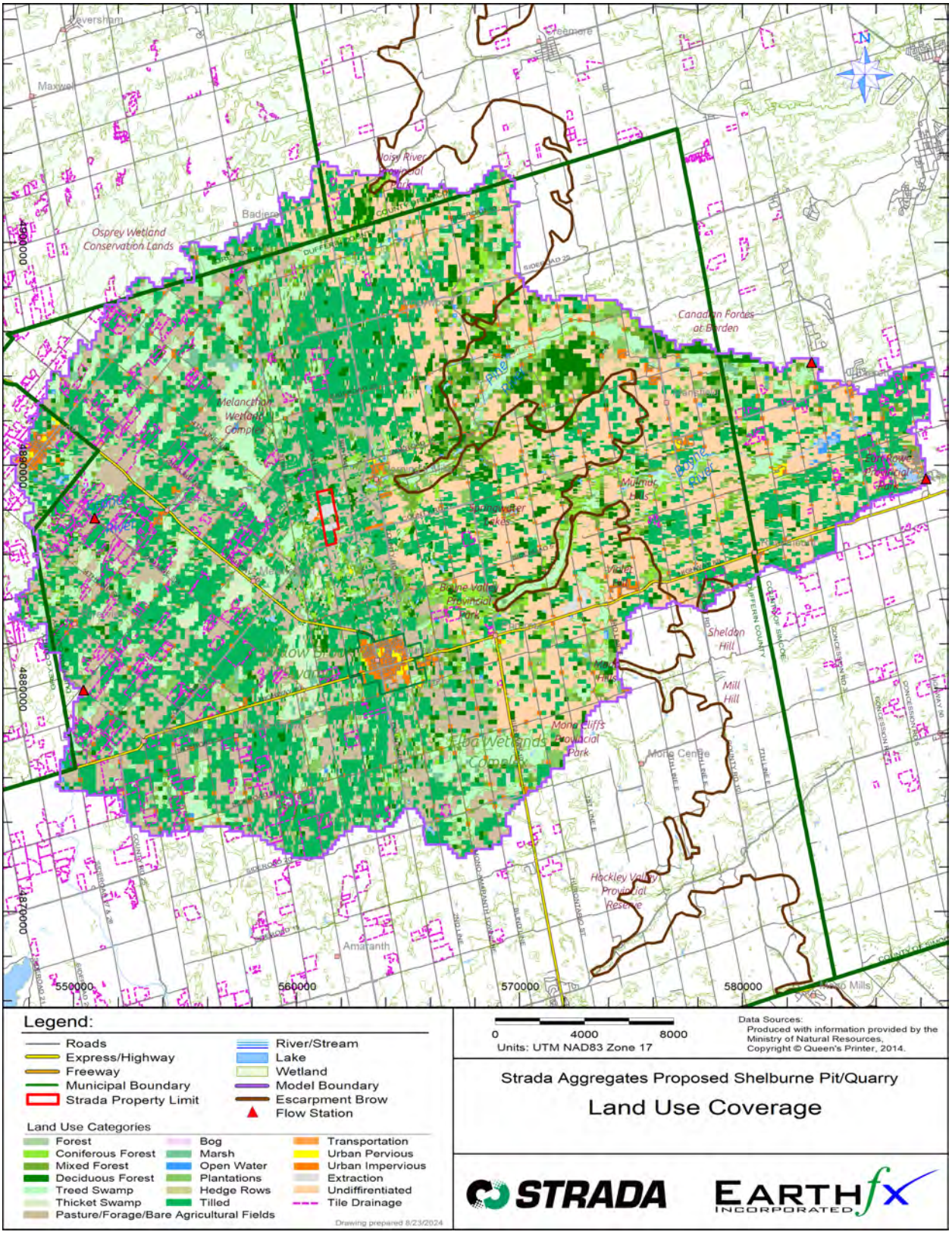


Figure 3.13: Land use classification.

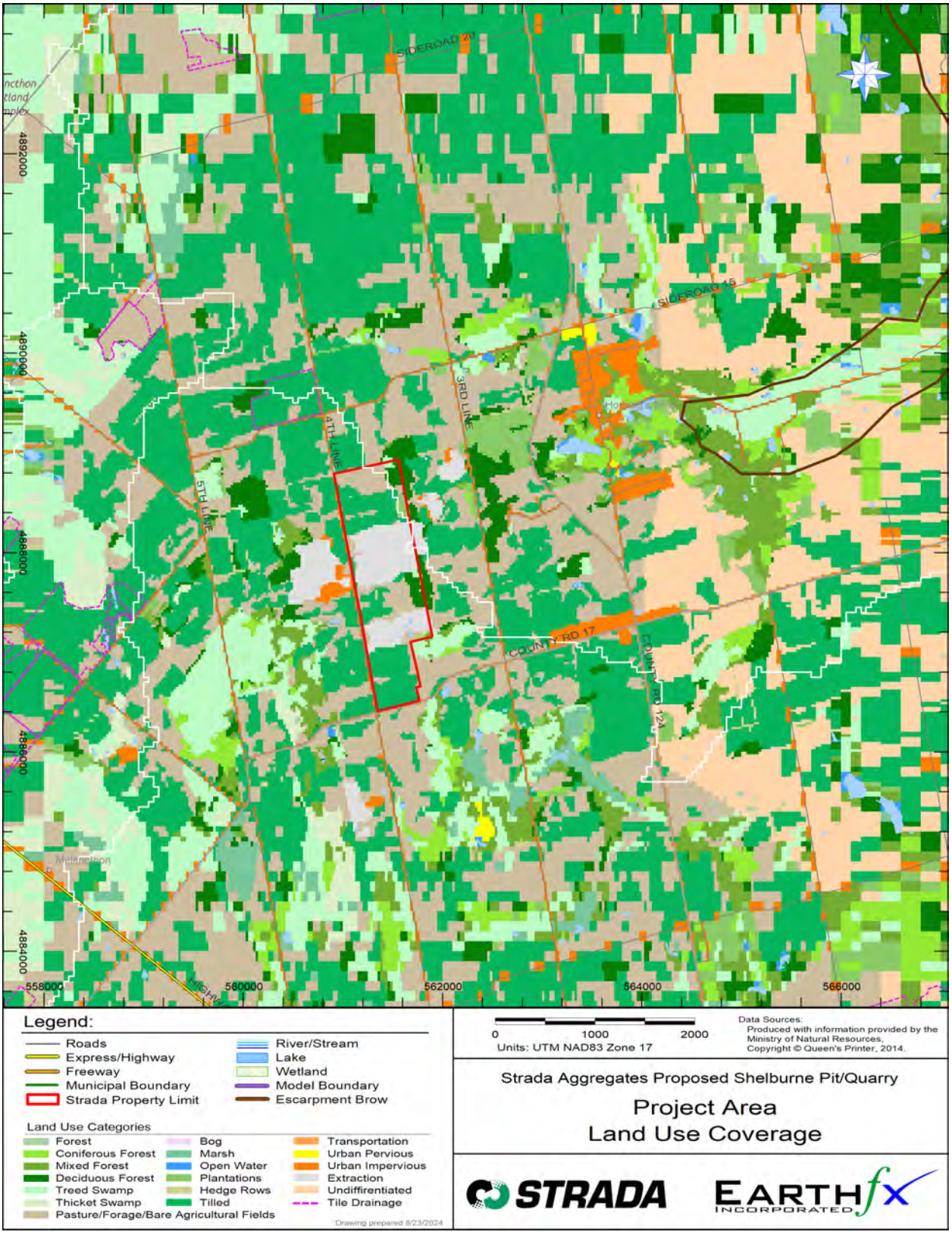


Figure 3.14: Land use coverage in the project area.

Table 3.3: Land use lookup table.

Index	Description	% Area	% Imperv.	% Return Imperv.	Imperv. Maximum Storage (mm)	Vegetation Index	Summer Cover Density	Winter Cover Density	Summer Rain Intercep. (mm)	Winter Rain Intercep. (mm)	Snow Intercep. (mm)	Depres. Storage Avg Depth (mm).
90	Forest	0.17%	0	0	0	3	0.9	0.5	3.5	2.25	3.5	178
91	Coniferous Forest	2.67%	0	0	0	3	1	0.85	3.5	3	3	178
92	Mixed Forest	5.94%	0	0	0	3	0.9	0.5	3.5	2.25	3.5	178
93	Deciduous Forest	6.56%	0	0	0	3	1	0.4	3.5	1.5	1	178
131	Treed Swamp	9.34%	0	0	0	3	1	0.4	1.5	1	3.5	229
135	Thicket Swamp	2.05%	0	0	0	1	0.75	0.5	1.8	1.25	1	229
160	Marsh	0.91%	0	0.15	0	1	0.75	0.5	1.5	0.75	0.375	127
170	Open Water	0.49%	0.7	0	3	0	0	0	0	0	0	305
191	Plantations–- Tree Cultivated	3.16%	0	0.15	0	3	0.95	0.6	3.5	1.5	0.75	127
192	Hedge Rows	0.48%	0	0.15	0	2	0.75	0.25	2	1	0.5	127
193	Tilled	26.76%	0.05	0	0	2	0.85	0.1	2	0.25	0.25	127
201	Transportation	2.70%	0.9	0.2	2	1	0.1	0.1	1	1	1	127
202	Built-Up Area–- Pervious	0.23%	0.2	0.5	2	2	0.9	0.5	2	1	0.5	127
203	Built-Up Area–- Impervious	1.32%	0.4	0.35	3	1	0.75	0.35	1.5	0.75	0.5	127
204	Extraction–- Aggregate	0.21%	0.25	0.2	15	0	0	0	0	0	0	508
205	Extraction–- Peat/Topsoil	0.00%	0	0.15	0	1	1	0.7	1	0.5	0	127
250	Undifferentiated	24.42%	0.03	0.425	0.5	1	0.25	0.125	1	0.25	0.5	127
251	Pasture/Forage/ Bare Agricultural Fields	12.57%	0.02	0.85	1	1	0.85	0.25	1.5	1	2	127

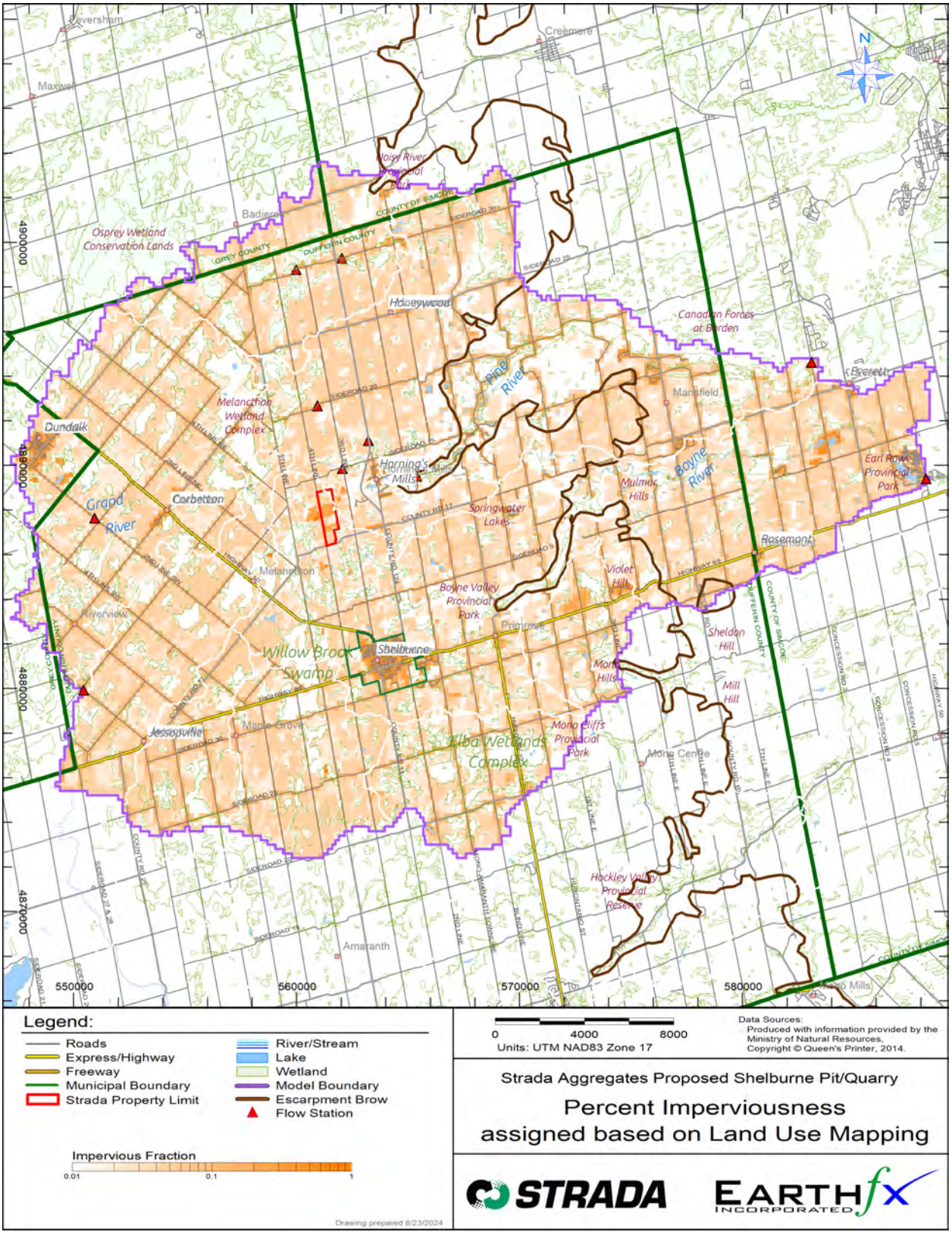


Figure 3.15: Percent impervious cover per cell assigned based on land use coverage.

3.4.4 Hydrological Processes Parameters

As noted earlier, the modified Jensen-Haise method (Jensen and Haise, 1963) was used to estimate daily PET. In addition to daily temperature and incoming global solar radiation values, the method requires two additional user-specified parameters. These can be estimated using regional air temperature, altitude, vapor pressure, and plant cover, as discussed in Markstrom *et al.* (2008). The first term serves as a monthly factor to better match measured PET. The second term essentially acts as an elevation correction factor with less PET at higher elevations.

$$jh\ coef\ hru_{HRU} = 27.5 - \left[0.25 \times \left(\rho_{high\ temp} - \rho_{low\ temp}\right)\right] - \frac{hru\ elev_{HRU}}{1000}$$

Where ρ stands for the saturation vapor pressure for the mean maximum and minimum air temperature for the warmest month of the year. This parameter is calculated for each cell in the grid using the surface calculation feature in VIEWLOG.

The snowpack submodel has a large number of additional parameters. For simplicity and consistency, uniform (basin-wide) values were used where appropriate. Independent testing of the process submodels was done to determine optimal values for the parameter. For this study, the calculated snow pack depths were compared against snow course measurements of snow depth and snow pack water equivalent at Environment Canada climate stations in the study area, and to locally consolidated radar snow depth data (i.e., CaPA System, see Section 3.5.2).

As mentioned in section 3.3, the depression-storage submodule was incorporated in the PRMS model to account for natural and man-made depressions on permeable surfaces. These depressions capture runoff from pervious and/or impervious surfaces, making it available for groundwater recharge, evaporation, and slow release to the cascade network. Specifically, ponds smaller than 1 hectare were not represented explicitly as MODFLOW “lakes” (Section 4.4.2) but their areas were included in PRMS as part of depression-storage of the cells they were in, in addition to nominal depression storage applied to the cell. In urban areas, the depression storage was used to represent storm water detention facilities and low-lying paved areas with drainage infrastructure. The seepage rate from depression storage was assigned based on the hydraulic conductivity of the surficial materials.

3.5 *Climate Data Sets*

Three datasets were analysed to characterize the climate of the study area. The datasets include 1) daily precipitation, 2) maximum and minimum daily air temperature, and 3) daily net incoming solar irradiation.

3.5.1 **Precipitation and Temperature**

Precipitation and temperature data collected at Environment Canada AES and GRCA stations proximal to the study area was used as a primary model input. The period of record varies among the available climate data sources; however, a continuous climate dataset was compiled beginning in water year (WY) 1866 through WY2020 (note: water years begin on October 1 of the preceding calendar year). Data from 66 stations were available within this time period. Figure 3.16 shows the stations located inside and within 35 km from the center of the study area.

Daily measurements recorded at each climate station were interpolated to a 1-km grid using an inverse distance weighted technique. As part of the data analysis, average annual precipitation and temperature for each station were interpolated over the study area as shown in Figure 3.17 and Figure 3.18, respectively. The precipitation distribution shows an increasing trend from all directions towards the northwest, exhibiting its lowest values in the east. This behaviour may be related to the Niagara Escarpment where lower elevations tend to receive less precipitation. The gradient for temperature across the study area increases from west to east, exhibiting a variation of up to 4ºC. There seems to be a clearer pattern pointing at the Niagara Escarpment as a boundary effect, creating colder temperatures above it. Areas of low temperatures and high precipitation dominate in the west and northwest, whereas areas of high temperatures and low precipitation are most likely to be found in the east.

Figure 3.19 and Figure 3.20 show the distribution of precipitation and temperature for the last 30 years (WY1990 – WY2020). These can be compared to the corresponding figures for the full historical period. In general, the figures show similar precipitation patterns across the region, although recent precipitation (Figure 3.19) appears to be both less spatially variable (i.e., less spotty) and slightly more extreme (i.e., greater range in precipitation within model area) than the historical. The decommissioning of stations strongly affects results, but a general trend of increasing annual precipitation might be discerned. A general rise in average temperatures can be discerned, as opposed to precipitation where locations of high and low precipitation exhibit higher and lower precipitation, respectively, in the last 30 years. The variation in the number of stations reporting precipitation and temperature and the different periods of record make it difficult to confirm these assertions for both parameters.

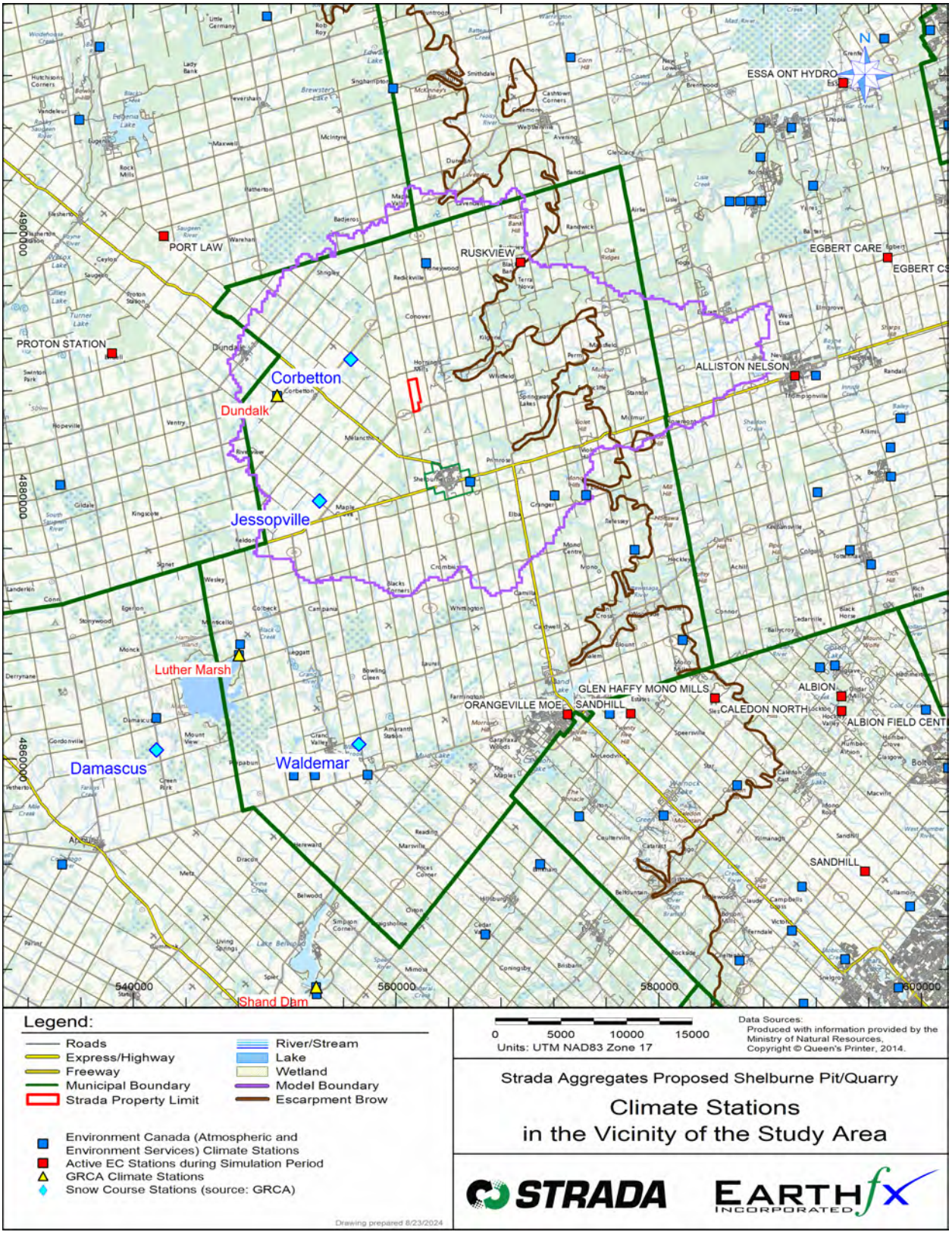


Figure 3.16: Environment Canada AES climate stations within 35 km of the project area.

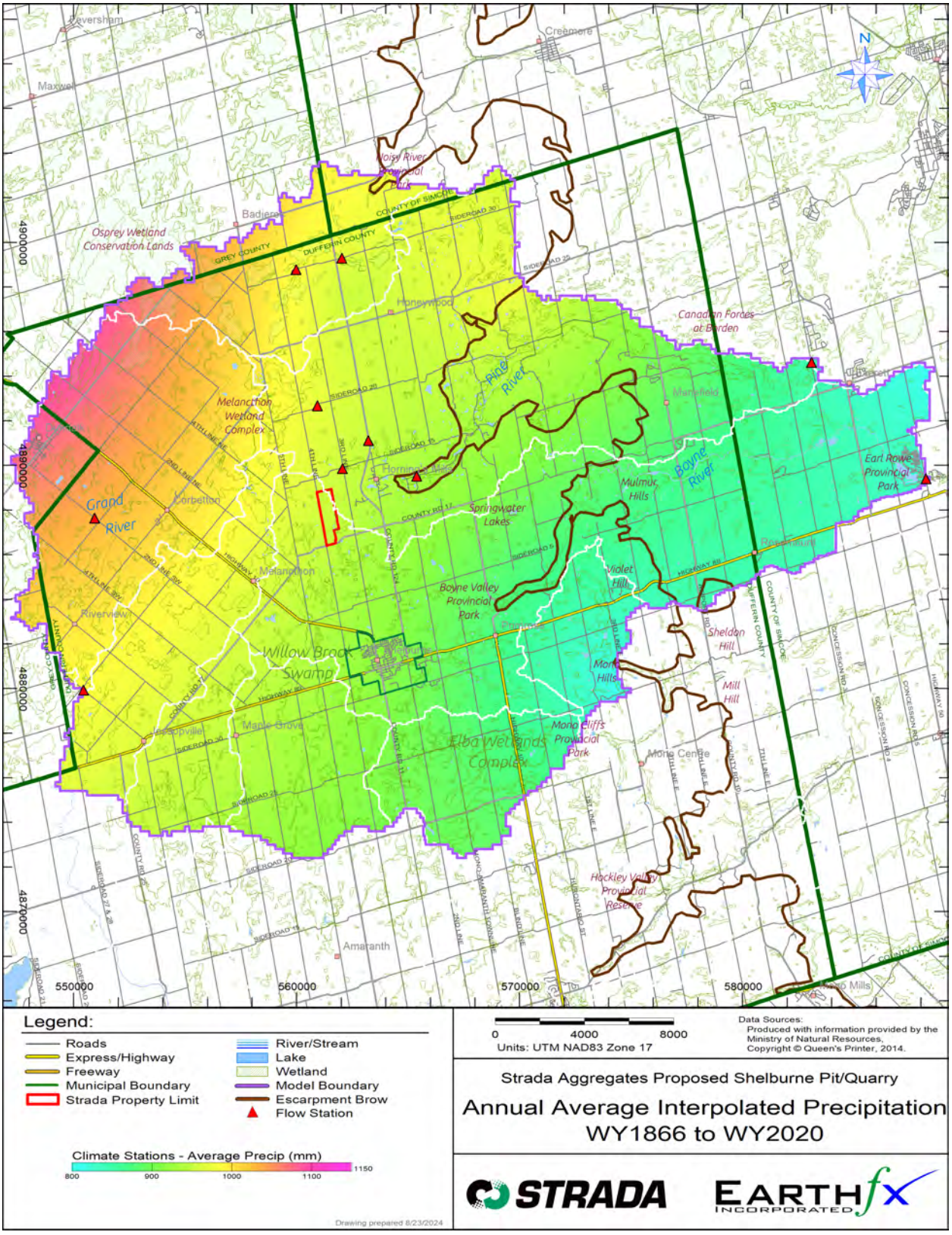


Figure 3.17: Interpolated annual average precipitation (data from WY1866 to WY2020).

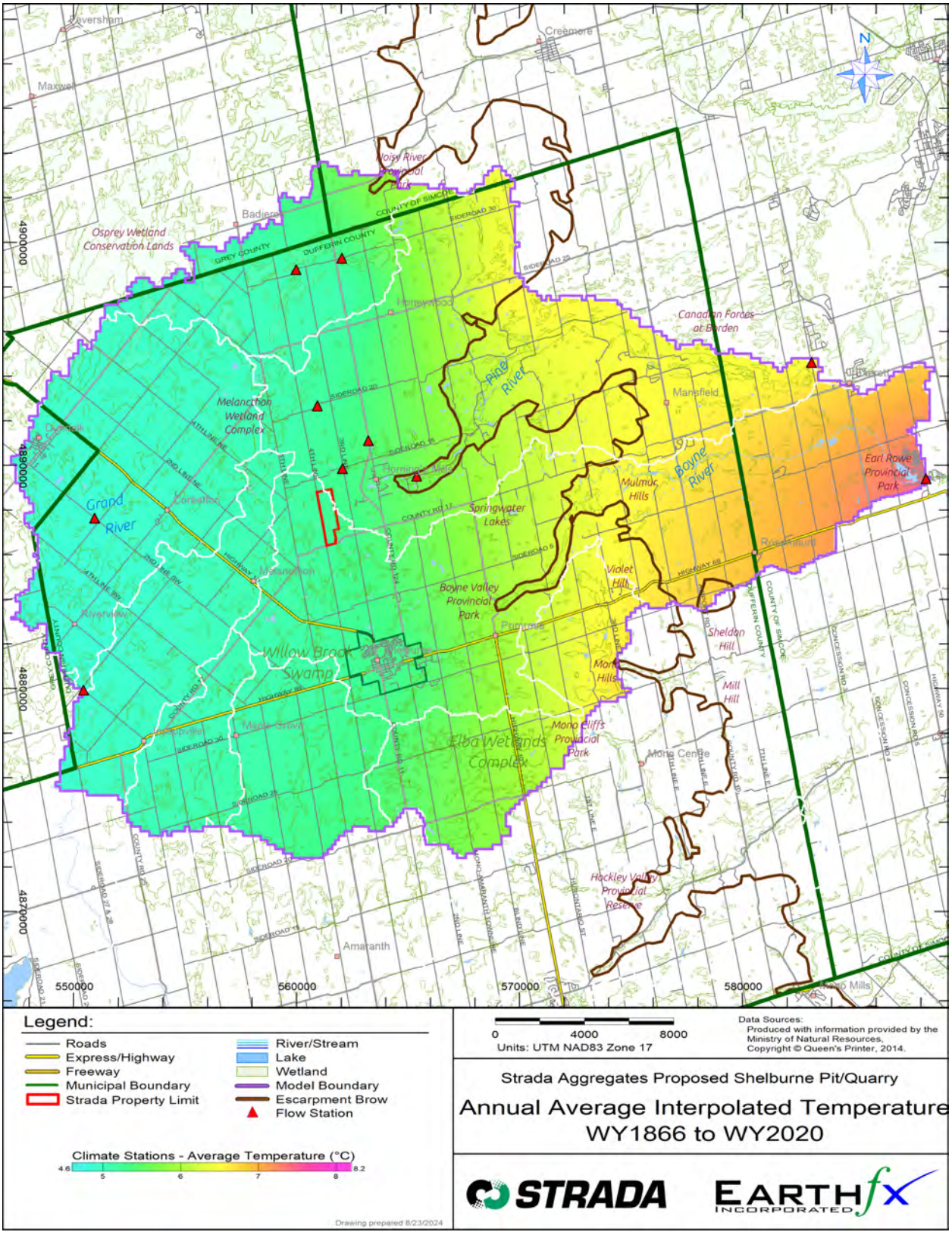


Figure 3.18: Interpolated annual average temperature (data from WY1866 to WY2020).

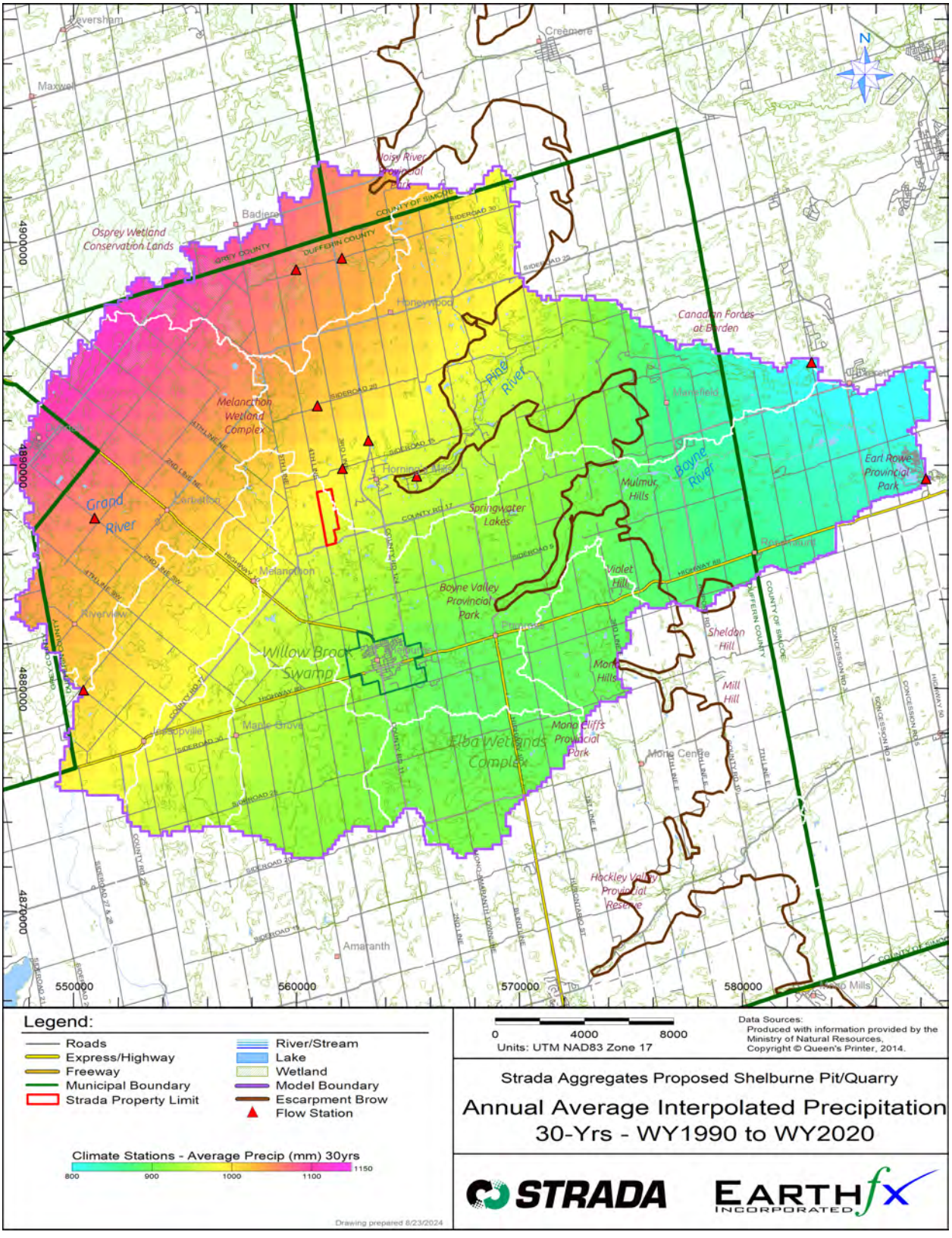


Figure 3.19: Interpolated annual average precipitation (data from WY1990 to WY2020).

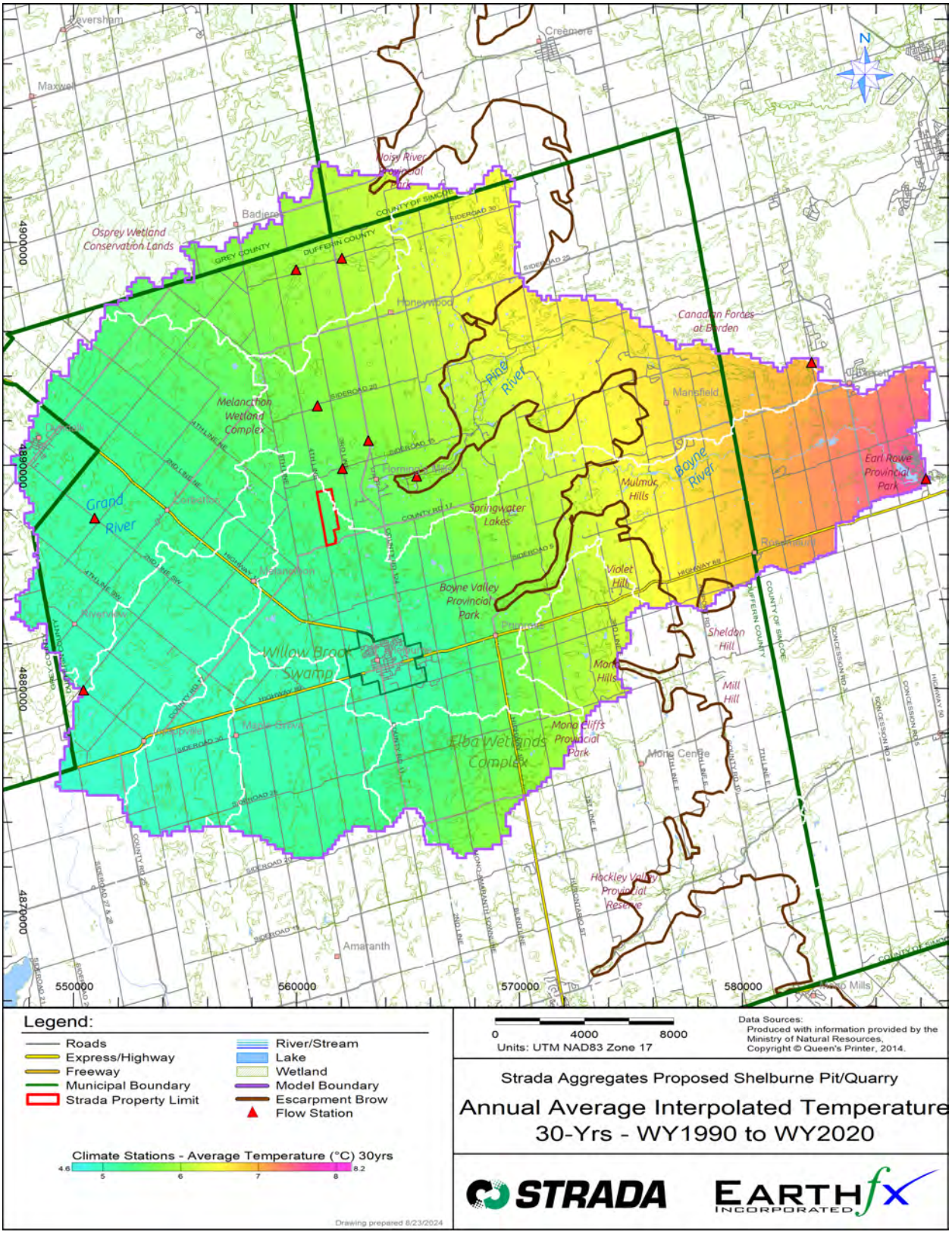


Figure 3.20: Interpolated annual average temperature (data from WY1990 to WY2020).

As noted, the 66 stations identified above have variable periods of record. Figure 3.21, shows the annual mean precipitation recorded over the study area along with the number of stations available each year. It also shows the overall mean multi-annual precipitation (893 mm/yr), as well as the 7-year moving average to indicate trends in the historical record. Precipitation in years 2015, 2016, and 2019 was low, only matched by that of 1958. The year 2008 was a historical high in precipitation, followed by the precipitation in years 1967 and 1954. The 7-year average suggests that starting in 2008 to 2013 but excluding 2012, the precipitation was above average, creating a bump in the trend that is followed by a dip in the record comparable to that occurring in the first years of the 1960's. However, both the bump and the dip occurring in the decade can also be questioned due to the lack of rainfall stations recording these changes. The number of stations has shown a steady decline since 1995, by 2016 there were three stations, and by 2020, there was only one station recording precipitation in a 6.5-km perimeter around the model area.

Figure 3.22 shows the median, and the 25th and 75th percentiles of the observed annual precipitation at the recording stations of each year. It follows the high and low periods identified above and shows the wide range in the data. The graph shows that the dip of the last decade is much lower and of longer duration than that of the early 1960's. The monthly quartiles are presented in Figure 3.23 for the period 2000-2016. Precipitation at this temporal scale highlights the seasonality and exhibits peaks that are dampened in the annual record. For instance, the 2000's summer season is of significance in this period, whereas the summer of year 2007 was very dry. The low precipitation for 2012 is mainly due to the lack of snowfall events.

The variability of the multi-annual monthly precipitation is summarized in Figure 3.24. A wider range in the variability is observed in the summer months indicating that the occurrence of rainfall varies more than that of snowfall.

Figure 3.25 examines the month-to-month distribution of rainfall events that exceed specific rainfall depths from 1950 to 2020. As expected, the frequency of rainfall events from December through February is low and increases for the remainder of the hydrologic year in a bimodal distribution. This distribution is clearer for events greater than 1 and 5 mm/d, rendering it flat for events greater than 10 mm/d, and becoming a unimodal distribution peaking in the month of August for events greater than 25 mm/d. The convective storms that dominate rainfall events during the summer months control the distribution of the largest events of the year.

The PRMS model accepts either direct input of observed snow and rain or partitions total precipitation into snow and rain based on temperature. The model cannot switch between these two options during a simulation nor can it accept a mix of station types. The Strada PRMS model worked with observed total precipitation.

Temperature, humidity, and wind speed and direction control the occurrence of three forms of precipitation that are typically recorded: rainfall, snow, and mixed events. Figure 3.26 shows the bivariate histograms for the relative occurrence of these events with respect to mean daily temperature for 1950 to 2016. Each bivariate histogram peaks around 18ºC, -8 ºC, and 1 ºC, respectively. Mixed events do not necessarily occur at the same location in a low-pressure system, but during the day, precipitation events that may occur as snowfall and as rainfall can be recorded separately in the study area. The shoulders of the histograms dive into negative and into positive temperature values, for rainfall and snowfall events, respectively, and are likely associated with sharp changes in temperature during the day, which are also great conditions for mixed events. In this project, Figure 3.26 was key in the proper parametrization of the precipitation module to split observed values among these three forms of precipitation.

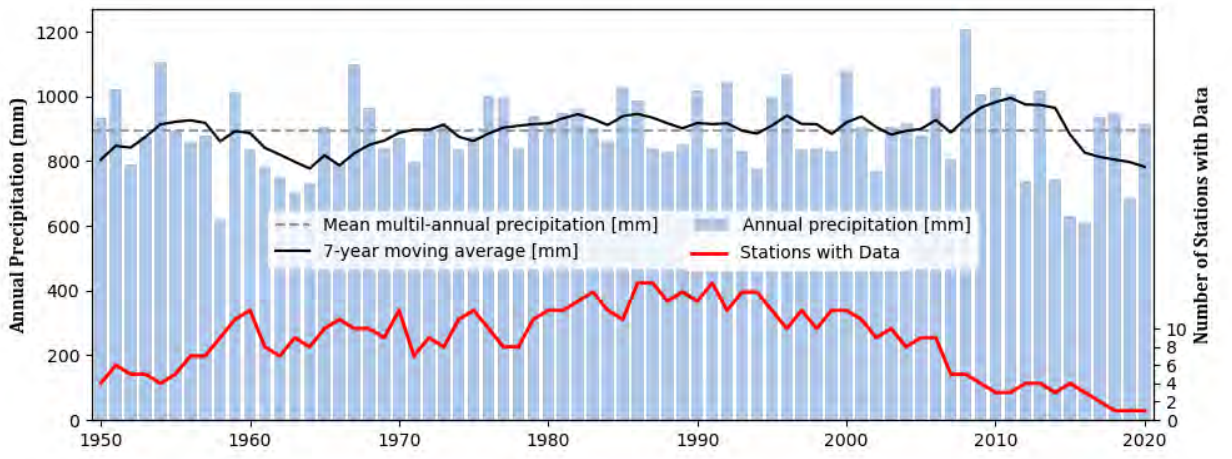


Figure 3.21. Annual average precipitation in the study area defined by 6.5 km search box around the model boundary (1950-2020).

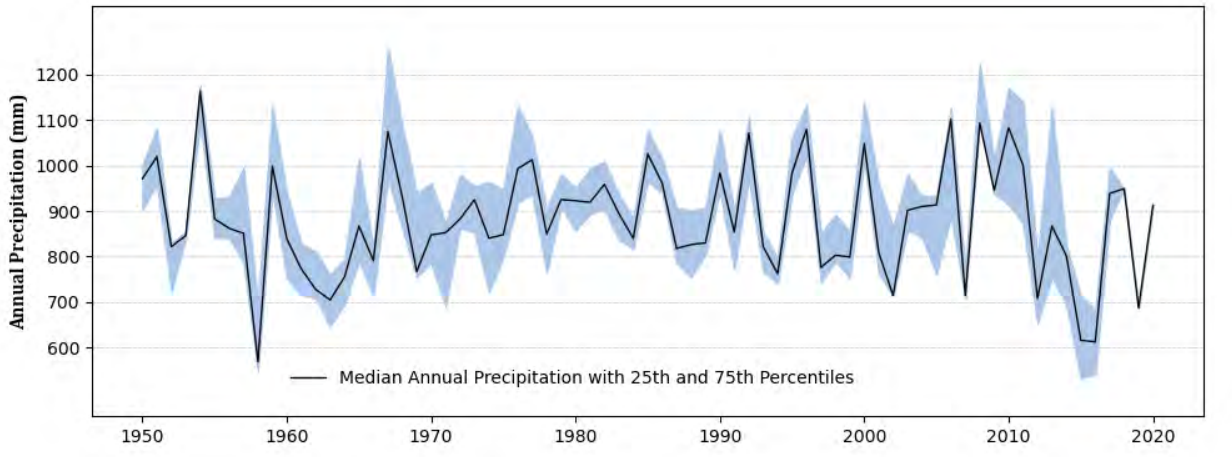


Figure 3.22. Annual precipitation quartiles in the study area (1950-2020).

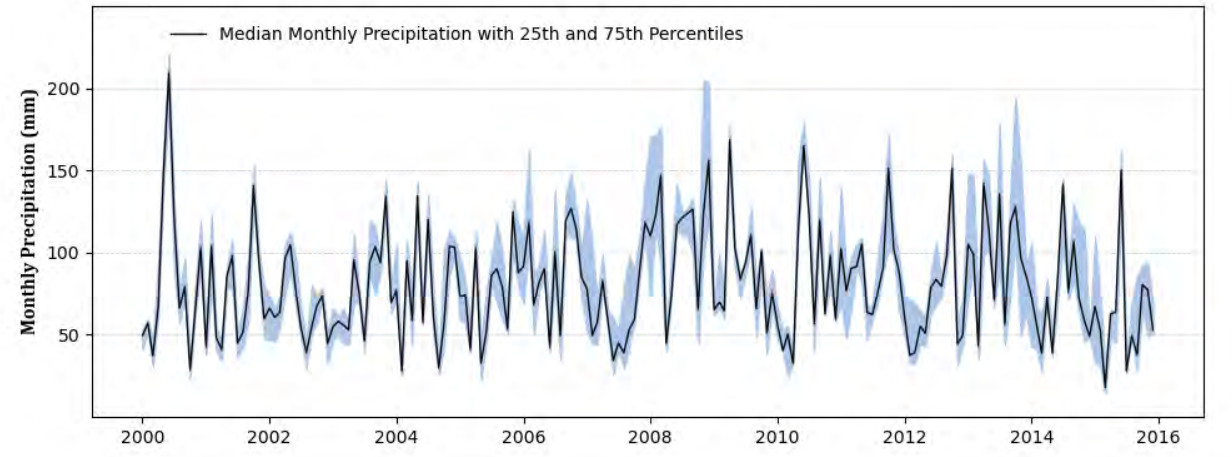


Figure 3.23. Monthly precipitation quartiles in the study area (2000-2016).

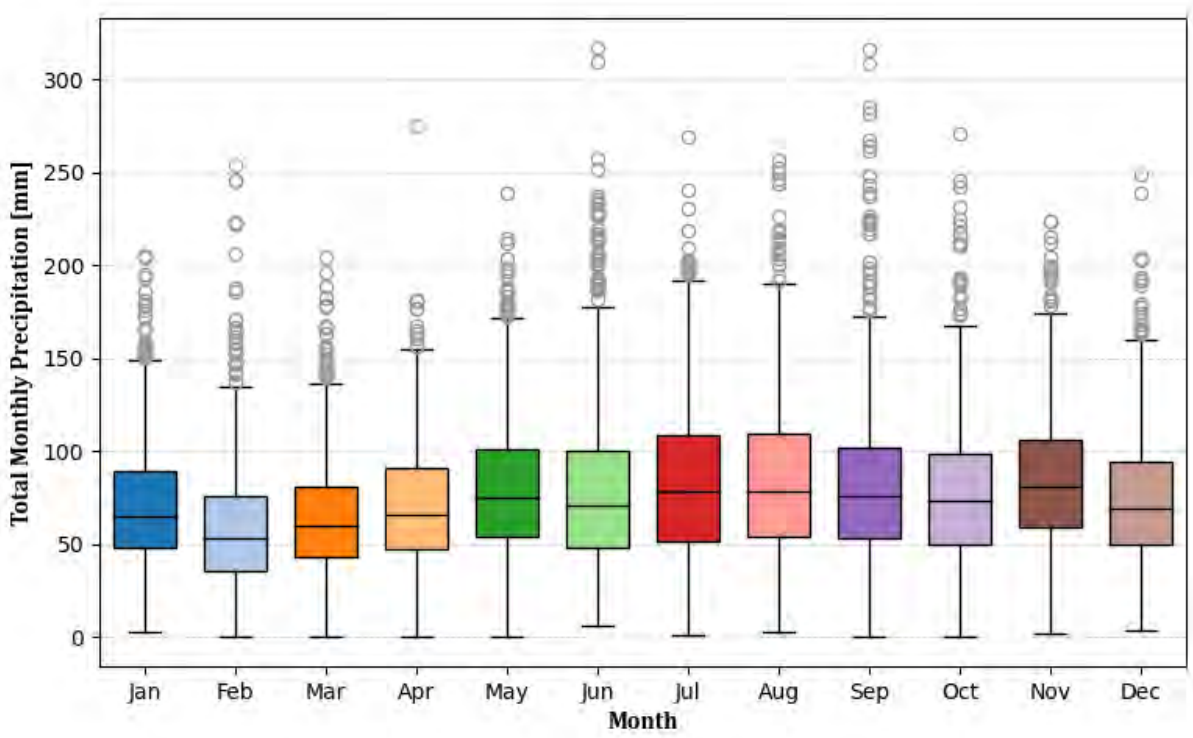


Figure 3.24. Box-whisker plot for monthly precipitation in the study area (1950-2020).

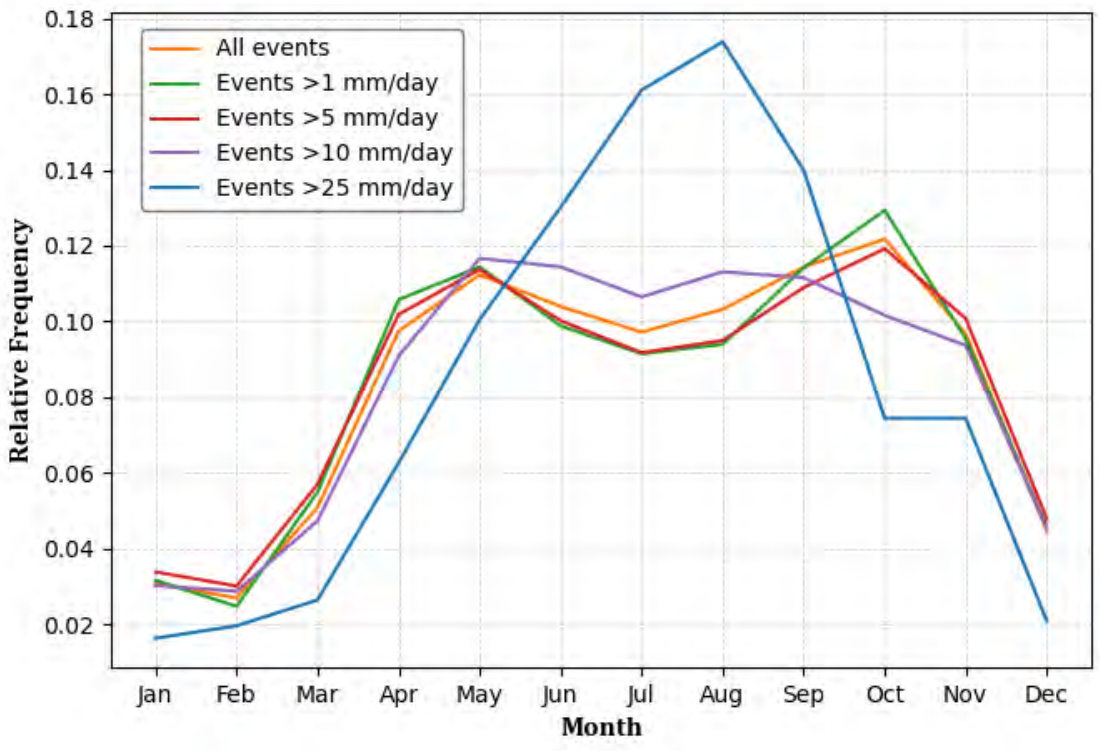


Figure 3.25. Monthly relative distribution of daily rainfall totals in the study area (1950-2020)

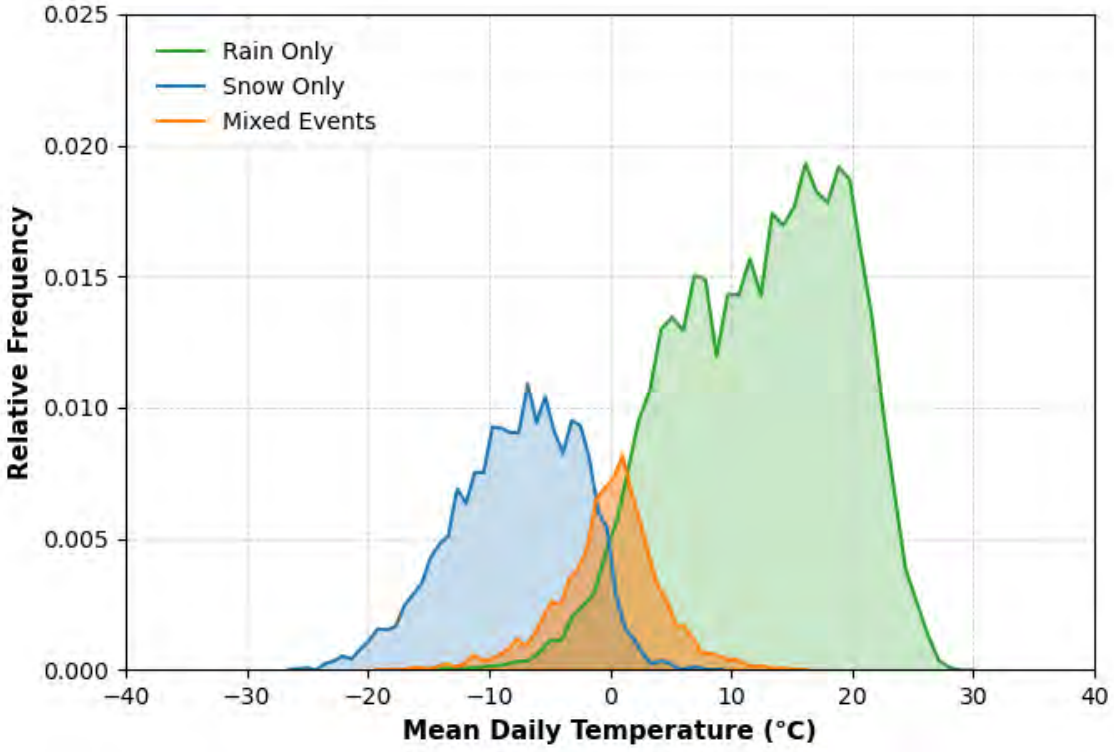


Figure 3.26: Bivariate histograms of rainfall, snow, and mixed events with respect to mean daily temperature during the time period 1950-2016.

3.5.2 **Canadian Precipitation Analysis (CaPA) Data**

The Canadian Precipitation Analysis (CaPA) system provides estimates of precipitation amounts for the region of northern United States and southern Canada by consolidating data from radar and precipitation gauges. Initially, the network of gauges included only those from EC, but recently (2021) the process of incorporating the networks from local agencies (GRCA and TRCA) has started. Currently, three products are available from this data system:

- 2.5 km gridded precipitation data, available since 2016.
- 2.5 km gridded snowpack data, available since 2017.
- 10 km gridded precipitation data, available since 2002-2016, with a gap of few months in 2012.

The CaPA system is the future of precipitation data in southern Canada and it is intended to fill the gap of decommissioned stations and become the center for weather data analysis. For the Strada project, all three products were downloaded and made available in VIEWLOG as source parameters up to the year WY2021. Figure 3.27 shows the locations of these gridded products together with active weather stations in the area.

A day-to-day comparison was made between CaPA precipitation and a selected set of gauges closest to the model area, for their respectively shared period of analysis. Average monthly values (Figure 3.28) and total annual values (Figure 3.29) were compared against EC stations Port Law, Alliston Nelson, and Ruskview, and GRCA stations Dundalk and Luther Marsh. These stations are shown in Figure 3.27.

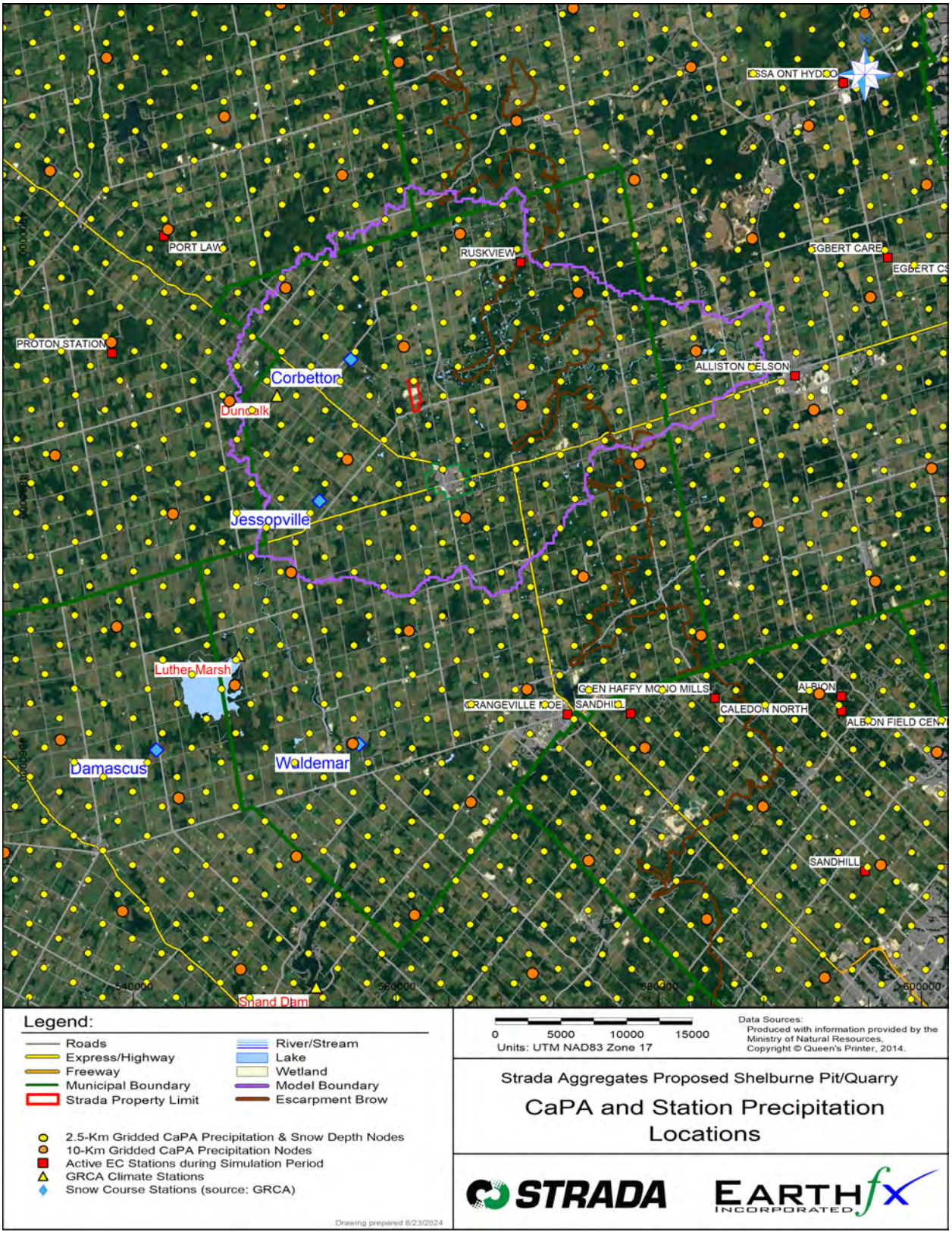


Figure 3.27: Gridded CaPA locations for 2.5-km dataset for precipitation and snow depth, and 10-km dataset for precipitation, and active stations with precipitation data.

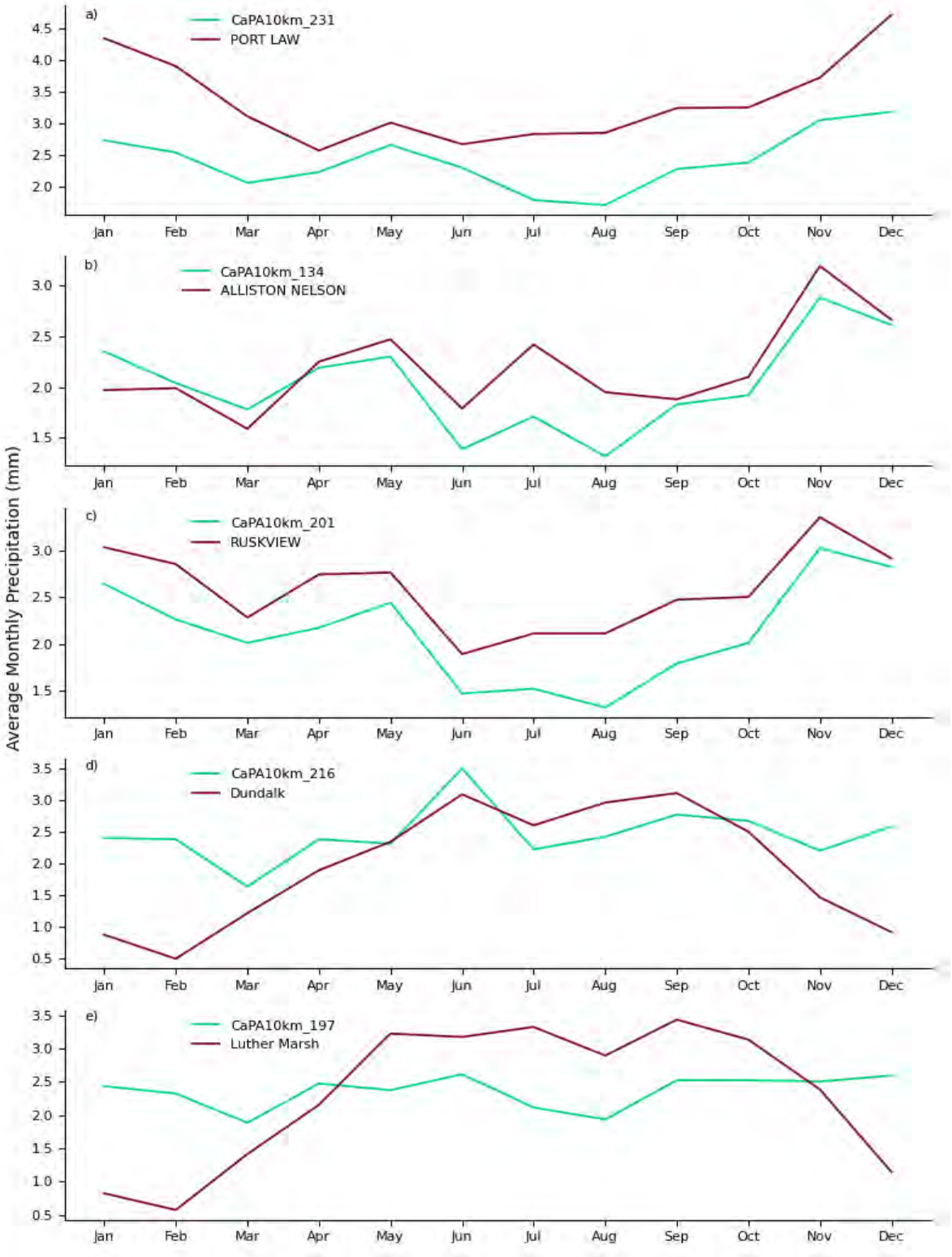


Figure 3.28: CaPA precipitation at 10-km resolution compared to EC (a, b, c) and GRCA (d, e) stations for averaged monthly values, and for a shared period with each station.

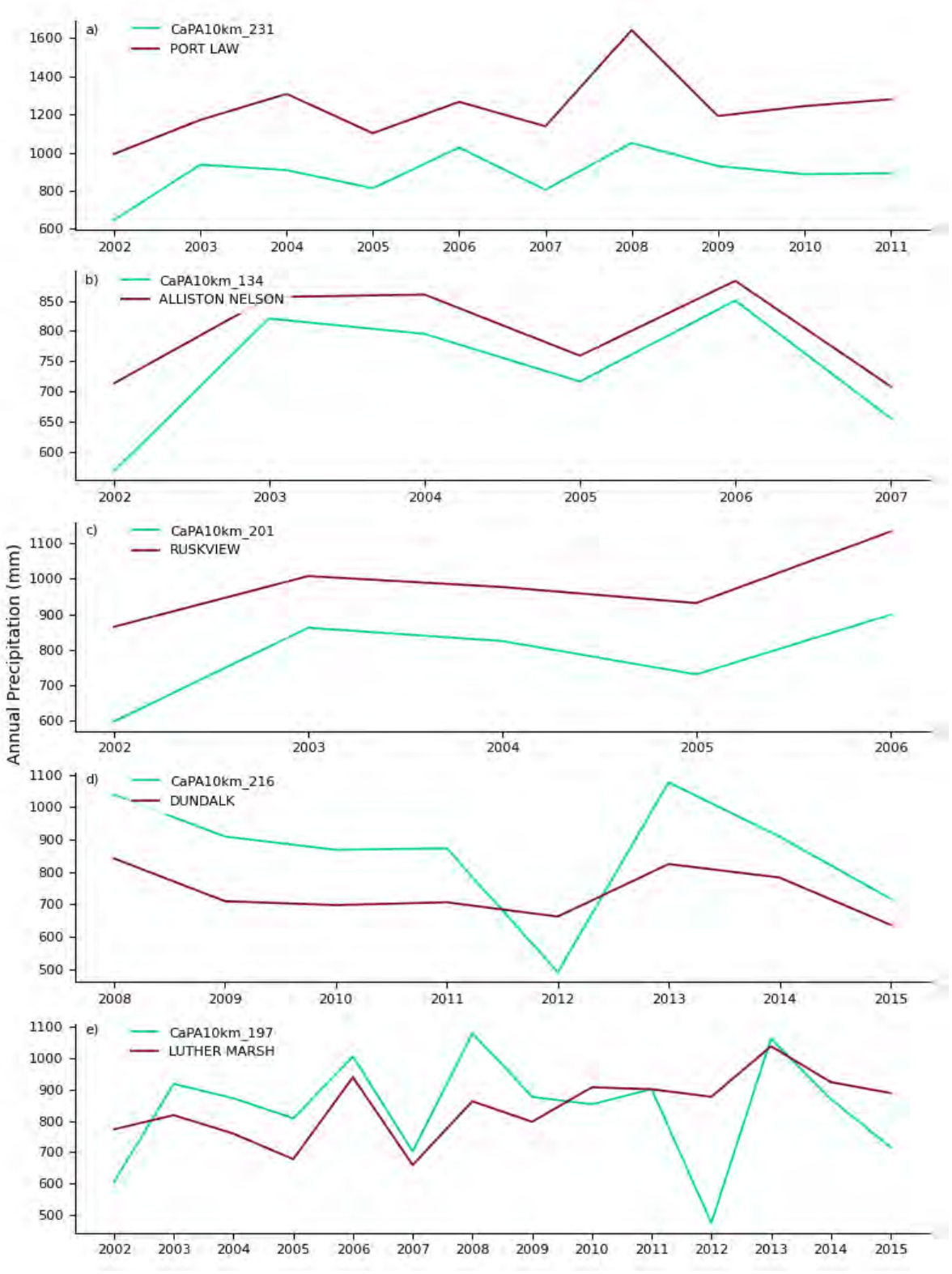


Figure 3.29: CaPA precipitation at 10-km resolution compared to EC (a, b, c) and GRCA (d, e) stations for annual values, and for a shared period with each station.

From these stations only Ruskview and Dundalk are located within the model boundary.

In the monthly plots, EC precipitation is systematically averaging higher values than the CaPA dataset, throughout the entire year, except for the first three months in Alliston Nelson. In the GRCA stations, neither dataset is predominant throughout the year. However, in these multi-year averages (i.e., 8-year for Dundalk and 14-year for Luther Marsh), a significantly diminished snowfall is observed in the months of December, through February, with respect to the CaPA estimates. Rainfall monthly averages, on the other hand, are similar if not somewhat overestimated, in the case of Luther Marsh.

Table 3.4 shows the percent difference statistic between both datasets for monthly, Winter-only, and annual time periods. The overestimation of the CaPA system around the stations Luther Marsh and Dundalk is significant and it is mostly driven by the Winter months. The underestimation of the CaPA system in the average monthly values ranges between 19 to 27 percent with respect to the EC stations, describing a decreasing gradient from northwest to east. For the annual values (Figure 3.29), the underestimation is persistent throughout the entire period of record of each EC station, and its range is similar to that of the monthly estimates. The difference in the annual values is lowest for Luther Marsh despite having the second largest monthly differences. The year 2012 in the CaPA dataset is incomplete, and it was excluded from the statistic estimates presented in Table 3.4. The station in best overall agreement with the CaPA dataset is Alliston Nelson located to the east of the model boundary, below the Niagara Escarpment.

Table 3.4: Average percent difference between CaPA and station precipitation estimates for monthly, Winter-only, and annual time periods.

Station	Agency	Avg % Difference in Monthly Values	Avg % Difference in Winter Values	Avg % Difference in Annual Values
Port Law	EC	-27	-31	-28
Alliston Nelson	EC	-6.8	4.5	-8.1
Ruskview	EC	-19	-12	-21
Dundalk	GRCA	69	164	23
Luther Marsh	GRCA	44	134	3.4

3.5.3 **Final Precipitation Dataset**

In order to have a comprehensive dataset that elapses both calibration and evaluation periods of analysis, the CaPA dataset was used as the core precipitation data for the 19-year simulation period WY2003 to WY2021, and was complemented with station data during periods with data gaps.

In spite of the discrepancies of the data at both monthly and annual timescales described previously, the use of a consistent data system throughout the periods of analysis is key to obtain responses in the model that are not associated to applying different data sources to each period.

We understand that the CaPA dataset is far from being perfect and that continues to be updated, most recently with network data from local Agencies including the GRCA. In all likelihood, the differences observed with their stations in this report would be significantly diminished in future releases of the CaPA dataset.

3.5.4 **Solar Radiation**

Solar radiation is the main source of energy present in the hydrological cycle. The amount of shortwave radiation emitted by the sun that finally arrives to the Earth' surface after passing through the upper layers of the atmosphere is known as incoming solar radiation.

Incoming solar radiation is controlled primarily by the number of possible hours of sunshine per day and the percent cloud cover, which makes it highly dependent of the geographic location of where it is measured. Solar radiation data are collected at very few stations in Ontario; therefore, the data had to be compiled from a variety of sources. Through linear regression analysis, it was shown that the widely-separated Ontario solar radiation stations exhibited good inter-station correlation (Earthfx, 2010a). Accordingly, a continuous dataset was created by averaging and infilling of daily solar radiation information from 11 southern Ontario stations. Data provided in sub-daily increments were summed to daily energy gains and converted to Langley per day (Ly/d = cal/cm^2/day or 41.84 kilojoules/m^2), the input units required by PRMS.

The incoming solar radiation dataset was based primarily on the average of measurements from four climate stations maintained by EC between 1956 and 2005. These stations include: 611KBE0 (Egbert CARE); 6142285 (Elora Research Station); 6158350 (Toronto); and 6158740 (Toronto MET Research Station). The period of record of these four sites only extends to August 31, 2003; therefore, the remaining data up to 2019 had to be infilled using a combination of measurements from the University of Waterloo, York University, University of Toronto Mississauga campus, and the Burford Tree Farm (GRCA). Where direct observations were unavailable, solar radiation was estimated by the Hargreaves and Samani (1982) method which uses daily minimum and maximum temperatures.

3.5.5 **Snow Depth**

Snow depth (or snowpack) is not an input dataset but it is an important environmental parameter that can be used in the calibration process to evaluate how the model interprets the snow accumulation and melting processes. In PRMS, the snow module computes snow pack accumulation on a cell-by-cell basis and evaluates snowpack depletion based on snowpack density, temperature, and albedo conditions on a sub-daily basis.

The GRCA collects snow course data within their watershed including snow depth and snow water equivalence. Four GRCA stations are in the vicinity: Jessopville, Corbetton, Damascus, and Waldemar (Figure 3.16). Of these, only Jessopville and Corbetton are located within the PRMS model domain. The measurement of snow depth and water equivalent start October 1 of every year and measurements are made every 2 weeks until the end of April. A total of 14 measurements are taking every water year at each site. Their time series for snow depth is shown in Figure 4.7 and Figure 4.8 of Appendix C (Earthfx, 2024a).

Part of the CaPA system dataset includes 2.5-km gridded snow depth based on radar-derived estimates. This dataset is available from WY2016 to the present. Unlike the biweekly nature of the GRCA snow course time series, the CaPA snow depth dataset is continuous and more apt to capture both sudden melting and accumulation events. Both datasets were used in assessing the calibration and evaluation periods for the PRMS model.

3.6 *PRMS Model Results*

3.6.1 PRMS Periods of Analysis

Model calibration was conducted for hydrologic years WY2006 to WY2011, using the first year as a warm-up period (Table 3.5). This period of analysis was chosen based on the considerations related to the historical information available at the site. Model parameters adjusted during calibration are tested during the evaluation period WY2016 – WY2021, which includes the most recent changes to the pit operational conditions. A 19-year simulation period, WY2002 to WY2021, was considered for the presentation of the long-term PRMS simulation results in this section of the report. The first year of each period of analysis was discarded from the statistics as it is considered time required by the model to develop proper initial boundary conditions.

Table 3.5: Periods of analysis in PRMS: Calibration and Simulation Results.

Analysis	Period of Analysis
Calibration Baseline	WY2006 – WY2011
Evaluation Period	WY2016 – WY2021
Simulation Results	WY2002 – WY2021

3.6.2 PRMS Calibration Results and Discussion

The PRMS model outputs daily values for all components of the water budget including precipitation, interception, snowmelt, evapotranspiration, overland runoff, infiltration, and groundwater recharge. The daily outputs are best visualized with hydrographs or animated maps in VIEWLOG, the latter cannot be provided in printed reports, unfortunately. The PRMS code contains routines to sum most of the daily values over the subbasins and the entire model area; others were summed in the VL-GSFLOW post-processor.

Note, as discussed in Appendix C (Earthfx, 2024a), Section 4.3, that all inputs to the model are defined on a cell basis and not a catchment or watershed basis. Catchments and watershed boundaries were used only for illustrative purposes or summarization (for example, the pie carts presented below).

3.6.3 Surface Water Calibration Results

Simulated runoff discharged to streams was calculated for the gauged catchments (Figure 3.4) and compared to observed streamflow measurements (Table 3.6). The gauged catchments extend over a total area of 524 km^2. The drainage area shown in Table 3.6 is accumulated for those catchments that received streamflow from other subbasins. The Grand River subbasins makes up almost a quarter (22%) of the model area, while three-quarters of it drains to below the Escarpment through both the Pine and Boyne Rivers.

The Strada Quarry is located in the headwaters of both the Pine and the Boyne River catchments, which have similar mean streamflow, drainage areas, and therefore specific discharge (i.e., flow/drainage area). Surface water specific discharge values may be inaccurate in catchments with

significant groundwater underflows or water takings, which affect both catchments due their proximity to the escarpment. The specific discharge values for the GRCA catchments are appreciably greater (except for SW8's, based on limited manual discharge readings), and these differences are most likely attributable to their distinct surficial geology features (Figure 3.30).

Table 3.6: HYDAT monitoring stations used for calibration of the PRMS model.

Streamflow Station	Station ID	Monitoring Period	Mean Flow (m^3/s)	Drainage Area (km^2)	Spec. Disch. ($m^3/s/km^2$)
Boyne River at Earl Rowe Park	02ED102	Oct/1967 – Dec/2021	2.11	217.9	$9.68x10^{-3}$
Pine River near Everett	02ED014	Oct/1967 – Dec/2016	2.18	190.4	$1.14x10^{-2}$
Grand River near Dundalk*	14518	Mar/2002 – Dec/2021	1.07	66.2	$1.62x10^{-2}$
Grand River near Riverview*	15050	Aug/1999 – Dec/2021	2.77	115.9	$2.39x10^{-2}$
Highland Companies – Melancthon Quarry monitoring sites – subbasins on the headwaters of Pine River					
GENIVAR DP-SW5	SW5	Apr/2008 – Jul/2010	0.08	12.79	$6.25x10^{-3}$
GENIVAR DP-SW7	SW7	Apr/2008 – Jul/2010	0.42	16.58	$2.53x10^{-2}$
GENIVAR DP-SW8	SW8	Apr/2008 – Jul/2010	0.04	3.76	$9.57x10^{-3}$
GENIVAR DP SW10	SW10	Jun/2008 – Jul/2010	1.04	58.3	$1.78x10^{-2}$

* GRCA monitoring station

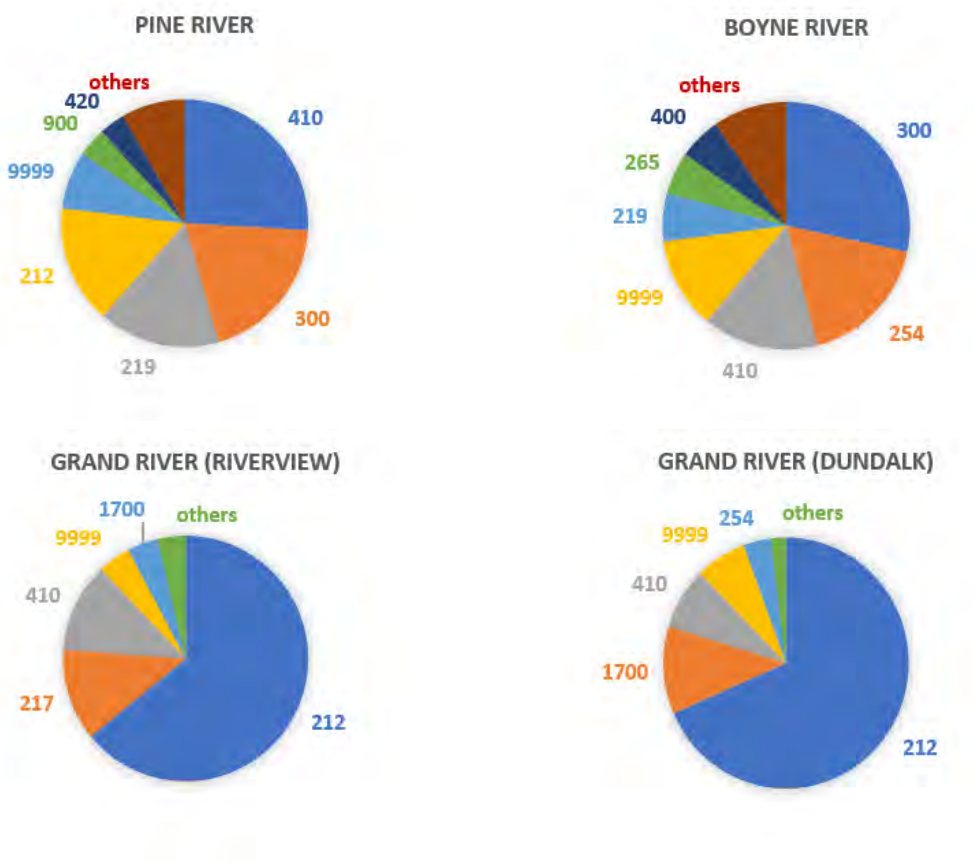


Figure 3.30: The most prevalent surficial geology groups for each calibration catchment.

From the GENIVAR locations, SW8 is the nearest to the Strada site and located just upstream of an aquaculture commercial facility with water permit that allows them to capture water from surface water and groundwater sources. Unfortunately, the rating curve developed for this gauge is of poor quality (Figure E-7 in GENIVAR, 2011), which deemed the collected data unusable. Manually collected discharge was available (Table H-9, in GENIVAR, 2011), however, for a limited time, averaging 36.2 L/s (see more details on GSFLOW results at this location see Appendix E, (Earthfx, 2024a)).

When focusing on the catchments used for calibration, the breakdown of surficial geology on these units shows a distinct pattern: the Grand River catchments are generally dominated by tight materials (tills, peat, organics) whereas, the eastern catchments discharging below the Escarpment exhibit a mixed nature of texture materials ranging from sand and gravels to tills.

During calibration, soil storage parameters were spatially distributed using Quaternary geology and soil type as an indicator of their values. Accounting for surface storage was necessary to match observed flows in these catchments. This was achieved by incorporating depression storage processes (discussed earlier) where water is stored temporarily in small variations of topography within the cell. The PRMS depression storage module results were most sensitive to both the value of the depression storage flow coefficient (expressed as a fraction per day) as it controls the amount of flow leaving surface storage as runoff, and the value of seepage rate. The latter parameter was distributed based on Quaternary geology and soil type.

The Nash-Sutcliffe Efficiency (NSE) index was used for assessing the goodness of fit of the hydrologic model. The NSE is given by (Nash and Sutcliffe, 1970):

$$\text{Nash Sutcliffe Efficiency} = 1 - \frac{\sum_{n=1}^{nobs}(Q_o - Q_s)^2}{\sum_{n=1}^{nobs}(Q_o - \overline{Q_o})^2} \qquad \text{(Eq. 3.2)}$$

where Q_O is the observed flow and Q_S is the simulated flow. The NSE can range from 1 to minus infinity, with 1 being a perfect fit. A Nash-Sutcliffe efficiency of 0.6 is considered a reasonable value (Chiew and McMahon, 1993). It must be recognized that the model simulates flow on a daily basis and would not be expected to achieve a perfect match to observed mean daily flows, especially in channels with longer times of concentration.

Another statistic used to estimate goodness-of-fit is the percentage of volumetric difference, calculated with respect to the observed values. Positive values of volumetric difference represent an overestimation on simulated estimates.

Figure 3.31 through Figure 3.34 present simulated streamflow, precipitation, and snowmelt results for the catchment gauges, during the calibration period (WY2007 to WY2011). Specifically for the eastern catchments, the observed flows are well correlated to the simulated rainfall and snowmelt events and the timing of the peak flows generally match the observed events. The slope of the recession curve, occurring after the spring freshet and extending through the summer, matches that of observed streamflow. Other mismatches to observed values are likely related to the way the PRMS model simulates certain processes, mainly cascading runoff and snowmelt.

This version of the PRMS code does not implement stream flow routing (stream routing is conducted in the MODFLOW-NWT model, as discussed later on). The lack of PRMS stream routing allows the maximum generated flows to reach the gauge on the same day as the precipitation event. This creates an early peak response with respect to observed daily flows, especially in large catchments.

Another discrepancy with observed flows is the lower simulated values occurring after the end of the freshet and early summer, especially in the Boyne River catchment. Several factors that could be contributing to the higher observed streamflow during this period include baseflow contributions from wetlands, groundwater discharge from storage, water retention structures, and effluents from wastewater treatment plants.

Overall, the calibration is acceptable, and it is unlikely that a better match to summer low flows can be achieved without the use of a fully integrated surface water and groundwater model that properly represents the interaction with the groundwater system. Section 6 describes the development of a such a model for the Proposed Strada Quarry site, after the development and calibration of the groundwater model described in Section 5.

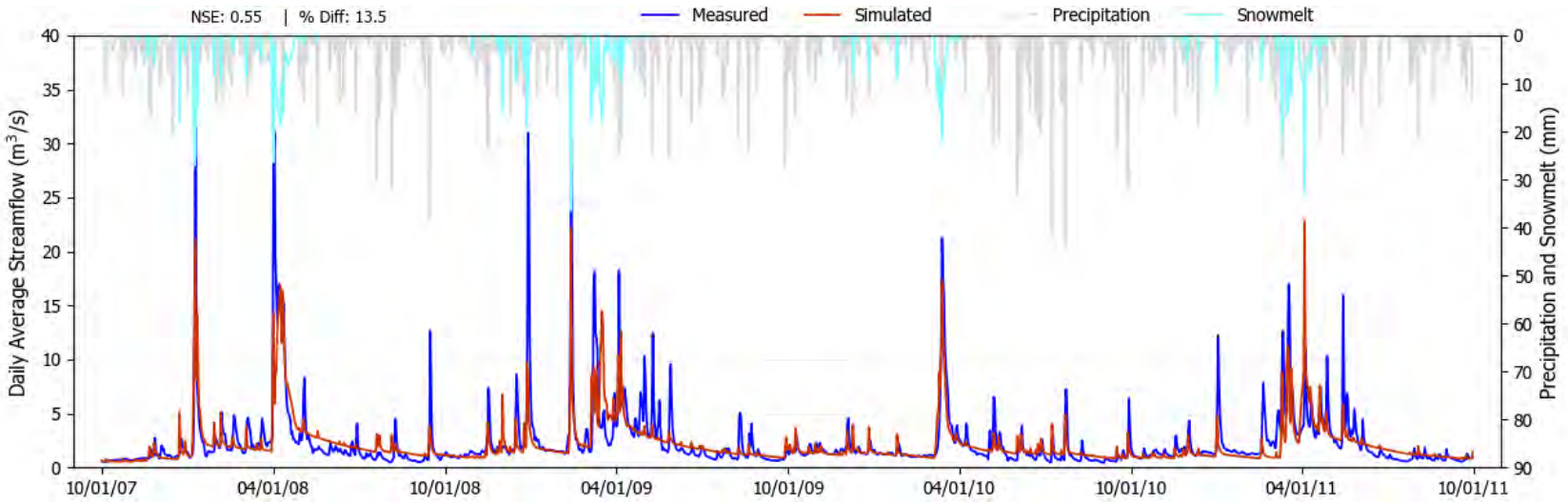


Figure 3.31: Simulated and observed streamflow (m^3/s) at the Boyne River at Earl Rowe Parks gauge along with precipitation and snowmelt for the calibration period WY2007 to WY2011.

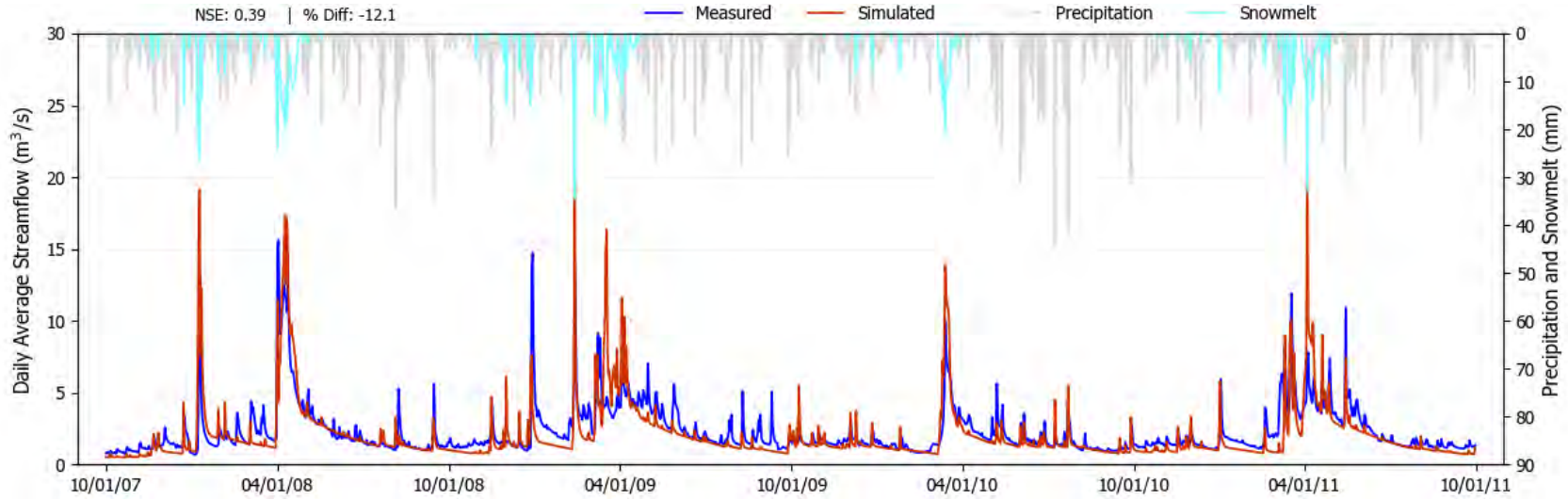


Figure 3.32: Simulated and observed streamflow (m^3/s) at the Pine River near Everett gauge along with precipitation and snowmelt for the calibration period WY2007 to WY2011.

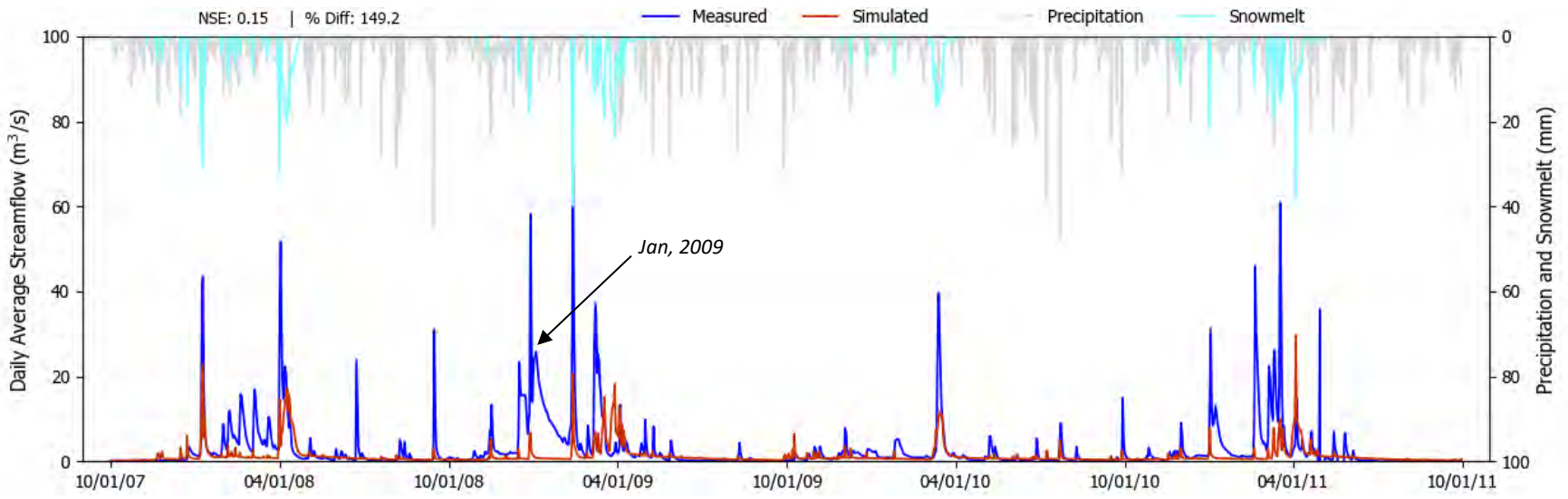


Figure 3.33: Simulated and observed streamflow (m^3/s) at the Grand River near Riverview gauge along with precipitation and snowmelt for the calibration period WY2007 to WY2011.

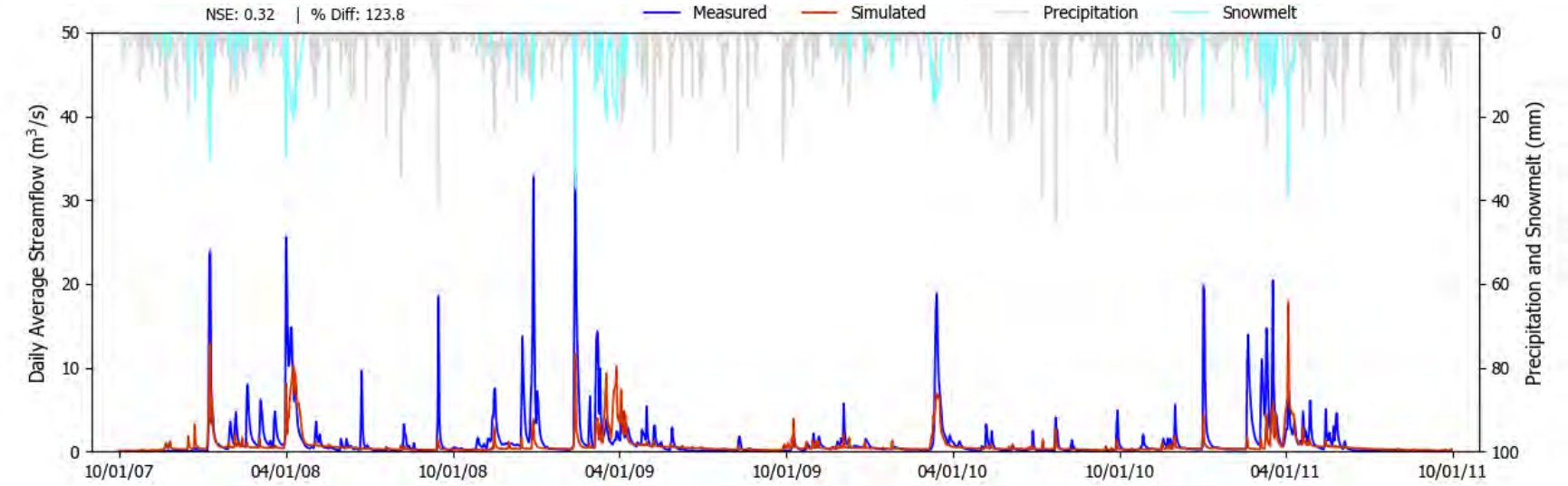


Figure 3.34: Simulated and observed streamflow (m^3/s) at the Grand River near Dundalk gauge along with precipitation and snowmelt for the calibration period WY2007 to WY2011.

The model in the western catchments performed differently. The gauge near Dundalk along the Grand River is monitored, independently, by both the GRCA and Environment Canada (EC). Data was recently downloaded from both platforms and compared against each other and against the downstream gauge near Riverview. The dataset from GRCA with timeseries ID 8749042 in their WATERDATA platform showed that streamflow at this location was greater than that near Riverview 16% of the time, whereas, with the data collected by EC (station ID: 02GA041), it was only 6% of the time, in isolated events. We suspect that the GRCA gauge near Dundalk has been compromised.

The level of responsiveness of a catchment to precipitation in the form of streamflow is not expected to follow a linear pattern considering the complexity of the hydrological process (i.e., soil type, land use, antecedent conditions, interception, time of the year, etc.). However, by conditioning the occurrence of this forcing on the system allows for comparing the responses of adjacent watersheds to precipitation. Applying the following conditions to create a subset for the precipitation and streamflow timeseries, a comparison can be made among catchments:

- Focusing on the precipitation events occurring only during the months of April through September (i.e., rainfall only),
- For daily rainfall records greater than 2 mm, and
- For daily average streamflow values greater than zero.

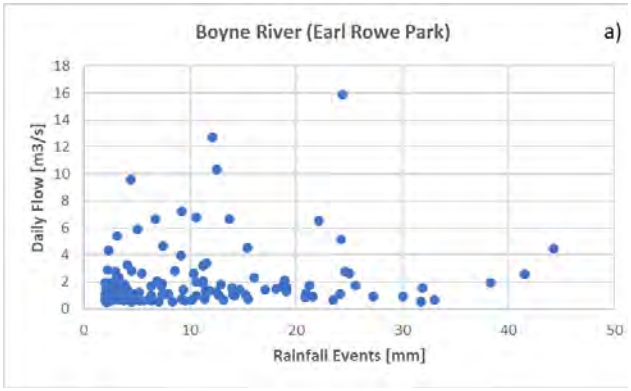
The resulting common datasets are plotted against each other for each catchment in Figure 3.35a through Figure 3.35e, including parametric and non-parametric measures of statistical dependence, namely, the correlation coefficient (*r*) and the Spearman's rank correlation coefficient (rS), respectively. (Note: A Spearman rank correlation describes the monotonic relationship between two variables). The probability value for the significance of the relationship in a two-tailed test is also included for rS. For either statistic, and based on the predominance of surficial geology groups in each catchment, it is expected that their values should be greater in the Grand River gauges. This is the case only for the EC gauge near Dundalk, and the r_S statistic, which makes the dataset of the Grand River near Riverview somewhat questionable based on this level of responsiveness to rainfall. Either statistic, the non-parametric more so than the parametric, highlights the fact that the timeseries from EC is a better dataset for the gauge at the Grand River near Dundalk.

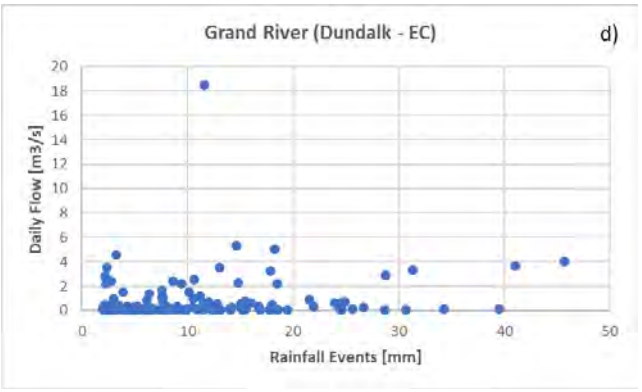
Additionally, Figure 3.36 shows a couple of historical aerials taken from Google Earth for the gauge at the Grand River near Riverview location, where it can be observed: i) the downstream location of the gauge off the bridge, ii) that the site might be influenced, during certain periods of time, by obstructed flow conditions as it is the case for June, 2018 (Figure 3.36a). Similarly, Figure 3.37a through Figure 3.37c shows the available historical aerials for the gauge at the Grand River near Dundalk location. The obstruction downstream of this gauge is even more significant, and likely more frequent, preventing free-flowing conditions required for adequate streamflow measurement. At this site, what could be considered as the normal conditions seems to be obstructed (Figure 3.37b, for October, 2014). It looks as though the parcel the river is crossing were accessed for plowing during part of the year, which could compromise measurements at the gauge.

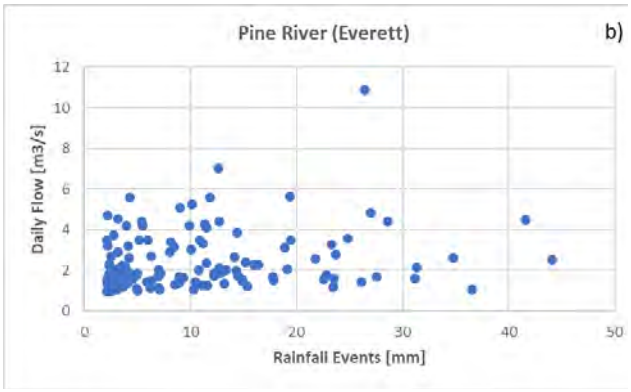
The recession curve exhibited by the observed streamflow at the Grand River near Riverview gauge (Figure 3.33) is unjustifiably long considering both the minor melt event occurring in January, 2009, and the minor precipitation events prior the large melt event occurring in mid-February, 2009. This pattern can be associated to the lack of free-flowing conditions that might be occurring at these gauges. Similar receding curves can be identified in other periods in their observed streamflow timeseries.

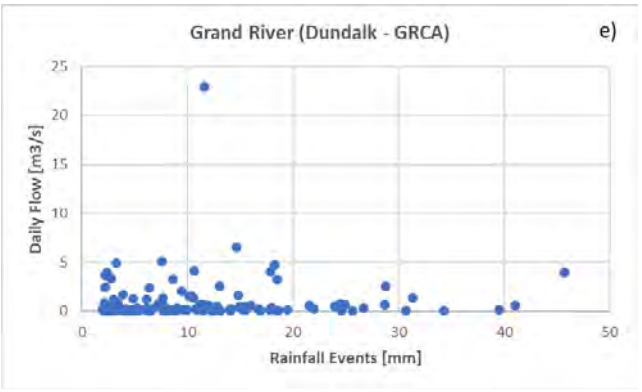
A summary of statistics of goodness of fit (i.e., NSE, for streamflow (Q) and baseflow (BF), and % of Volumetric Difference for Q) is presented in Table 3.7 for the selected, actual periods of analysis in Table 3.5: WY2007-WY2011, WY2017-WY2021, and WY2003-WY2021. The last period

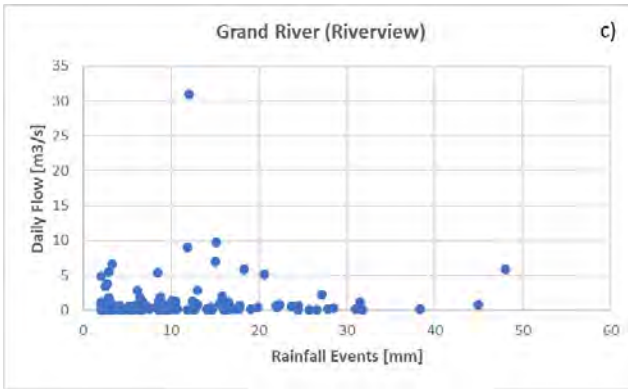
encompasses all previous simulation periods. The NSE index is estimated therein for both streamflow (Q) and baseflow (BF), and the percent volumetric difference for streamflow only.











Catchment	Corr. Coeff. (r)	Spearman's Rank Corr. (r_S)	p-value
Boyne River	0.16	0.21	0.014
Pine River	0.21	0.21	0.017
Grand River (Riverview)	0.09	0.14	0.088
Grand River (Dundalk – Environment Canada)	0.17	0.23	0.007
Grand River (Dundalk – GRCA)	0.08	0.19	0.023

Figure 3.35: Graphs of selected daily streamflow and rainfall events for the calibrated catchments, including correlation coefficient, Spearman's rank correlation, and p-value for the timeseries.



Figure 3.36: Google Earth aerial photography of the streamflow gauge at the Grand River near Riverview location, in year a) 2018 (June) and b) 2021 (October).



Figure 3.37: Google Earth aerial photography of the streamflow gauge at the Grand River near Dundalk location, in year a) 2009 (August), b) 2014 (October), and c) 2018 (June).

Table 3.7: Summary of goodness-of-fit statistics for selected periods of analysis.

Catchment	WY2007-WY2011			WY2017-WY2021			WY2003- WY2021		
	Q-NSE[1]	Q-%Diff[2]	BF-NSE[3]	Q-NSE	Q-%Diff	BF-NSE	Q-NSE	Q-%Diff	BF-NSE
Boyne River at Earl Rowe Park	0.55	13.5	0.27	0.32	13.6	0.51	0.47	21.2	0.33
Pine River near Everett	0.39	-12.1	0.43	n/a	n/a	n/a	0.26	-8.9	0.39
Grand River near Riverside	0.15	149	-0.04	0.25	133	0.38	0.23	232	0.07
Grand River near Dundalk	0.32	124	0.23	0.39	118	0.26	0.38	156	0.22

[1] NSE statistic for streamflow
[2] Percent volumetric difference for streamflow
[3] NSE statistic for baseflow

Streamflow at the Pine River gauge stopped being recorded in December 2016. Statistics for the evaluation period (WY2017-WY2021) at this gauge are not included in Table 3.7. For this period, the goodness-of-fit statistics in the Grand River gages improved their performance with respect to the calibration period (WY2007-WY2011), and their performance was maintained for the 19-year period of analysis. The reasons behind the variability in performance of the model are threefold:

- the degree of goodness of fit of the model changed with each time period as the hydrologic forcings (i.e., daily precipitation and daily minimum and maximum temperatures) change within those periods,
- the averaged nature of the chosen values for the model parameters makes the model work better in some years than in others,
- model parameters assigned based on either land use and soil/surficial geology distributions have different sensitivities in each catchment.

For the catchments where the Strada property is located (i.e., Boyne and Pine Rivers) the performance of the model is the best from all the calibrated catchments. The statistics for baseflow, for the 19-year simulation period, was either maintained or improved for all catchments.

The results reflect a sensitivity analysis that was conducted to test the model response to parameter value changes. A GSFLOW-PRMS pre-processor was used to automatically create the respective control and parameter files for each test. The output for each test was then evaluated using a Monte Carlo-Global Optimization Analysis Tool (MC-GOAT™, Earthfx Inc.) to identify the optimal parameter value based on the NSE index and the percent volumetric difference estimated for each run.

The PRMS estimates of daily groundwater discharge (i.e., baseflow) were also compared to baseflow derived from applying a hydrograph separation technique called the Modified UK Institute of Hydrology (UKIH) method (Table 3.7). Figure 3.38 compares log simulated and estimated baseflow for the calibration catchments. For all the catchments, except for the Grand River near Riverview, the simulated baseflow exhibits an acceptable performance. For this catchment, both the magnitude and timing of the peaks and of the recession curve, are missed. This performance is reflected in the statistics (Table 3.7). The NSE statistic for baseflow (i.e., BF-NSE) has either, in the evaluation period, significantly improved, or in the 19-year simulation period, averaged, over the calibration period's values.

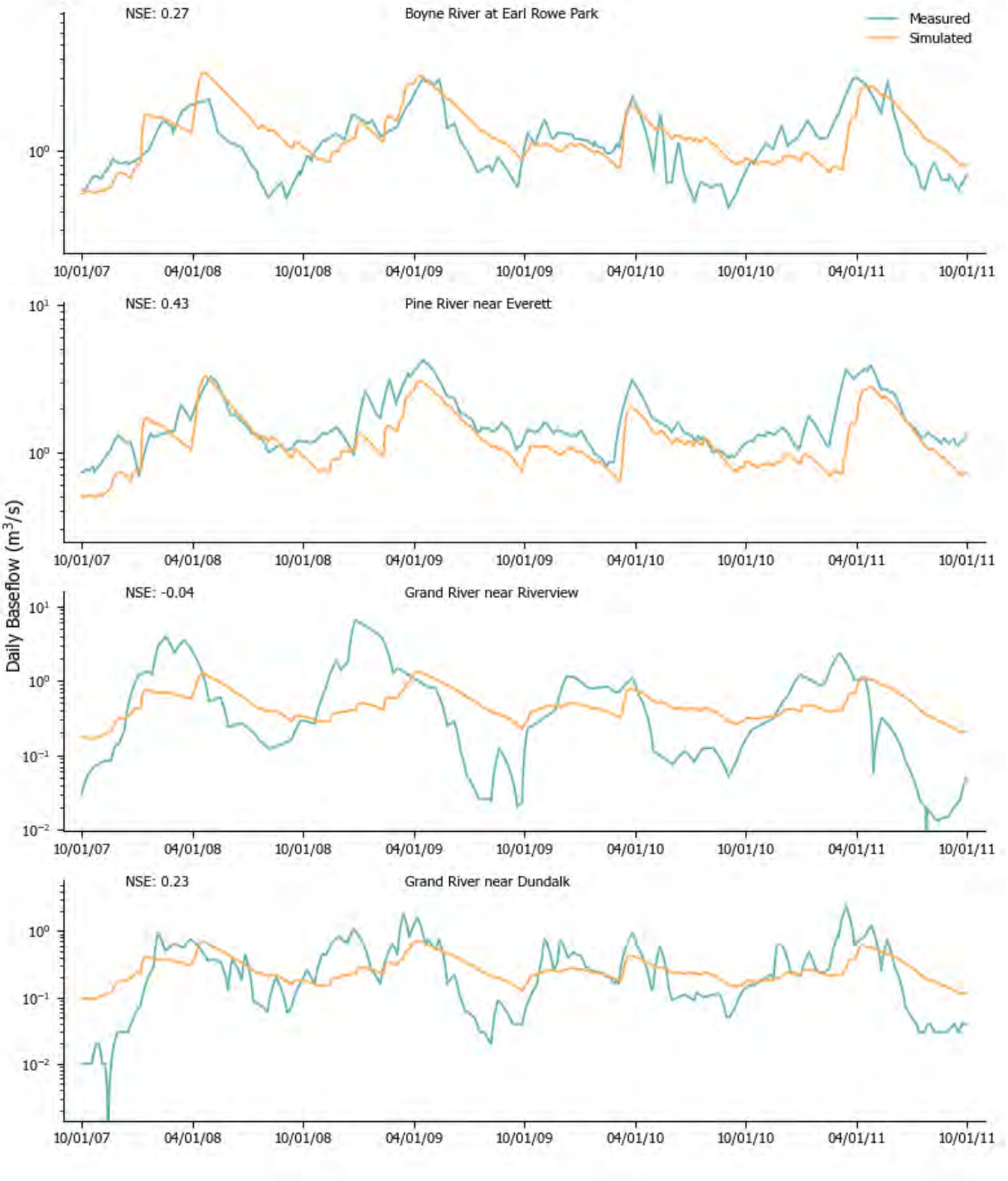


Figure 3.38: Estimated baseflow timeseries using the UKIH hydrograph separation technique compared against simulated baseflow in PRMS for the calibration period.

3.6.4 Monthly and Seasonal Calibration Statistics

Monthly averaged streamflow values were also estimated for both observed and simulated conditions. A summary of statistics of monthly averaged streamflow is presented in Table 3.8 for three periods of analysis: the calibration period (WY2007-2011), the evaluation period WY2017-2021 and the 19-year simulation period WY2003-WY2021. Figure 3.39 shows the estimated monthly averaged streamflow at the calibration catchments. The average monthly values resemble the trends observed with the daily dataset, that is, high-volume freshet in the year WY2009 and low-volume freshet in the year WY2010. Daily high stream flows during the spring freshet are better matched than the low flows around both the summer and the fall, when the system in the summer months relies more on rainfall distribution and baseflow discharge than in snowmelt processes. This observation is also corroborated by the unmatched monthly peaks during warmer temperatures in the Boyne and Pine River catchments.

Table 3.8: Goodness of fit statistics for monthly streamflow at calibration catchments and for three different periods of analysis.

Calibration Catchment	WY2007-WY2011		WY2017-WY2021		WY2003-WY2021	
	NSE	%Diff	NSE	%Diff	NSE	%Diff
Boyne River at Earl Bowe Park	0.85	-0.86	0.71	0.72	0.78	7.5
Pine River near Everett	0.76	-14.3	n/a	n/a	0.68	-9.4
Grand River near Riverview	0.09	55.6	0.35	66.9	0.26	148
Grand River near Dundalk	0.42	60.6	0.48	71.5	0.51	115

The statistics of the monthly averaged streamflow significantly improved over the daily values for all periods of analysis and catchments, except for the Grand River near Riverview catchment. The Grand River catchments exhibit a clear, and significant discrepancy with observed monthly values, especially for the downstream station located near Riverview (Figure 3.39). This result is consistent with the differences observed in the daily flows. The performance of the Grand River near Dundalk dataset is much better than its downstream counterpart in all periods of analysis, especially for the 19-year simulation.

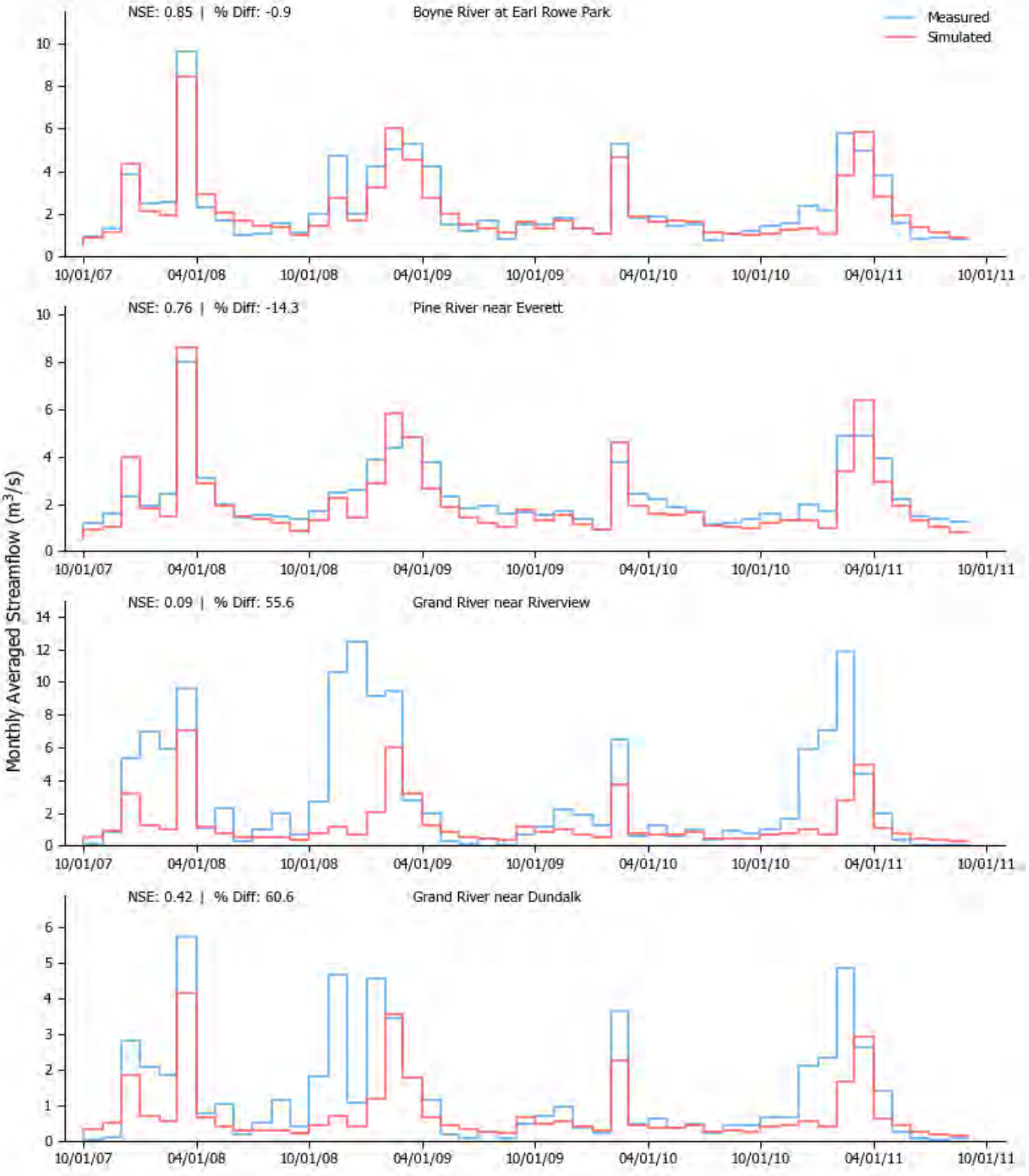


Figure 3.39: Monthly averaged streamflow simulated and measured values, for the calibration catchments.

3.6.5 Snowmelt Calibration

The snowmelt events generated by the model correlate well with the peaks in streamflow measured at the stations, especially in the eastern catchments. The snow course data collected by the GRCA at a 15-day interval during the winter months was compared to the continuously simulated snow depth generated by the PRMS model (Figure 3.40).

Figure 3.40 shows that PRMS model matches observed snow course data quite well. Three stations with snow course data were available: Corbetton, Jessopville, and Waldemar (Figure 3.16). The beginning and end of the snow accumulation is well predicted in the months of November and April, respectively. The shape of the accumulation of snow defines the snowpack at each point in time in the Winter season. The model simulates the snowpack closely in all catchments, and for all the years of the calibration period.

An underestimation and an overestimation of the modeled snowpack is apparent in the year of WY2009 and WY2010, respectively. The assigned snow course station is located several kilometers away from the centroid of each catchment. There is not a likely correlation between the degree of goodness-of-fit attained on each catchment and the distance of the assigned snow course station to the centroid of the catchment. Statistically, the modeled snowpack seems consistent in all catchments, especially for the NSE statistic.

Comparing the remote sensing snow depth data collected by CaPA (2.5-km grid), at a location in the grid closest to the catchment's centroid, and the modeled snowpack for the evaluation period (i.e., WY2017-WY2021), a similar picture emerges on the performance of the model's ability to simulate snowpack (Figure 3.41). This, in spite of the CaPA snow depth dataset being a continuous timeseries as opposed to a discrete one, as it is the case for the snow course data used in the calibration period. In this continuous dataset, it is easier to identify both the similarities and differences between the simulated and remotely-measured timeseries. For instance, the snowpack in the WY2018 is closely followed despite its many meltdowns and build-up subperiods. The first meltdown of that year occurred in mid-January (2018) that the model failed to simulate the extension of the meltdown. However, the subsequent meltdowns occurring in March and April, were followed more closely.

The snowpack of the year WY2020 was satisfactorily simulated by the model until the end of January's complete meltdown which was trailed by the largest peak of snowpack in the evaluation period. Neither the dip nor the peak of the snowpack was adequately modeled by PRMS. The sensitivity of the parameters that control the buildup and meltdown of the snowpack were repeatedly tested around these dates, however, no clear conclusion emerged to explain the lack of response to the temperature changes that drove this meltdown.

Table 3.9 summarizes the goodness of fit (i.e., NSE and r-squared) of the simulated and measured snow depth for the calibration catchments and three time periods. Notwithstanding the different datasets for observations, and weather variability through the years, the level of performance of the model in representing snowpack was maintained through the periods of analysis.

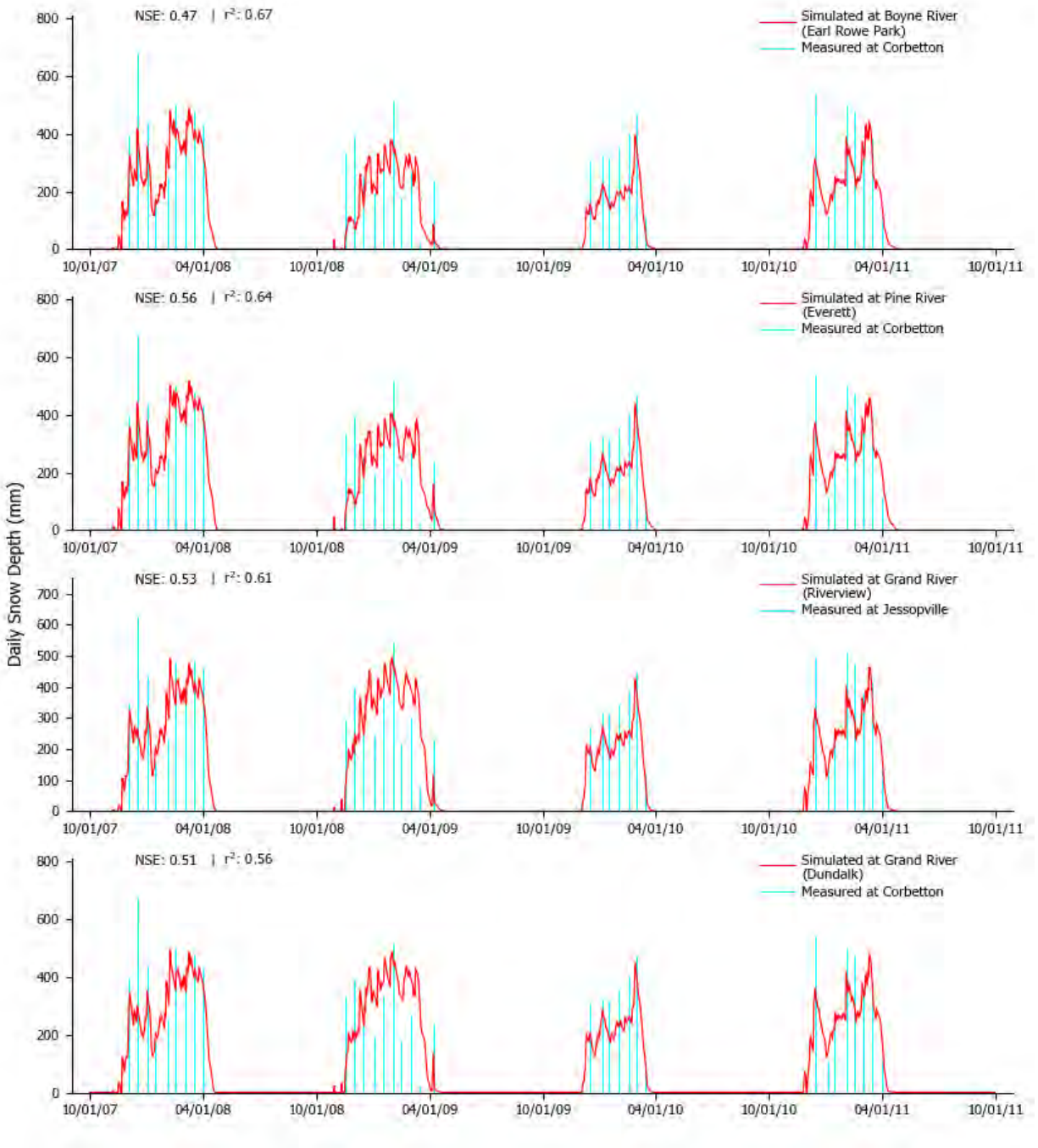


Figure 3.40: Simulated snow depth (mm) within the calibration catchments is compared to discrete measures of snow depth as part of snow course sampling data at the Corbetton, and Jessopville stations, available from the GRCA.

Table 3.9: Summary of statistics for snow depth for three periods of analysis and different observation datasets.

Catchment	GRCA Snow Course Station	Distance to Catchment's Centroid (km)	WY2007-WY2011[2]		WY2017-WY2021[3]		WY2003-WY2021	
			NSE	r^2	NSE	r^2	NSE	r^2
Boyne River at Earl Rowe Park	Corbetton	16.3	0.47	0.67	0.47	0.49	0.52	0.7
Pine River near Everett	Corbetton	12.5	0.56	0.64	n/a	n/a	0.61	0.71
Grand River near Riverside	Jessopville	8.5	0.53	0.61	0.47	0.55	0.6	0.64
Grand River near Dundalk	Corbetton	2.5[1]	0.51	0.56	0.51	0.54	0.58	0.63

[1] Snow course station located within catchment | [2] Calibration period using snow course dataset | [3] Evaluation period using CaPA snow depth dataset.

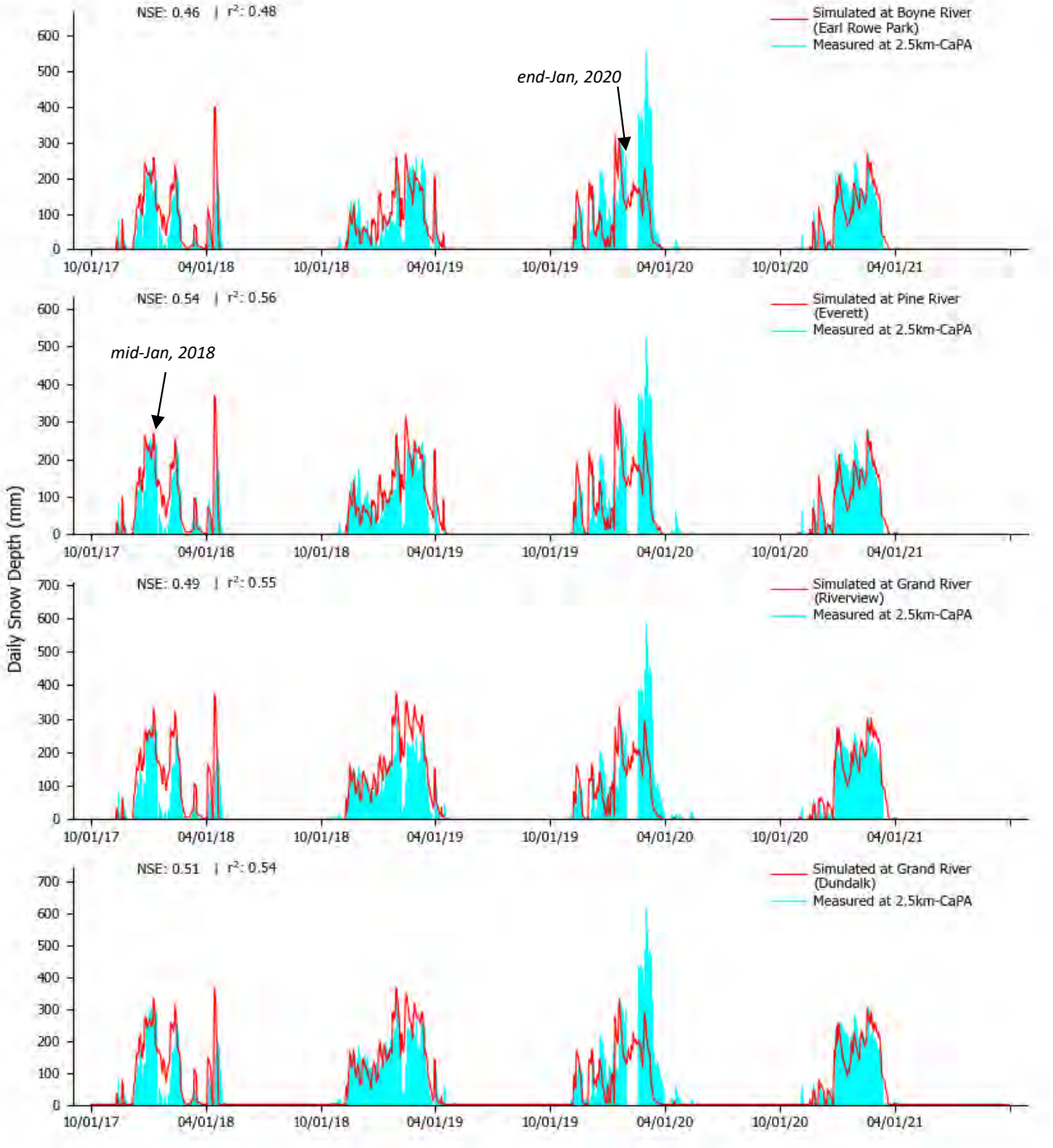


Figure 3.41: Remote sensing CaPA snow depth product (2.5-km grid) compared to continuously simulated snow depth (mm) in PRMS, for the evaluation period WY2017-WY2021.

3.6.6 Simulation Results

Figure 3.42 through Figure 3.49 show the cell-based average values for simulated and calibrated parameter results corresponding to a 19-year simulation period, WY2003 to WY2021. This time period was chosen to determine the average annual groundwater recharge rate to include both calibration and evaluation periods. The simulated average annual precipitation in particular (Figure 3.42) indicate that the results are generally consistent with the long-term and 30-year average input precipitation patterns (Figure 3.17 and Figure 3.19) but, as discussed previously, the CaPA dataset generally underestimates station data. The upper limit of the averaged precipitation is 980 mm/yr whereas in Figure 3.17 and Figure 3.19 reach 1150 mm/yr. Notwithstanding these differences, values vary over a significant range, from 775 mm/yr in the east end of the model area to 920 mm/yr in the northwest. The Niagara Escarpment might be providing an orographic effect in the distribution of precipitation around the model area. Precipitation in the south and southeast varies from 845 to 890 mm/yr.

Average annual net precipitation is shown in Figure 3.43. This value includes losses from canopy interception and sublimation from the snow pack. Values range from 590 mm/yr to 870 mm/yr. These results are strongly influenced by land cover type (Figure 3.13), vegetative cover density, interception storage, as well as the distribution of precipitation. Values for interception/sublimation range from zero for water features to 230 mm/yr over forested lands and wetlands.

Figure 3.44 shows the average annual Hortonian runoff and includes runoff from both impervious areas and runoff from pervious area (as computed using the curve number (CN) method). Values range from 1 to 600 mm/yr. Given the relatively undeveloped land cover that dominates the model area, surficial geology (Figure 3.8) has a large impact on Hortonian runoff distribution. However, around the Towns of Dundalk and Shelburne the percent imperviousness (determined from land use coverage) controls the Hortonian runoff. High values are also observed along roads. It should be noted that the values shown in Figure 3.44 are for runoff generated *within* the cell and do not include Hortonian run-on from upslope cells.

Figure 3.45 shows the average annual cascading runoff, represented in volumetric terms (i.e., m^3/d as opposed to mm/yr). A log-scale is used for the color ramp to highlight results. Cascading flow defines the average volume of water moving along the cascade flow path at a given location and includes interflow, Hortonian runoff, and Dunnian runoff. As noted earlier, Hortonian runoff from upslope cells is partitioned together with snowmelt and net precipitation. Upslope Dunnian runoff and interflow are added directly to the capillary reservoir. Dunnian flow is mainly generated in areas where upslope interflow and Dunnian flow exceed the storage capacity of the gravity reservoir. Figure 3.45 shows the dendritic nature of the runoff and interflow as a result of the cascade network. It highlights both the varying topography, characterized with short relief, and the fine-texture soil that describes the GRCA region in the model area and the headwater region of the Pine and Boyne Rivers, stretching through western boundary of the Strada site.

The most important output parameters, from a surface water balance perspective, are the components of interflow and runoff that reach the stream network. Figure 3.46 shows the combined average net runoff to streams (Hortonian and Dunnian) and interflow to streams. Runoff to lakes and shallow wetlands are smaller terms and are reported separately.

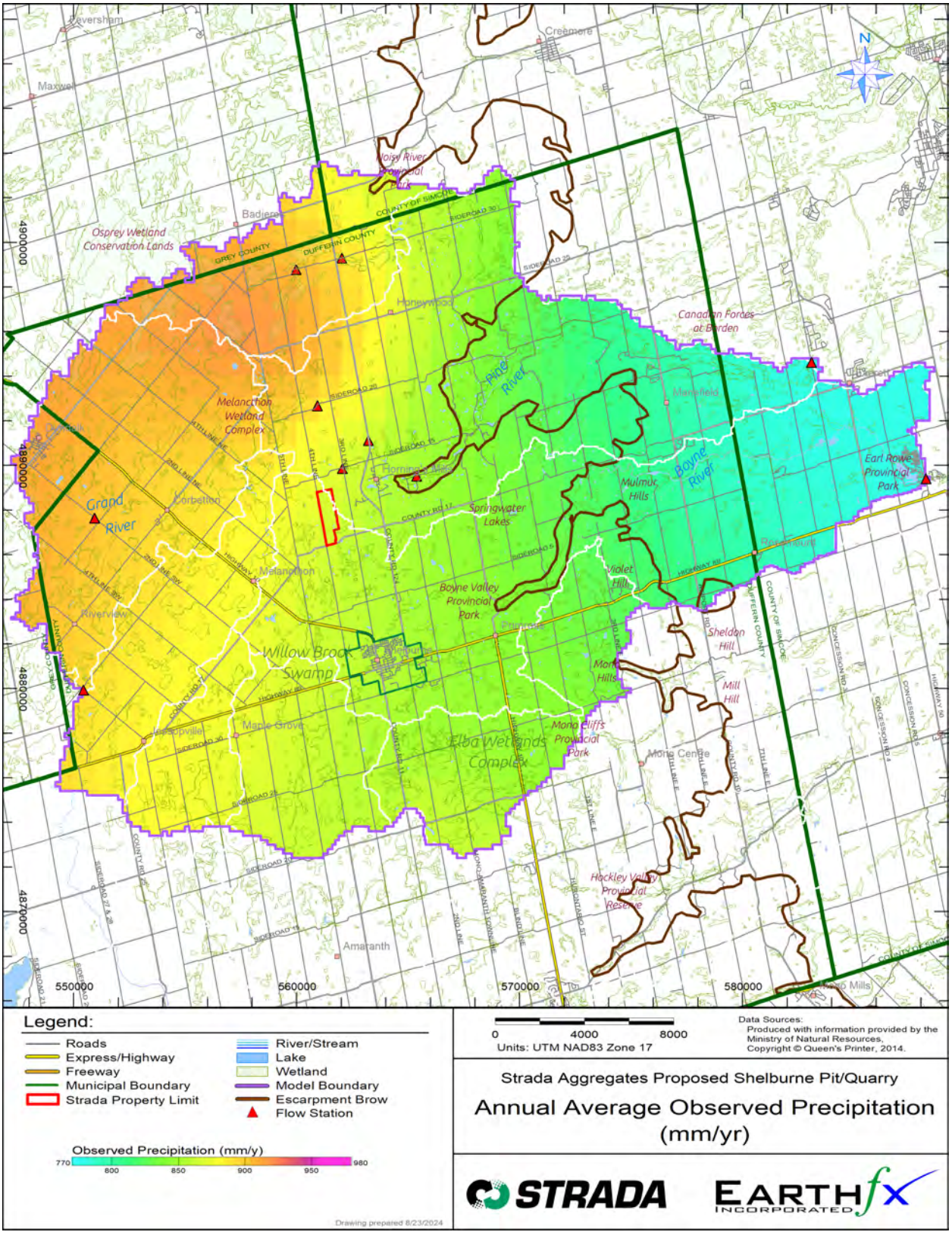


Figure 3.42: Simulated annual average observed precipitation (mm/yr).

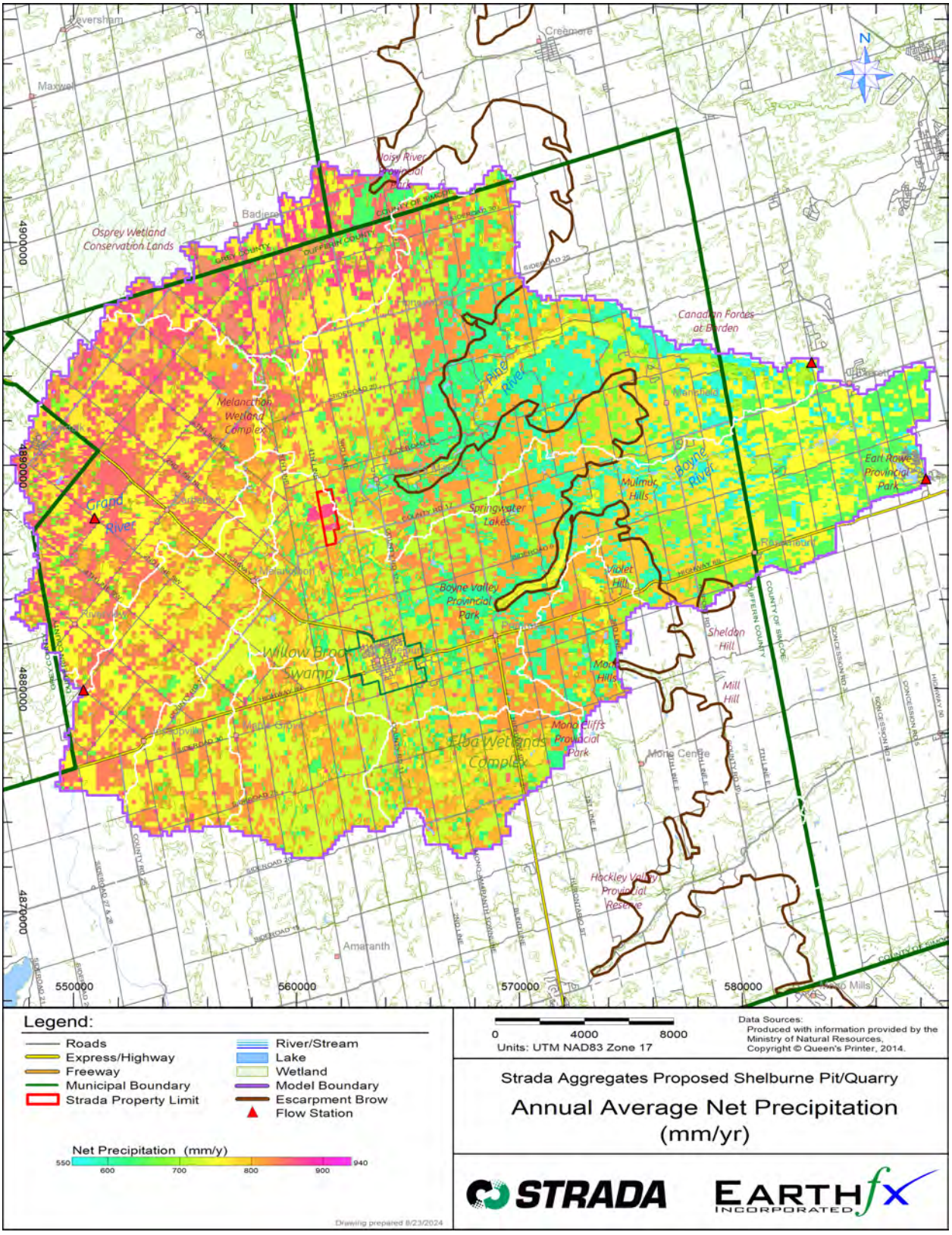


Figure 3.43: Simulated annual average net precipitation in mm/yr.

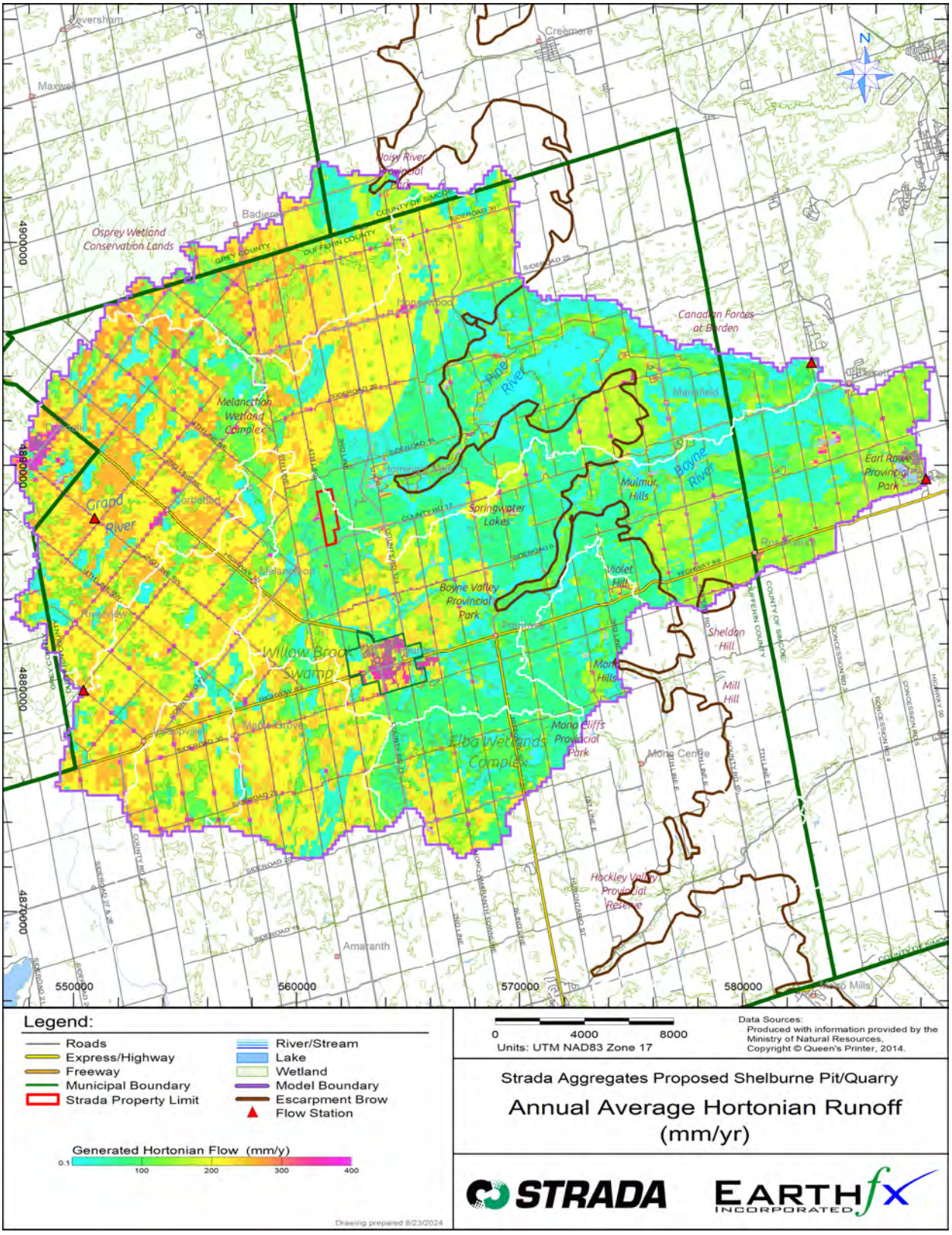


Figure 3.44: Simulated annual average Hortonian overland runoff in mm/yr.

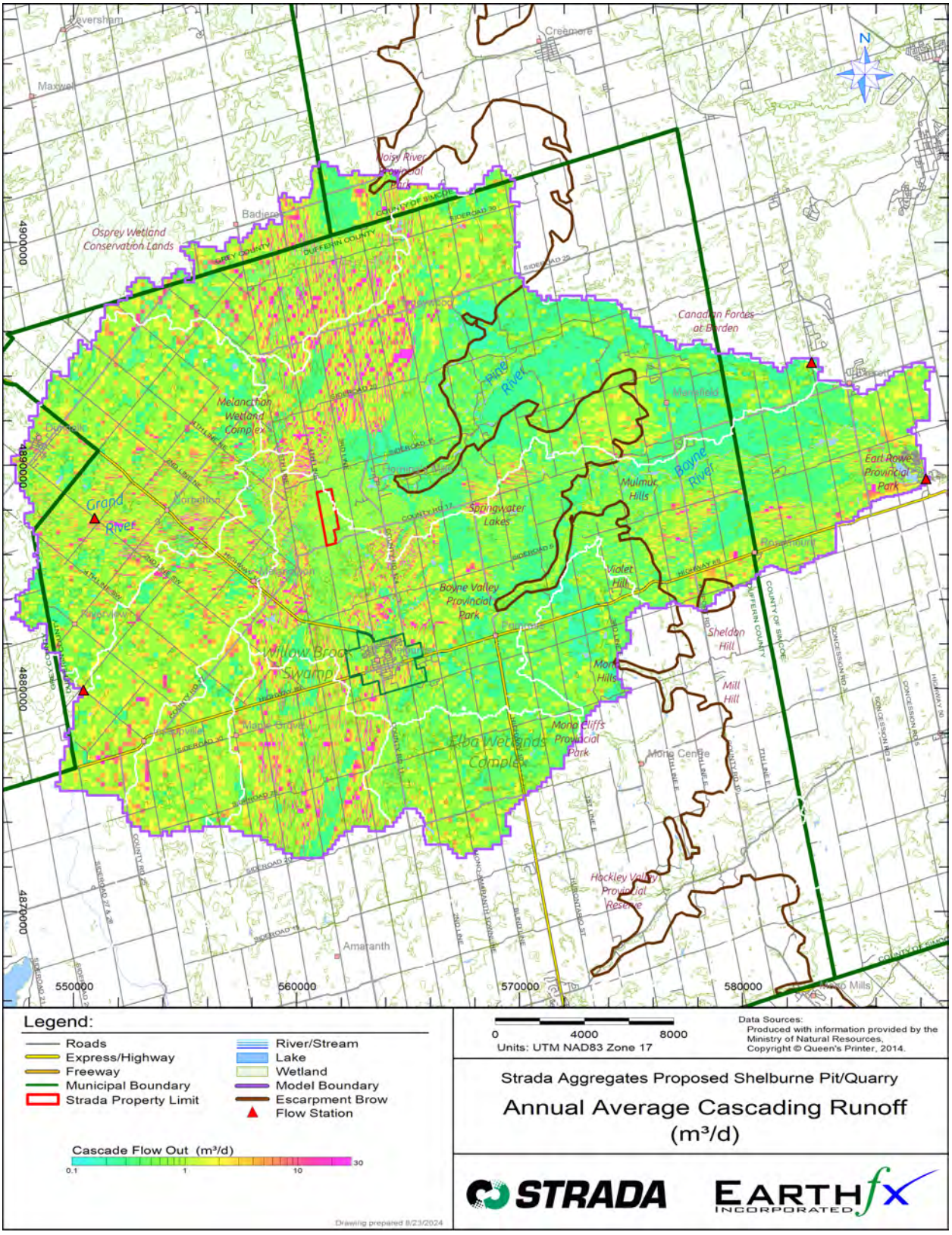


Figure 3.45: Simulated annual average cascading runoff (Hortonian, Dunnian, and interflow) passing through each cell in m^3/d.

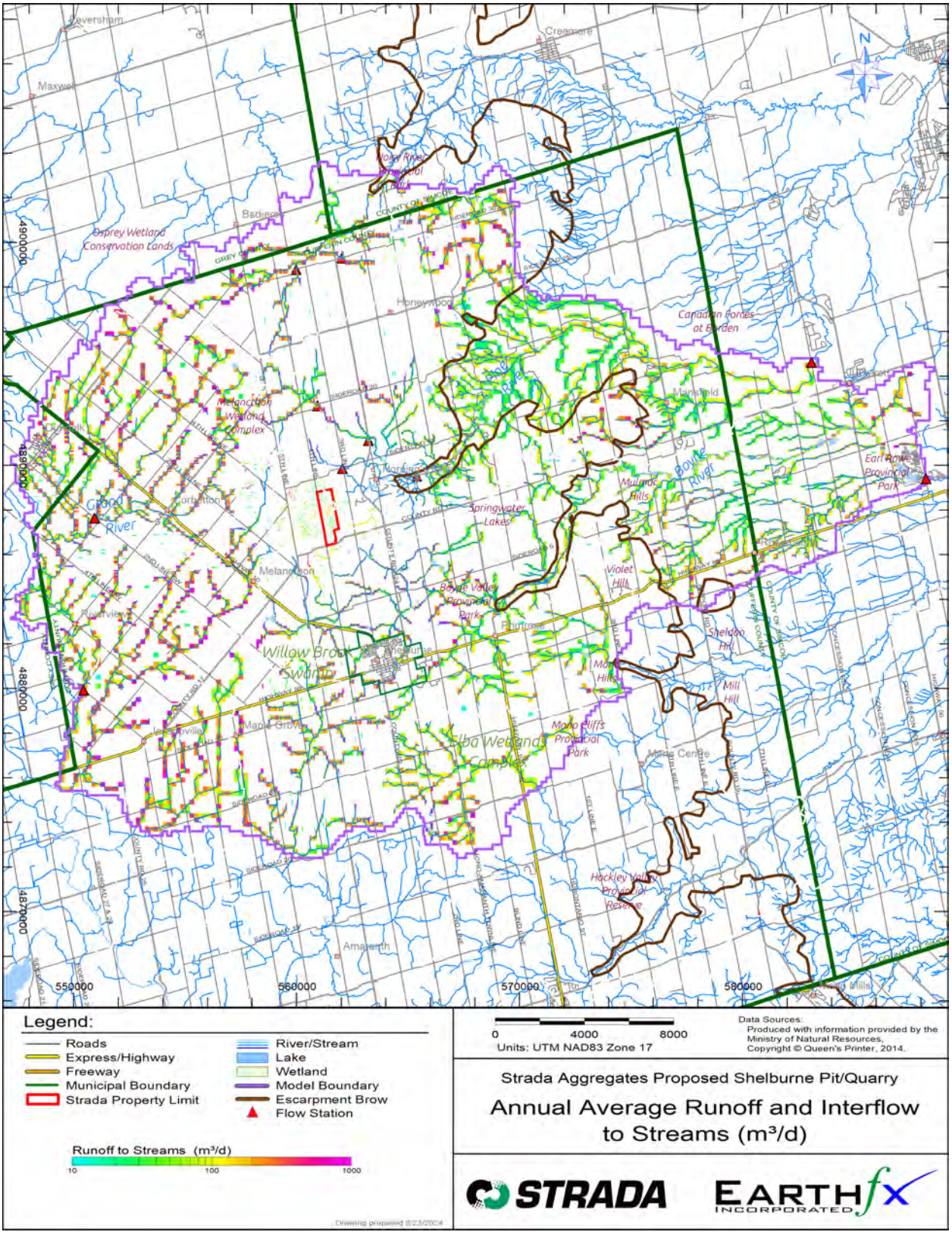


Figure 3.46: Simulated annual average runoff (Hortonian and Dunnian) and interflow to streams in m³/d.

Snowmelt, net precipitation and upslope Hortonian run-on that does not runoff are assumed to enter the capillary reservoir as infiltration. Figure 3.47 shows the simulated average annual infiltration for the study area. Rates higher than the observed precipitation can occur in downslope areas because of the re-infiltration of Hortonian run-on. Water is removed from the capillary reservoir by ET. As noted earlier, ET demand is based on PET (computed using daily temperature and solar radiation) and ranged from 1188 to 1246 mm/yr. Lower values generally occurred around and below the Escarpment, in wetlands and riparian areas. The northwest region, favored by greater precipitation, exhibits moderate values of ET, whereas in the southern region of the GRCA area in the model, maximum values were found along the dendritic slopes of its topography. The ET demand from the soil zone is equal to the PET minus any evaporation from the canopy and sublimation from the snowpack. The distribution of total actual evapotranspiration (AET) is presented on Figure 3.48. This includes interception and sublimation but not lake evaporation or losses from impervious areas. AET values ranged between 182 to 1046 mm/yr. High rates occur over the lakes, in wetlands, at the end of cascading flow paths, and other areas where soil water is not limited. Rates can exceed infiltration where upslope Dunnian runoff and upslope interflow occur. Also, rates can exceed precipitation at the end of cascading flow paths.

PRMS calculates the potential groundwater recharge, which is equal to all water entering the gravity drainage reservoir after interflow is removed. The values are limited in cases where the volume available exceeds the actual infiltration capacity of the soils underlying the soil zone. However, there is no mechanism in the stand-alone PRMS model to limit recharge in groundwater discharge areas where the water table is at or near land surface

Figure 3.49 shows average annual net groundwater recharge for the study area. Regionally, groundwater recharge ranges between 50 to over 1000 mm/yr with the variation due to the different combinations of soil types, land use, and topography. Cells near the end of the long cascade flow paths can have higher rates of focused groundwater recharge, and particularly those that also overlay sand and gravel zones where the recharge rate is not limited. The largest anomalies in recharge rates occurred in cells adjacent to riparian zones where alluvial deposits are found, from pathways passing through clayey and loamy soils. Figure 3.50 shows a close-up of this parameter around the Strada site. Of note here is the great number of swales present which is characteristic of having hummocky topography and permeable soils. This observation is in agreement with personal communications carried out by Earthfx and Hunter and Associates during the development of this model.

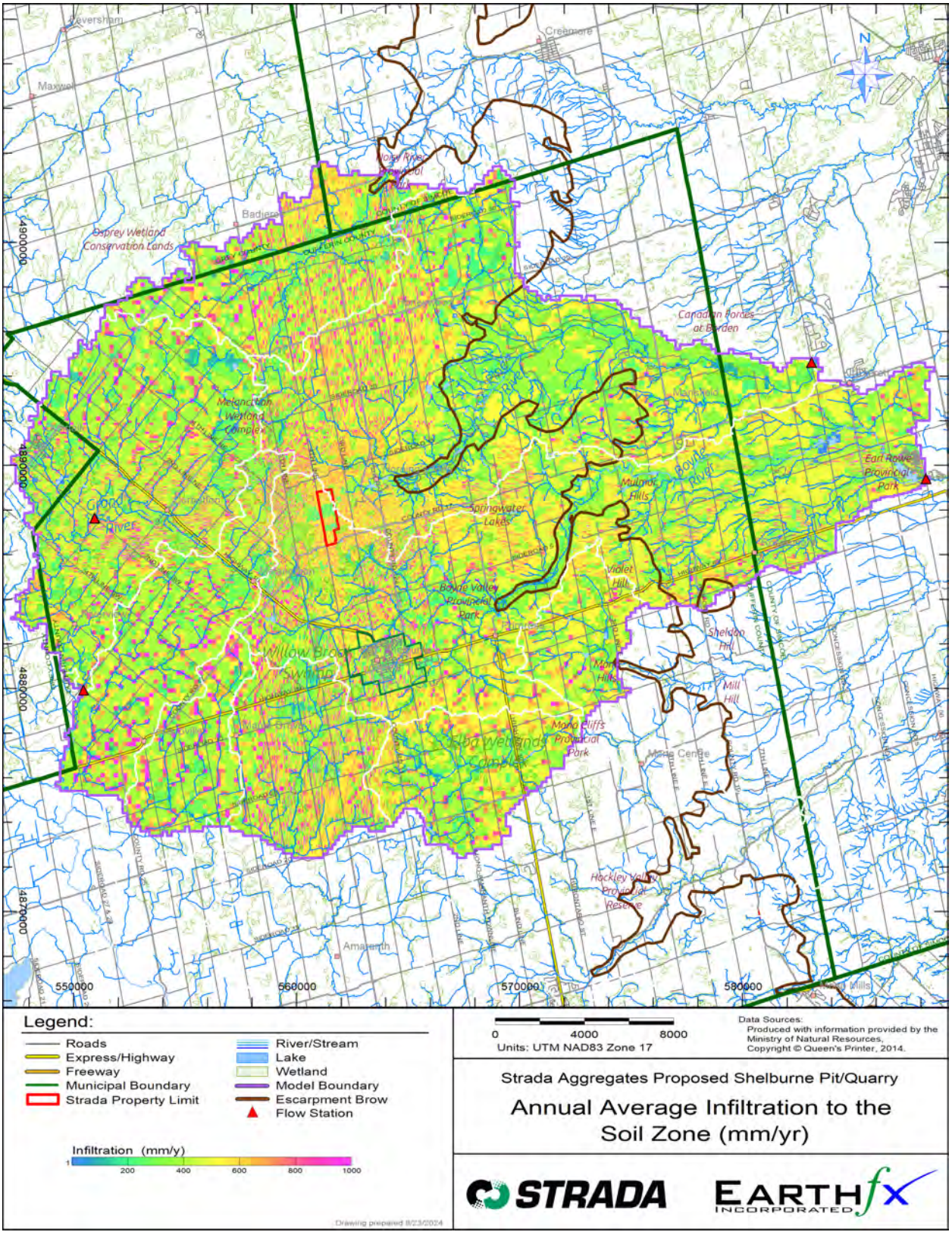


Figure 3.47: Simulated annual average infiltration to the soil zone in mm/yr.

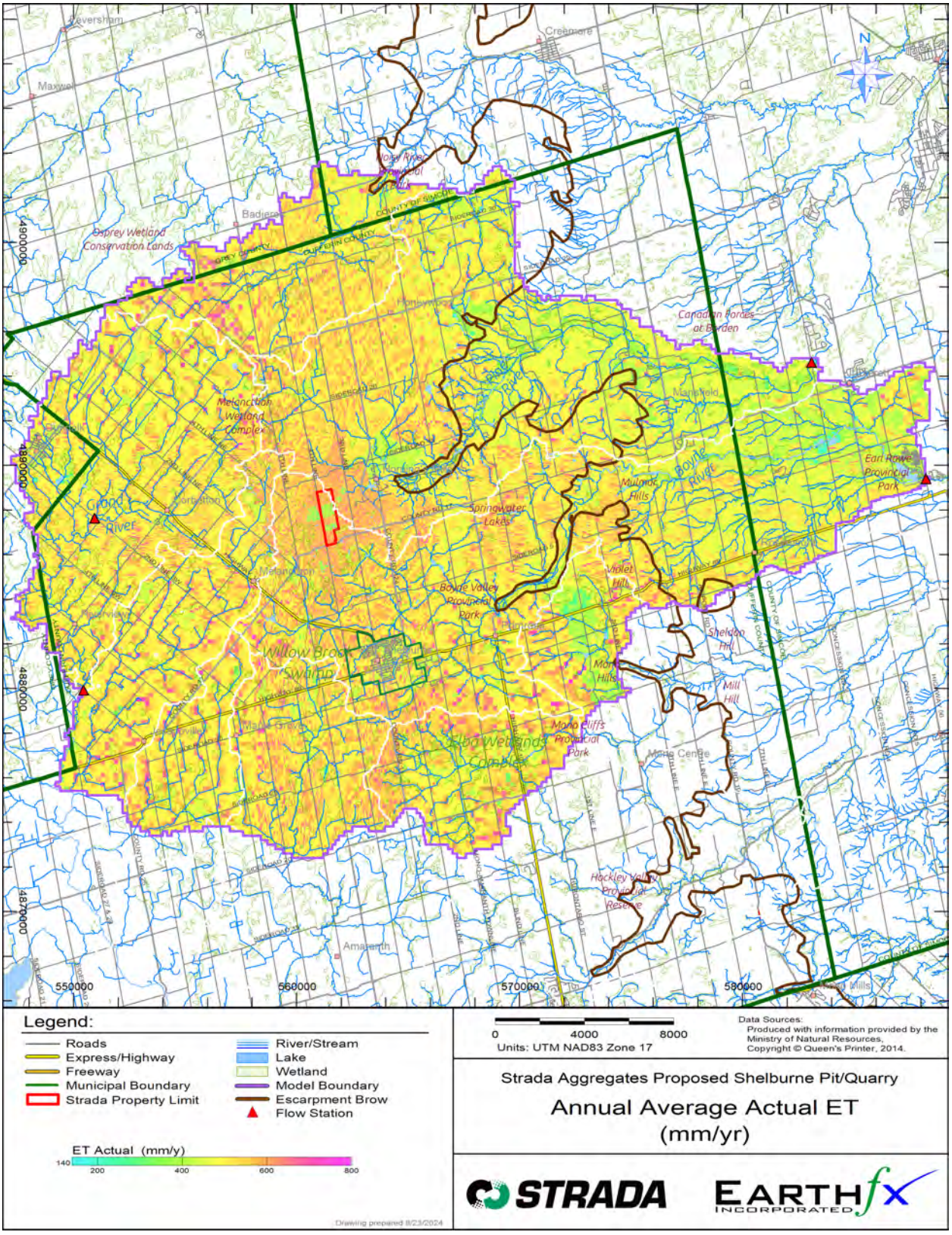


Figure 3.48: Simulated annual average actual evapotranspiration (soil zone ET, canopy losses and sublimation) in mm/yr.

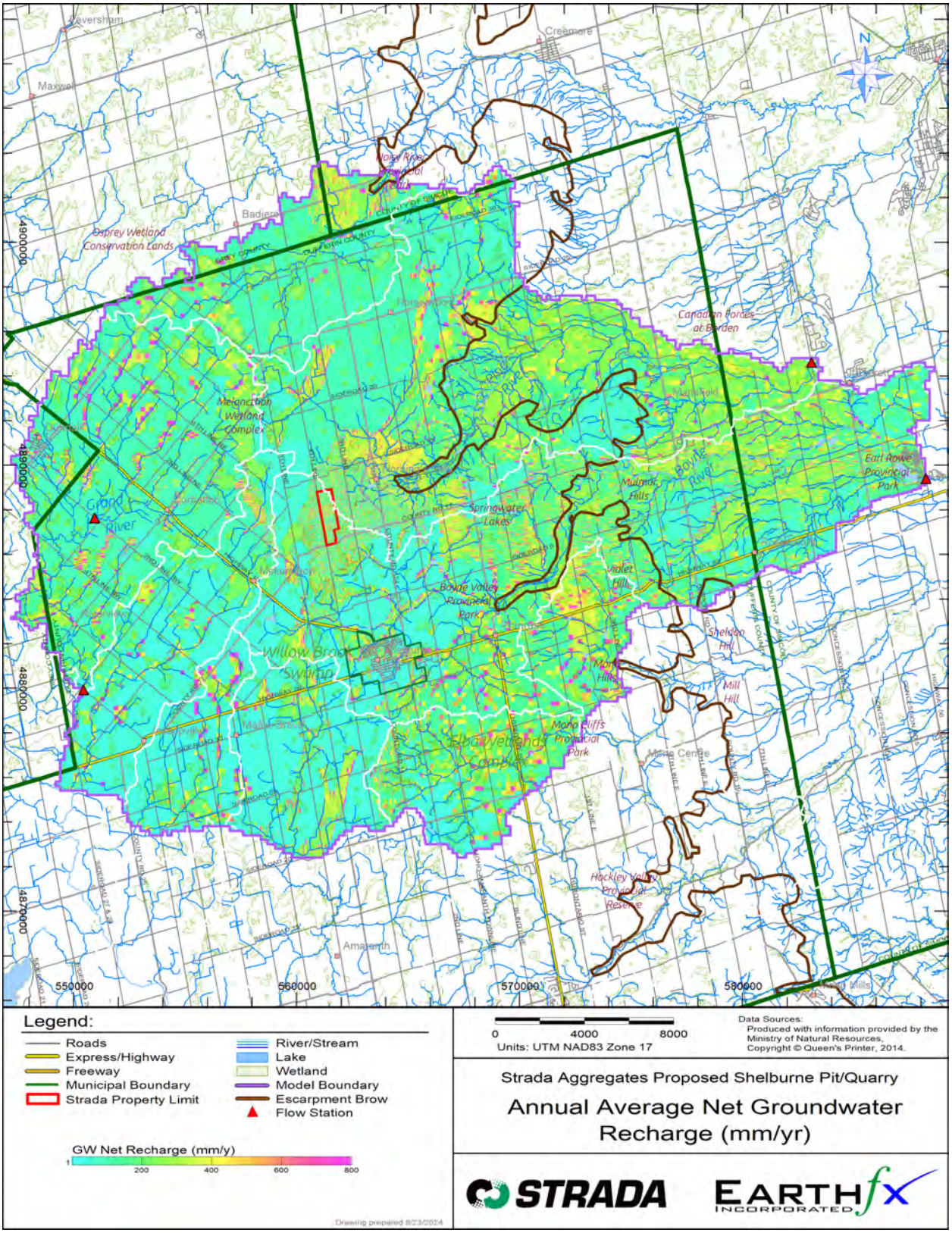


Figure 3.49: Simulated annual net average groundwater recharge in mm/yr.

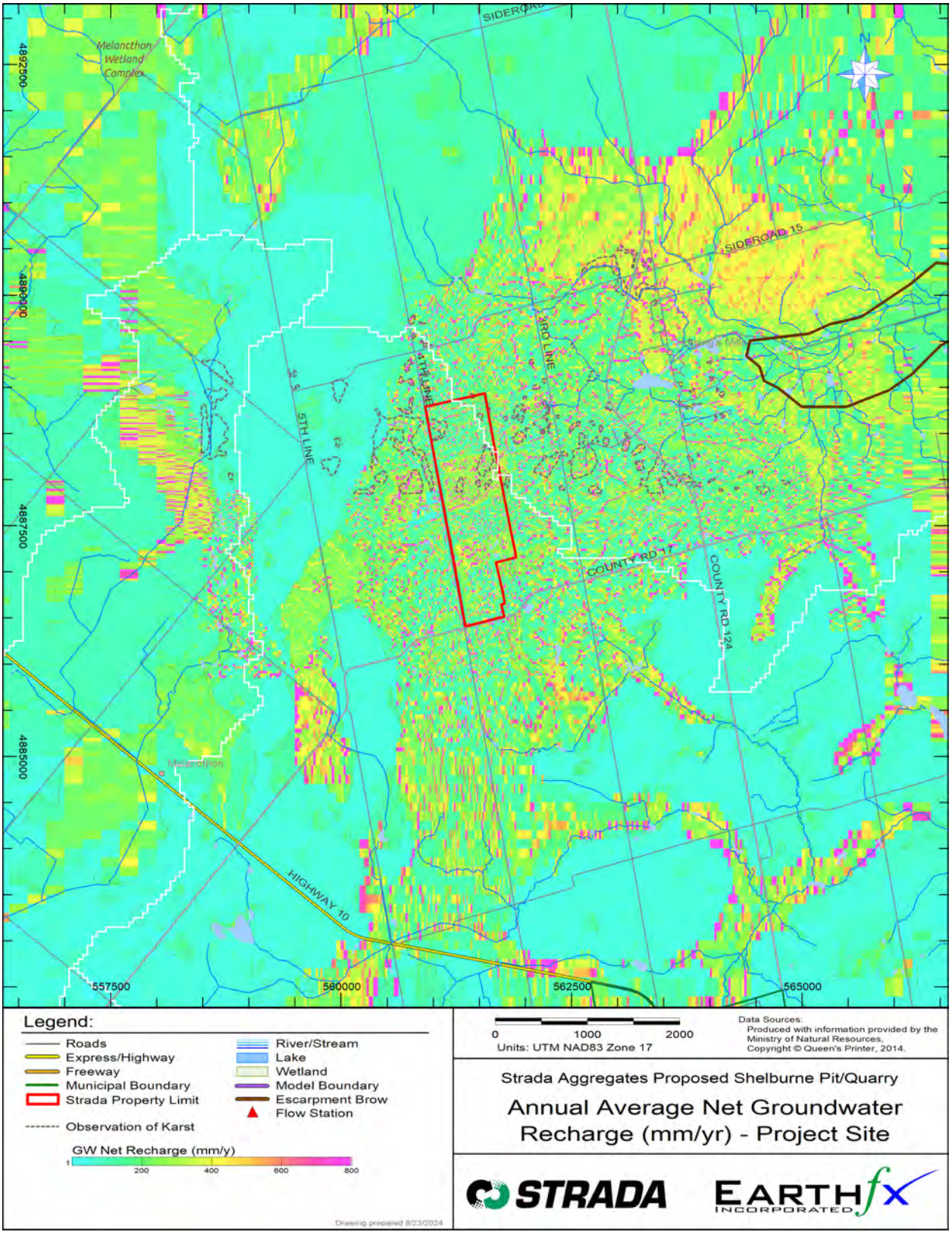


Figure 3.50: Simulated annual net average groundwater recharge (mm/yr) around the Strada property.

3.6.7 Swale Analysis

The role of closed depressions, or swales, was evaluated in the results. Figure 3.51 shows the distribution of recharge (per cell) after the correction of the cascade network, for the entire model area (black line), and for the two catchments, the Boyne and Pine Rivers, used in calibration. The relationship between these distributions with soil texture is also presented in Figure 3.51. The allocation of the area under each curve determines the average recharge; a higher value of recharge is proportional to a distribution whose area is mostly leaning to the right, which is associated to coarser-texture materials. Table 3.10 shows the average recharge after being corrected for swales for each calibration catchment and for the entire model area. They are primarily a reflection of the roles played by land use and cover, surficial geology, and topography in each catchment that were discussed earlier in the report.

Table 3.10: Average swale-corrected recharge per catchment and for the entire model area.

Catchment Associated to Streamflow Station	Station ID	Average Recharge (mm/yr)
Boyne River at Earl Rowe Park	02ED102	222
Pine River near Everett	02ED014	255
Grand River near Riverview	14518	181
Grand River near Dundalk	15050 (GRCA) 02GA041 (EC)	155
Model Area	--	222

In general, water accumulated in swales occurring in fine texture materials were initially redistributed to nearby areas with more drainable soils in order to provide a basis for this analysis. Of note, the distribution of groundwater recharge by soil type is clearly centered in the middle of the range of texture materials, highlighting the contribution of the predominant loamy soils (75.6% of the total area) to the total recharge in the model area. Results indicate that, volumetrically, more recharge occurs on the medium-grained soils rather than on the less prevalent coarser soils.

For the purpose of the final simulation presented in this section (Section 4.6), swales were not redistributed to more drainable areas as the occurrence of this swales are deemed common in and around the Strada property as per communications with Hunter and Associates. For example, Figure 3.52 shows the recharge, cascade network and swales in the local vicinity of the site. Numerous closed depressions, or swales, are seen in the cascade network and underlying hill-shaded LiDAR DEM. The bright pink cells at the center of these swales illustrate that overland runoff moves down the cascade network and can result in high recharge, exceeding 3000 mm/a, in the closed depressions.

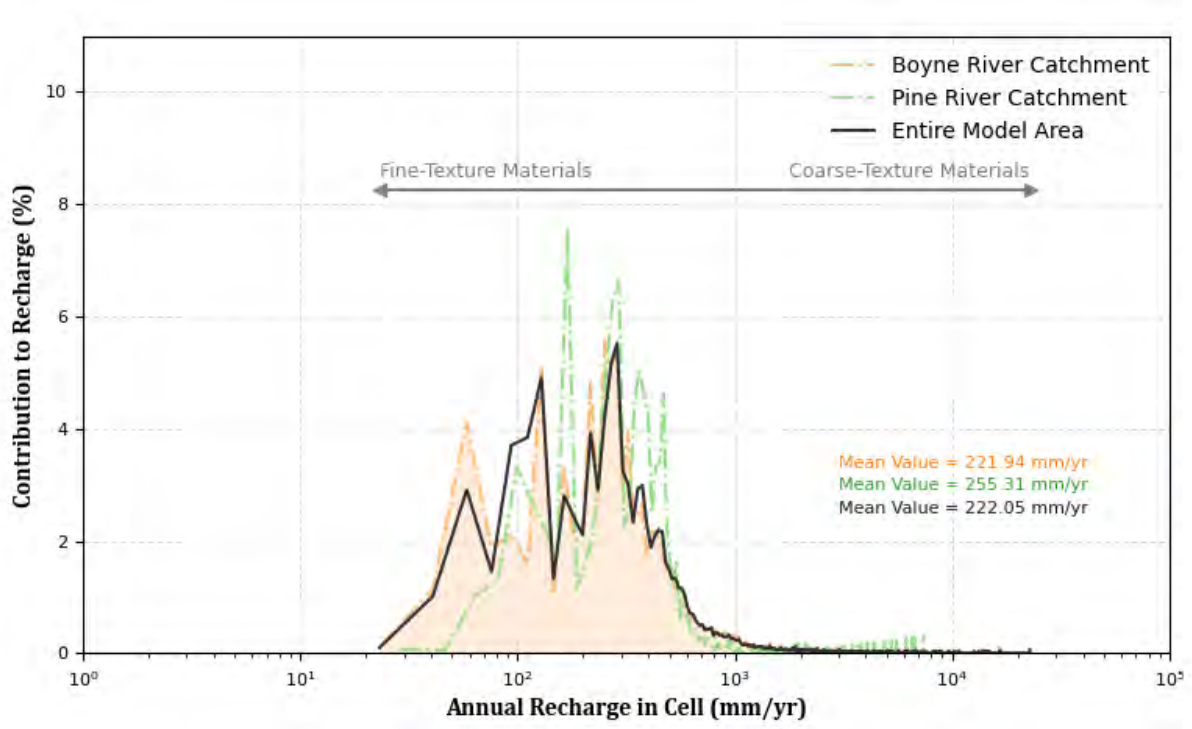


Figure 3.51: Recharge histograms in the study area and its relation with texture materials.

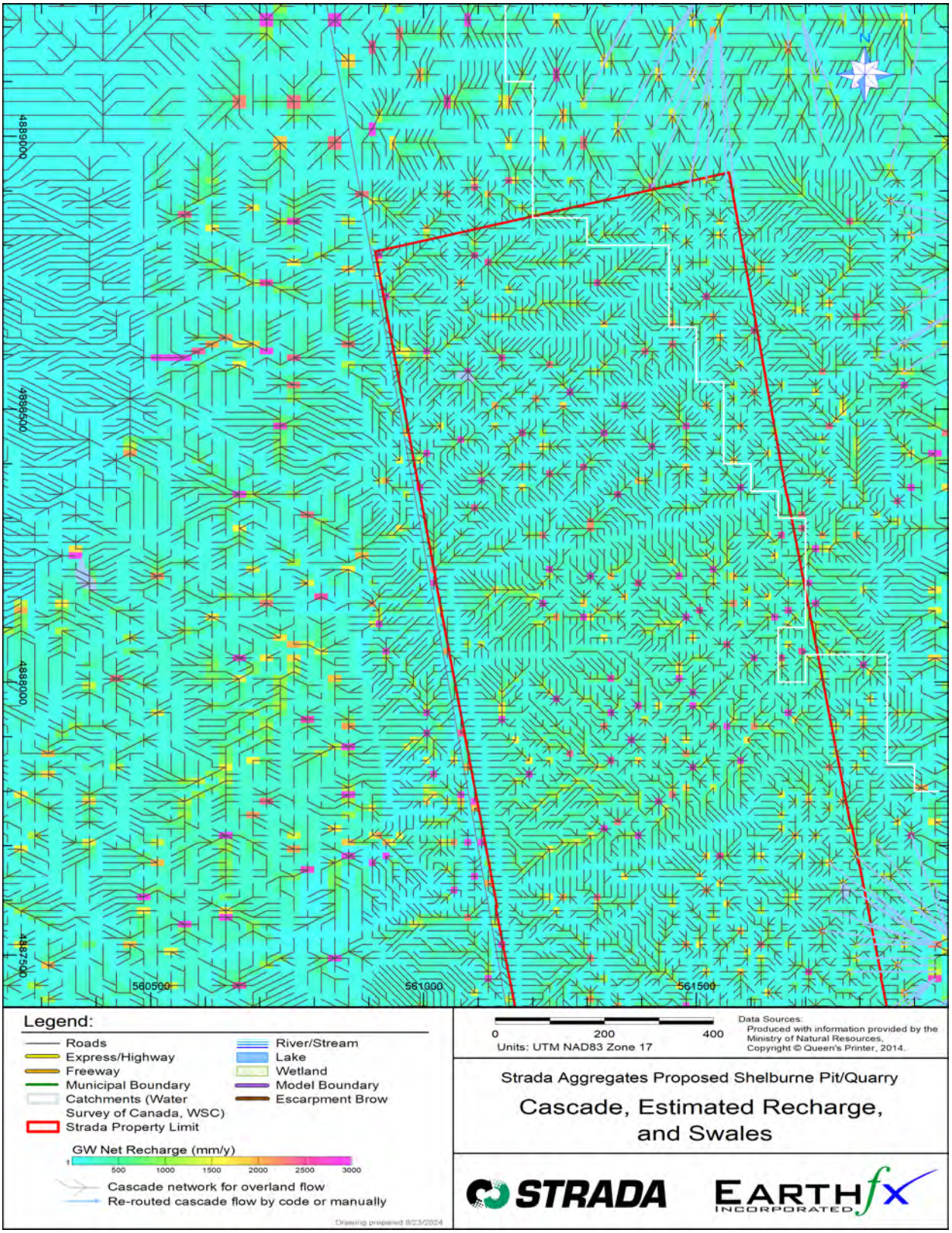


Figure 3.52: Local cascade network, estimated recharge and swales

3.7 *Conclusions*

The development of the PRMS model is a critical element of the Strada Pit/Quarry project. The main goal of the PRMS model development consisted of quantifying groundwater recharge rates.

The model area is dominated by glaciolacustrine till and ice-contact stratified deposits and mostly by row crops, hay/pasture, and forested land covers. The interaction among the underlying surficial geology, the current land cover, and the changing climate controls the hydrologic response of each catchment to precipitation events.

The snowpack formation in the PRMS model indicated that it is very well matched to that measured in both the snow course sampling as snow depth and the remote sensing CaPA snow depth product (2.5-km grid). However, monthly averaged streamflow estimates revealed that the snowmelt process is not fully quantified in the PRMS model, as peaks in winter and spring melt remained unmatched. In spite of this, the PRMS model, to date, has an excellent monthly NSE and percent volumetric difference, which demonstrate that the model is currently well calibrated for use in the estimation of long-term average recharge and baseflow. For the validation period WY2017-WY2021, in the Boyne River catchment, the model performance was maintained with values comparable to those in calibration, specifically for baseflow. The model performance on the Pine River catchment was only be validated for the entire simulation period WY2003-WY2021 as the streamflow station stopped collecting data in 2016.

4 MODFLOW Groundwater Model Development

A groundwater flow model is a simplified representation of the complex physical, hydrologic and hydrogeological processes that affect the rates and direction of groundwater flow. These processes relate to physical characteristics of the study area and include:

- stratigraphy (i.e., the bedrock and overburden stratigraphic layers, their top and bottom surface elevations, lateral extent of the formations, and unit thickness);
- hydrostratigraphy (i.e., descriptions of the aquifers and aquitards in the study area, their top and bottom surface elevations, and their lateral extent, thickness, and degree of continuity;
- aquifer and aquitard properties (i.e., estimated hydraulic conductivity, anisotropy, saturated thickness, transmissivity, porosity, and storage properties);
- inputs to the hydrologic system (i.e., rates of groundwater recharge and discharge and the underlying processes that affect these rates (e.g., precipitation, evapotranspiration, overland runoff, infiltration, and baseflow));
- properties of the surface-water system and factors controlling groundwater/surface water interaction;
- anthropogenic inputs and outputs from the groundwater system (pumping rates and return flows); and
- other significant features (e.g., surficial geology and topographic features such as slope that may affect recharge and discharge).

The groundwater flow model used in this study was built with the U.S. Geological Survey (USGS) MODFLOW computer code (Harbaugh, 2005). This code is well suited for modelling transient groundwater flow in multi-layered aquifer systems and can easily account for irregular boundaries, complex stratigraphy, and variations in hydrogeologic properties. MODFLOW-NWT (Niswonger et al., 2011), a newer version of the code, is especially well suited for representing thin aquifers and sharp changes in model layer stratigraphy, such as those encountered near the Niagara Escarpment.

4.1 *Groundwater Flow Equation*

Groundwater flow is governed by Darcy's Law, which states that flow is proportional to the hydraulic gradient and hydraulic conductivity of the aquifer material. Darcy's Law can be written as:

$$q = -K \frac{dh}{dx} \qquad \text{Eq. 4.1}$$

where q is the specific discharge or rate of flow per unit area, K is the hydraulic conductivity, h is the hydraulic head (equivalent to the groundwater level), and dh/dx is the hydraulic gradient (change in hydraulic head per unit length). Groundwater flow is also governed by the Law of Conservation of Mass which states that all inflows to an area must be balanced by outflows and/or by a change in

aquifer storage. When the mass balance equation is combined with Darcy's Law, it yields the governing equation for three-dimensional groundwater flow.

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)=S_0\frac{\partial h}{\partial t} \qquad \text{Eq. 4.2}$$

where:
- K_{XX} = hydraulic conductivity in the x direction;
- K_{yy} = hydraulic conductivity in the y direction;
- K_{ZZ} = hydraulic conductivity in the z direction;
- h = hydraulic head;
- S_0 = specific storage

For the regional calibration, steady-state conditions were assumed in order to approximate long-term average conditions in the groundwater flow system and the term on the right-hand-side of Eq. 5.2 (related to the change in head over time) is set equal to zero.

In the hydraulic approach to aquifer flow (see Bear, 1979), Eq. 5.2 can be simplified by integrating over the thickness of the aquifer. The resulting steady-state equation for two-dimensional flow in a confined aquifer is written mathematically as:

$$\frac{\partial}{\partial x}\left(T_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(T_{yy}\frac{\partial h}{\partial y}\right)+\left[\frac{K'_U}{B'_U}(H_U-h)\right]+\left[\frac{K'_L}{B'_L}(H_L-h)\right]+R-\sum_{k=1}^{N_{well}}Q'_k=0 \qquad \text{Eq. 4.3}$$

where:
- T_{XX} = transmissivity in the x direction (where $T_{XX} = K_{XX}B$);
- T_{yy} = transmissivity in the y direction;
- h = hydraulic head;
- K' = vertical hydraulic conductivity of an overlying (or underlying) confining unit
- B' = thickness of the upper (or lower) confining unit;
- H_L/H_U = head in the aquifer layer overlying/underlying the confining unit;
- R = rate of groundwater recharge;
- Q'_K = pumping rate (per unit area) at well k

Eq. 5.3 can be written for each aquifer in a layered sequence of aquifers and confining units. Eq. 5.3 is the partial differential equation that forms the basis of the mathematical model developed for the study area. Numerical methods are used to solve Eq. 5.3 for each cell in the model area subject to the boundary conditions and variable aquifer/aquitard properties, geometry, and rates of recharge and discharge across the study area.

4.2 *Model Extents*

The extents of the Proposed Strada Pit/Quarry groundwater model were selected to correspond to natural physical boundaries, where possible. The extent of the groundwater model is similar to that of the PRMS hydrologic model boundary, and is defined by the Nottawasaga River catchment to the south, and including the Grand River headwaters to the west, the Noisy River to the north, and the Earl Rowe Provincial Park to the east of the model domain. A short stretch along centerlines of the Grand River was treated as model boundary, at the southeast. The southern border of the model follows a topographic divide located just northwest of the Town of Mono Centre cutting across the Willow Brook catchment, a tributary to the Grand River (Figure 4.3). The active model area encompasses approximately 788 square kilometres (km^2).

4.3 *Model Discretization*

The model domain in MODFLOW requires the study area to be divided horizontally and vertically. The horizontal grid is comprised of small square or rectangular cells, while the vertical layers will vary with topography and the elevations defined by the regional hydrostratigraphy. Optimal `horizontal grid design is a balance between achieving the highest resolution possible (i.e., smaller cells) and minimizing model run times, which increases proportionally to the cube of the number of cells. The Proposed Strada Pit/Quarry groundwater model uses square cells, 200 m on a side, in areas far from the Strada property, and are systematically decreased first to 100 m, then to 50 m and 25 m, and down to 12.5 m in the area surrounding the Strada property. The model grid is shown in Figure 4.2 and consists of 415 rows and 505 columns making a total of 209,575 grid cells for each of the seven model layers. This discretization yielded a groundwater model with manageable run times but very fine detail in the vicinity of the study area.

An important consideration when translating the conceptual model layers to numerical model layers is that MODFLOW requires continuity of aquifer layers whereas the hydrostratigraphic model can have layers of zero thickness. The hydrostratigraphy of the study area presented a unique challenge because nearly all of the Paleozoic bedrock units gradually pinch out across the edge of the Niagara Escarpment. To meet the layer continuity requirements for the numerical model, a minimum layer thickness of 0.5 m was applied where physical layers pinched out.

MODFLOW works in a local, grid coordinate system based on row and column numbers, and their individual widths and lengths. The VIEWLOG-GIS preprocessor (Kassenaar, 2013) was used to help translate geo-referenced map data into MODFLOW coordinates. The local origin for the model grid is at UTM coordinates 546600 E and 4871800 N. All digital data for the study area were referenced using NAD83 (UTM Zone 17) grid coordinates.

To save on the number of model layers, hydrostratigraphic units above and below the Niagara Escarpment shared model space, as shown in Table 4.1. The general assignment of aquifer and aquitard properties was done by hydrostratigraphic unit. Layer 3 was treated a little differently (see Figure 4.8 which shows the hydraulic conductivity values for Layer 3) as it represents a Weathered Bedrock unit. A key assumption here is that near-surface processes have significantly affected the upper few metres of the bedrock compared to the rest of the unit. The hydraulic properties varied based on which unit was near surface (i.e., the properties of the weathered Guelph Formation differ from those of the weathered Queenston). Multiple layers were used to represent the weathered Queenston which was subdivided below the Niagara Escarpment; this preserved the continuity of the model layers which represented multiple bedrock layers that were truncated at the Escarpment.

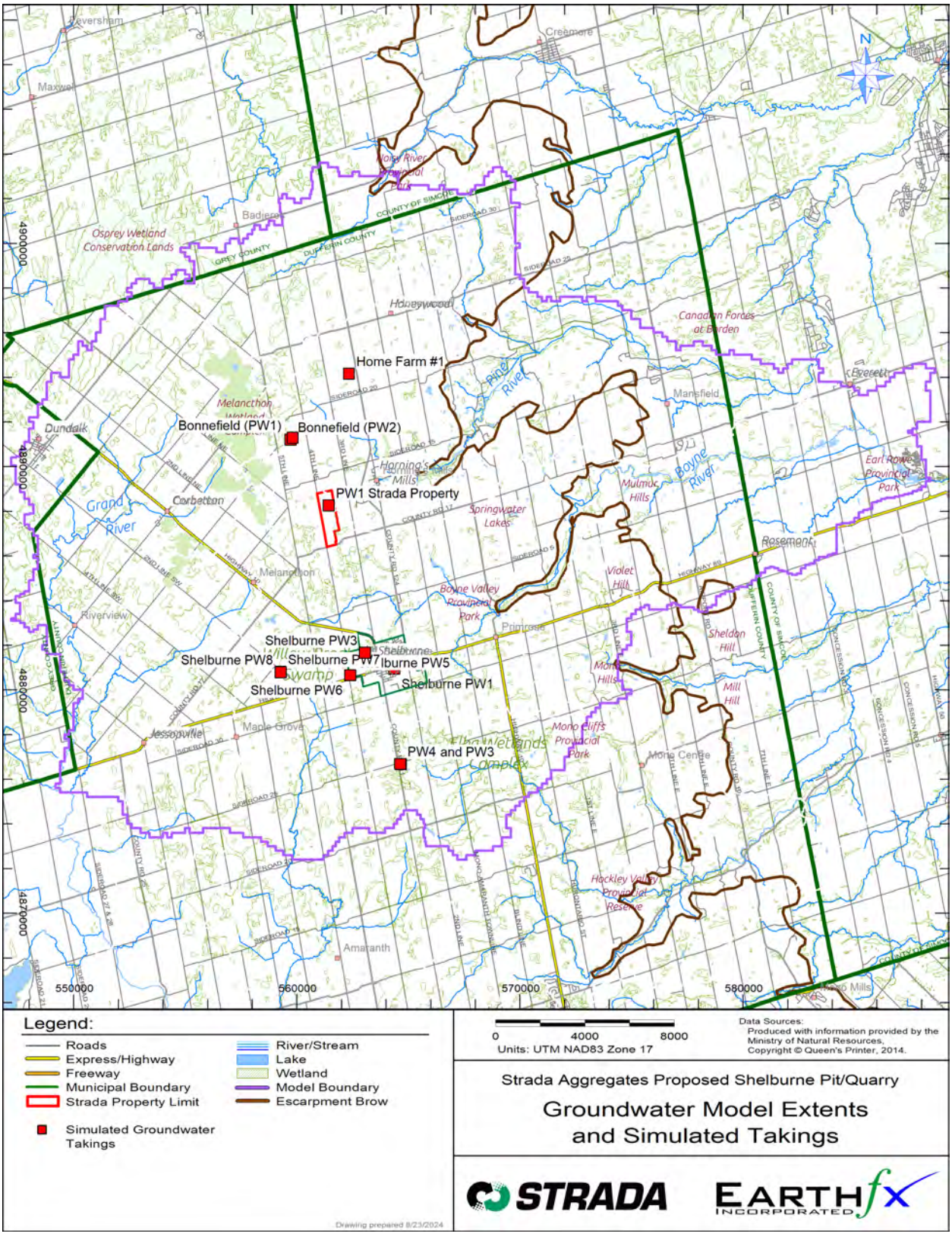


Figure 4.1: Groundwater model extents.

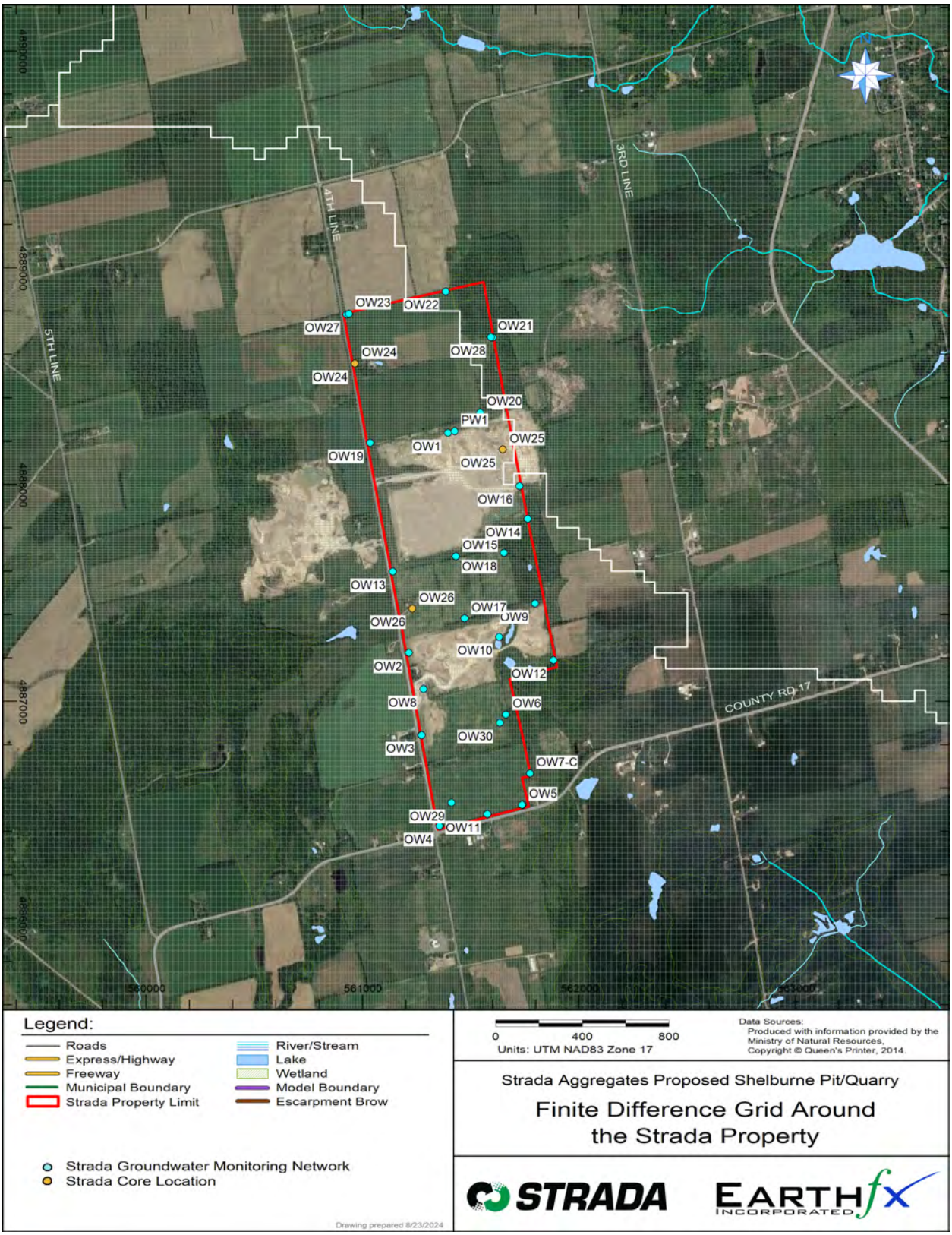


Figure 4.2: Finite difference grid around the Strada property.

To meet the layer continuity requirements, all hydrostratigraphic layers were checked to ensure they exceeded a minimum 0.5 m thickness. If a hydrostratigraphic layer did not meet this minimum, the base of the layer was pushed down slightly.

Table 4.1: Model layers and hydrostratigraphic units in the numerical model.

Model Layer	Above the Niagara Escarpment	Below the Niagara Escarpment
1	Sand/Gravel outwash/Weathered Till	Sand/Gravel outwash/Weathered Till
2	Tavistock Till	Tavistock Till
3	Weathered Bedrock	Weathered Queenston
4	Guelph/Eramosa Bedrock Formation	Moderately Weathered Queenston
5	Ancaster/Niagara Formation	Moderately Weathered Queenston
6	Gasport Formation	Moderately Weathered Queenston
7	Cabot Head	Queenston

4.4 *Boundary Conditions*

Boundary conditions are specified for cells that lie along lines corresponding to the physical boundaries of the groundwater flow system. Three general types of boundary conditions were utilized in the Proposed Strada Pit/Quarry groundwater model: constant head; no-flow; and head-dependent discharge boundaries.

4.4.1 Constant Head and No Flow Boundary Conditions

Figure 4.3 shows the location of constant head and no-flow boundaries for the model. Constant head boundary conditions were applied on the southwestern boundary of the model along the main branch of the Grand River. Additionally, constant heads were also applied at all points of intersection between the model boundary and streams that are flowing out of the model domain. The constant head boundaries allow groundwater flow in and out of the model through the designated cells. Constant head boundaries were assigned to ground surface and assumed to extend through all model layers.

A no-flow boundary condition was applied along the remaining lateral boundaries of the model, indicating that flow across the external boundaries is expected to be negligible. These boundaries were selected to coincide with the regional surface water divides for the subwatersheds surrounding the Strada Quarry property. A no-flow boundary condition was also applied at the base of the lowest model layer, corresponding to the intact (unweathered) shales of the Cabot Head Formation.

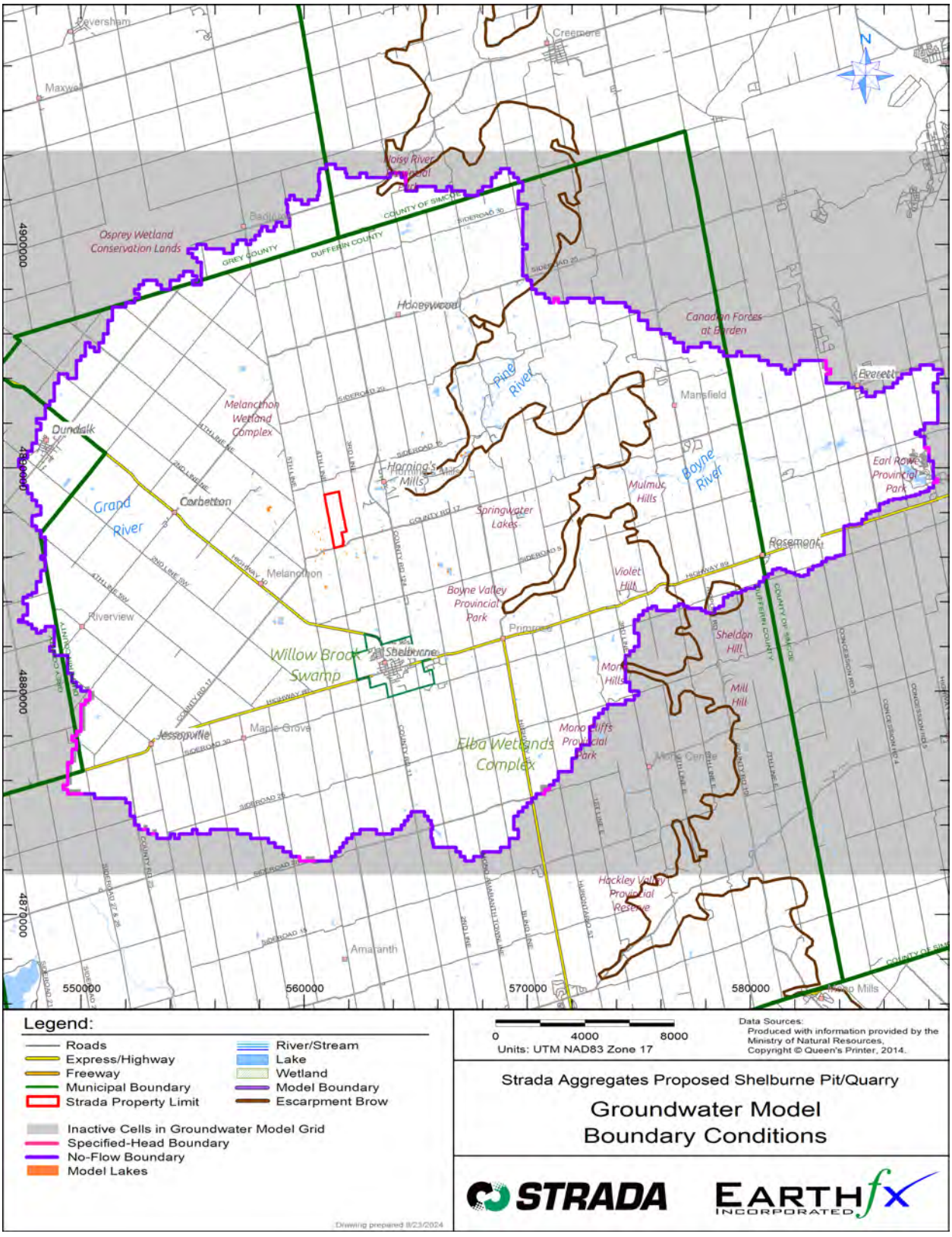


Figure 4.3: Boundary conditions for the Strada Quarry groundwater model.

4.4.2 Head-Dependent Discharge Boundary Conditions

Streams: Head-dependent flux boundaries were used extensively to represent groundwater/surface water interaction between streams, lakes, and larger wetlands within the model area. Flow between the streams and the underlying aquifer was assumed to be exchanged as "leakage" across lower-permeability streambed material. The rate of leakage is determined based on Darcy's Law where:

$$Q_L = \frac{K'}{B'} A_L (H_L - h) \qquad \text{Eq. 4.4}$$

where: Q_L = volumetric flow rate between aquifer and stream;
K' = vertical hydraulic conductivity of the streambed;
B' = thickness of the streambed;
A_L = wetted area of the streambed;
H_L = stream stage (in masl); and
h = head in the aquifer

Leakage between the stream and the aquifer is calculated on a cell-by-cell basis using the SFR2 module (Niswonger and Prudic, 2005). In SFR2, a stream "reach" is defined as the portion of a stream segment within a model cell. The MNRF Water Resources Information (WRIP) stream network (MNRF, 2012) was translated onto the MODFLOW grid by defining stream reaches and "segments" as per the sketch in Figure 4.4. Stream segments are numbered going downstream.

Over 1,096 km of stream channels were simulated in the model, including both intermittent and perennial streams (Figure 4.3). The study area contained a total of 3,816 stream segments broken into 25,479 individual cell stream reaches.

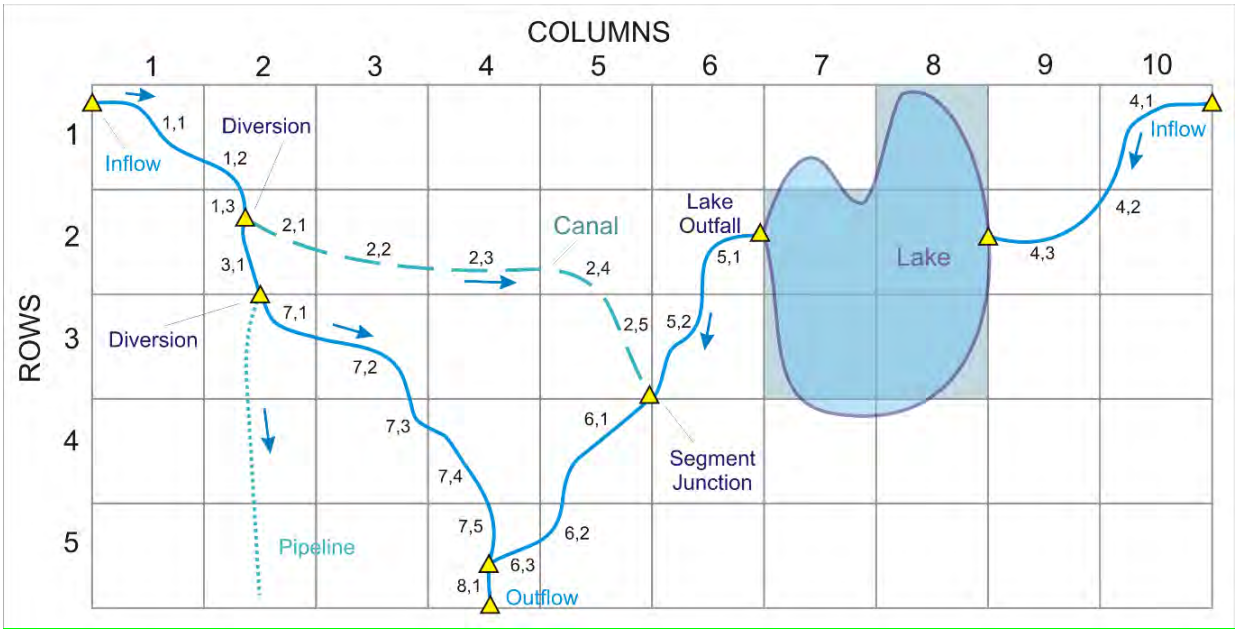


Figure 4.4: Stream network and lake representation in the SFR2 and LAK3 modules (modified from Markstrom, *et al.*, 2008).

Stream properties, including cross-sectional geometry and streambed elevation, roughness (Manning's n), thickness, and hydraulic conductivity, were defined for each stream segment. Streams segment properties were assigned base on their individual Strahler classification order. The hydraulic conductivity of the streambed material was scaled from the surficial geology values used in PRMS and distributed across the study area. Bed thickness was set to 0.5 m and Manning's n was set to 0.035. Stream slope and streambed elevation were estimated for each segment from the MNRF hydrologically-corrected 10-m DEM (MNR, 2008).

Representative 8-point stream cross sections and streambed conductance values were assigned to each stream based on their Strahler class order (Figure 4.5) after analyzing the database of morphologic characteristics summarized by Annable (1996) for watercourses in southern Ontario. The sections provide an overbank portion with a higher roughness coefficient (Manning's n of 0.045). The small slope assigned to the channel bottom was needed for numerical stability.

Flow at the midpoint of each reach is calculated based on the sum of upstream inflows (as calculated by SFR2), precipitation, evaporation, and overland flow to the reach. Stream stage is then determined from the stream roughness, slope and the cross-sectional geometry, assuming uniform flow. Leakage to or from the aquifer is then calculated based on Eq. 5.4 and the difference between stream stage and the head in the underlying aquifer. Multiple reaches can occur within a single cell and cells are small enough such that the head in the centre of the cell is a reasonable approximation to the head in the aquifer beneath the streambed.

Net outflow from the reach is routed to a downstream reach segment. Stream segments can terminate in a lake or wetland (as shown in Figure 4.4) or exit the model area. Because leakage can affect aquifer levels, and in turn, streamflow; the streamflow routing and the groundwater flow equations are non-linear and must be solved in an iterative manner until convergence is achieved (i.e., changes in simulated flows and heads between successive iterations fall below threshold levels).

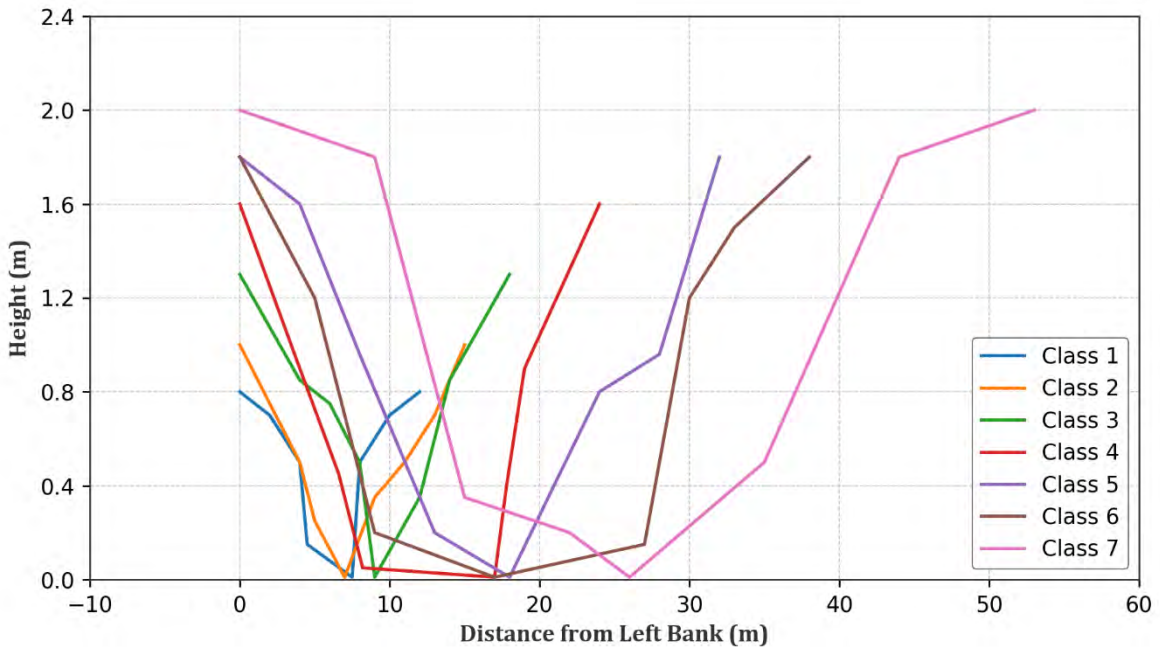


Figure 4.5: Simplified cross-sections for the seven Strahler classes derived from data collected by Annable for Southern Ontario.

Lakes and Wetlands: Leakage between lakes or other standing bodies of water and the aquifer is also governed by Eq. 5.4 and is calculated on a cell-by-cell basis using the LAK3 module in MODFLOW (Merritt and Konikow, 2000). In LAK3, a cell can represent all or a portion of a lake (see Figure 4.4). The area A_L in Eq. 5.4 is equal to the cell area. Head in the aquifer, h, is the head in the cell underlying the lake and H_L is the lake stage. Lake stage is calculated from specified stage-volume relationships. Lake volume is calculated in a separate water budget analysis for each lake based on the sum of upstream inflows (as computed by the SFR2 module); precipitation, evaporation, and overland flow to the lake; and outflow from the lake (also calculated by SFR2 based on lake stage). Lakes can penetrate multiple model layers and leakage can occur to cells adjacent to or underlying the lake. Typically, an outflow structure is installed in the model to help control lake stage and outflow.

The location and outline of lakes within the study area were based on the MNRF ONH waterbody coverage (MNRF, 2019) with some refinement based on recent aerial photography (Google Maps). Sixty-five MODFLOW lakes located in the vicinity of the Strada property were simulated in the model. Smaller ponds were not explicitly represented in the MODFLOW model at this time, but PRMS depression storage parameters were adjusted to represent wetland ponding over the entire wetland coverage. Lakes were assigned an average bottom depth of 5 m below the DEM elevation. Seventeen of these MODFLOW lakes were created at the lowest elevations of wetlands in the vicinity of the Strada property. In order to keep these lakes/wetlands in the top layer, a shallower depth of 2 m below the DEM elevation was assigned. This allowed us to take advantage of the LAK3 package in quantifying inflows and outflows from this surface water features.

4.5 *Karst Representation*

The occurrence of closed depressions in the LiDAR data may be related to two possible geologic processes. Hummocky topography is commonly found in glacial outwash deposits where rapid glacial ice block melting results in depressions, and, in extreme situations, kettle lakes. This form of hummocky topography is commonly found on the Oak Ridges Moraine, and is likely present in the sand and gravel outwash deposits in the vicinity of the Strada pit.

Closed depressions may also be an indicator of subsurface karst dissolution. Hunter and Associates (April 2010) inferred a network of underground karst channels that would preferentially move recharge from surface depressions along the bedrock surface. While these Hunter mapped channels have not been proven, they were added to the model to evaluate their possible effect on the flow system. The Hunter mapped network is shown as orange dotted lines on Figure 4.6.

Note: The high focussed recharge that occurs in closed depressions was simulated in the PRMS model, as discussed in Section 3.6.7.

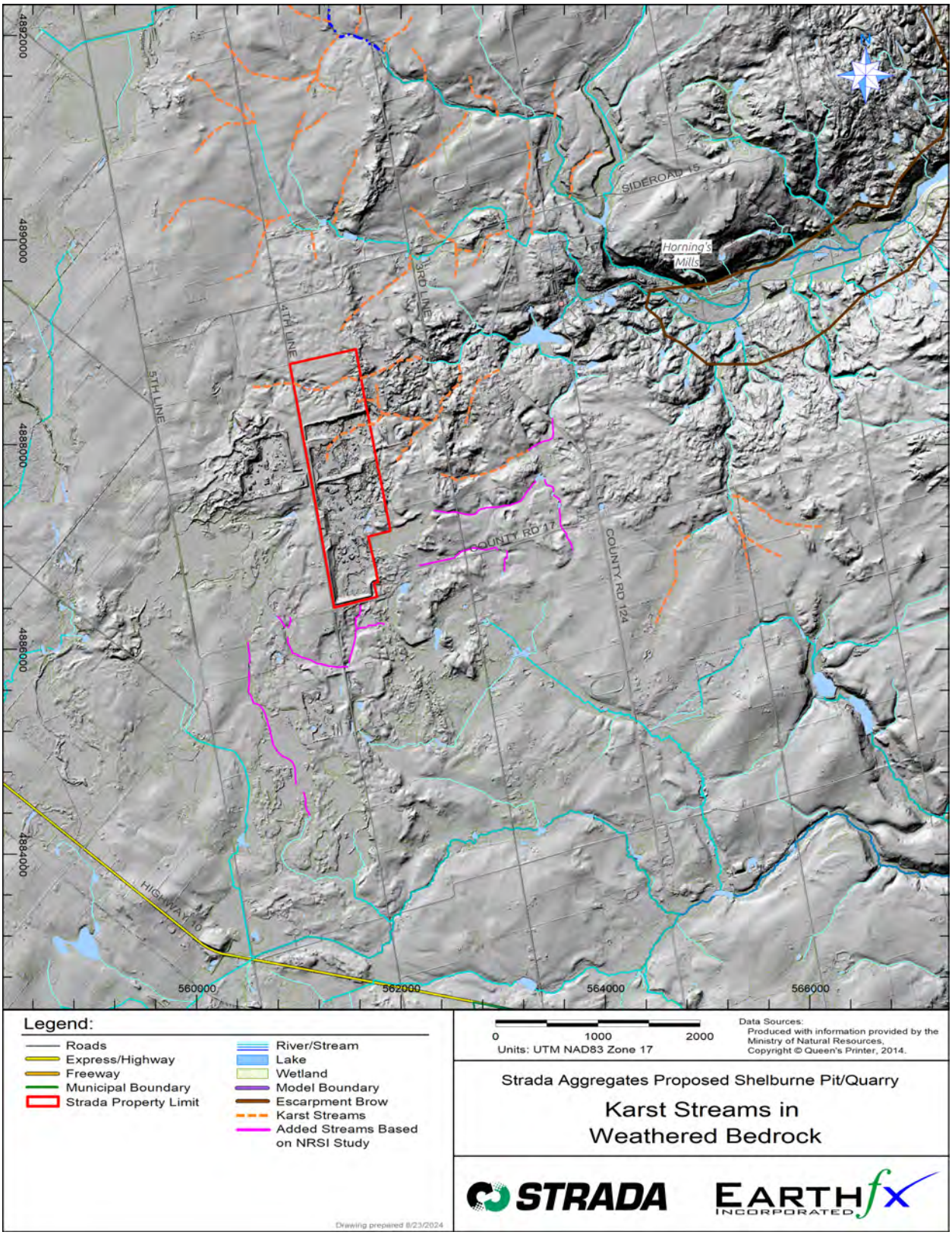


Figure 4.6: Inferred karst subsurface stream network (after Hunter and Associates, April 2010).

4.6 *Groundwater Recharge Estimation*

The PRMS model, described in Section 3, was developed to estimate the distribution of long-term average recharge in the study area. Groundwater recharge in the groundwater model was simulated using the Unsaturated Zone Flow (UZF) package (Niswonger *et al*., 2006) for MODFLOW. The UZF module compares the applied recharge to what can actually be accepted by the upper model layer based on the assigned vertical hydraulic conductivity. Recharge in excess of what can be accepted, referred to as "rejected recharge", is routed directly to the nearest stream segment. The UZF module also accounts for groundwater discharge to land surface in areas of high-water table. The groundwater discharge, referred to as "surface leakage" is also routed as runoff to nearby streams.

4.7 *Simulated Groundwater Takings*

Groundwater and surface water are extracted from the aquifers, streams, and lakes in the study area for communal water supply, agricultural use, commercial and industrial use, golf course irrigation, and private (domestic) water supply. Extraction of over 50,000 litres of water per day (L/d) from a surface or groundwater source requires a Permit to Take Water (PTTW) from the MECP. Permits are designated as surface water, groundwater, or both. The groundwater wells considered in the Proposed Strada Pit/Quarry groundwater model are listed in Table 4.2.

Actual water use rates are generally less than the permitted water takings. The Water Taking Reporting System (WTRS) database, maintained by the MECP, contains self-reported information on actual takings. Data for municipal wells are generally complete. Some known problems exist with the database for non-municipal pumping due to changing permit numbers, incomplete records, backlogs in the transcription of paper records, and non-compliance with reporting requirements. A subset of the WTRS data for 2007 to 2012 was used in this study due to the paucity and inconsistencies in the data prior to 2007. For takings where no historical reported rates could be found, it was conservatively assumed that pumping rates were at their maximum permitted daily value.

Table 4.2: Groundwater use details and simulated rates used for calibration.

Permit Number	Well Name	Easting	Northing	Water Use	Max. Permitted (m^3/d)	Average Rate (m^3/d)	Simulated Rate (m^3/d)
0580-78PPS2	PW1 Strada Property	561426	4888258	Commercial	328	-	303
0723-999LFU	Bonnefield (PW1)	559810	4891295	Agricultural	3273	-	1636
0723-999LFU	Bonnefield (PW2)	559714	4891209	Agricultural	3273	-	1636
1814-7QVK7S	Shelburne PW1	564361	4880947	Municipal	1642	519	1030
1814-7QVK7S	Shelburne PW3	563053	4881667	Municipal	1309	528	1067
1814-7QVK7S	Shelburne PW5	562391	4880659	Municipal	982	-	982
1814-7QVK7S	Shelburne PW6	562395	4880659	Municipal	982	344	982
1814-7QVK7S	Shelburne PW7	559266	4880808	Municipal	1634	-	1634
1814-7QVK7S	Shelburne PW8	559274	4880797	Municipal	1634		1634
2773-9G2RXX	PW2 and PW3	564663	4876678	Commercial	327	-	327
2773-9G2RXX	PW4	564632	4876687	Commercial	327	-	327
3005-7UGJ7G	Well 2	583288	4878285	Agricultural	137	0	137
4244-7NVLRZ	Home Farm #1	562330	4894162	Agricultural	2937	1012	1012

Notes: 1) Average rates based on WTRS reported takings for 2010 to 2012.
2) Simulated rate for PW1 Strada Property was calculated from daily volume rates of water extracted during work hours.
2) Simulated rates for Shelburne PW1 and PW3 are equal to maximum reported rates for 2013 (WSP, 2014).
3) Simulated rates for Shelburne PW5 and PW6 are equal to maximum operational takings (1964 m^3/d).

This list includes 13 wells with commercial, industrial, municipal, and agricultural water use assignations. Considering that this project is not explicitly modeling the hydrostratigraphy below the Escarpment, these wells were chosen for their location above it. The locations of the simulated groundwater takings are shown in Figure 4.7.

Simulated rates for the existing Shelburne municipal wells were selected based on the maximum reported taking for the 2013 calendar year, as documented in the Town of Shelburne 2013 Permit to Take Water Annual Monitoring Report (WSP Canada Inc., 2014). The intakes for the four Shelburne wells in the shallow system were assigned to model Layer 3 and 4, representing the upper bedrock aquifer system, while Shelburne wells PW7 and PW8 were assigned the Gasport model Layer 6.

Other groundwater permits (e.g., those related to dug ponds, dewatering ditches, pumping tests, or aggregate operations) were not considered in the model because of their temporary nature or the fact that they were not identified within the vicinity of the Strada property.

4.8 *Simulated Surface Water Takings*

Several permitted surface water takings fall within the general study area. Those located above the Escarpment are mainly clustered along the Noisy River in the far north portion of the model and likely have no significant consumptive use or impact on the model simulations.

Permit PTTW #7121-9Y7HP7, which is a surface and ground water permit sourced for commercial aquaculture purposes is located at approximately 1 km northeast of the Strada property. This permit allows takings from a tributary of the Pine River, and includes a groundwater component that relates to the capture of spring water within the property. As an aquaculture operation, all water diverted for use is likely returned locally to the steam, with limited “consumptive” use.

PTTW #7121-9Y7HP7 is significant due to its proximity to the study area. Details regarding this permit are summarized as follows:

- Source ID: Pine River #1, is allowed to divert a maximum volume of 65.4 m^3/d, throughout the year.
- Source ID: Pine River #2, is allowed to divert a maximum volume of 215.7 m^3/d, throughout the year.
- Source ID: Newell Pond, for a pond with a fixed volume of 281 m^3/d equal to the sum of the maximum volumes captured from the Pine River.
- Source ID: Springs, is allowed to divert a maximum volume of 179 m^3/d, for 180 days of the year.

The location of this permit is presented in Figure 4.7.

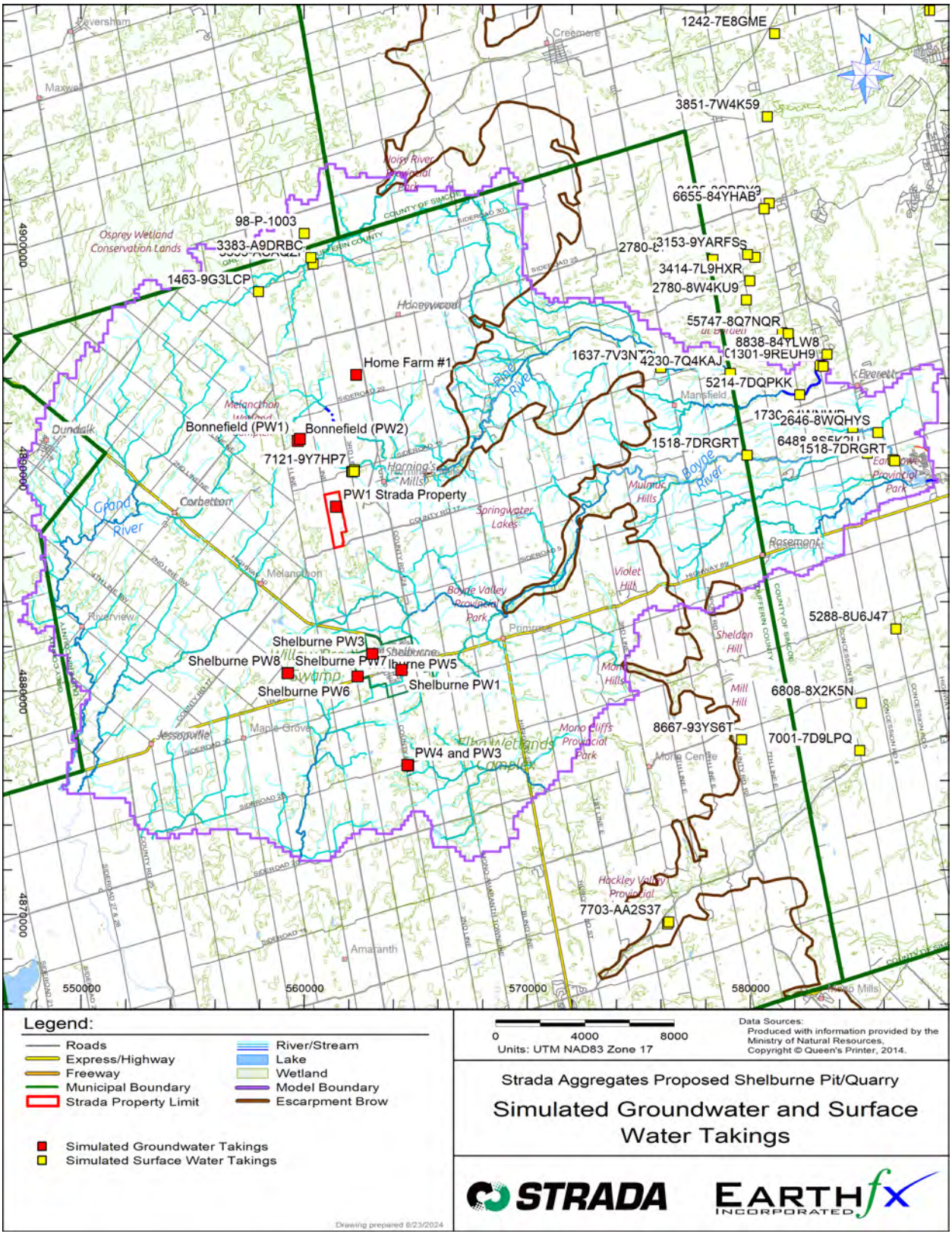


Figure 4.7: Simulated groundwater and surface water takings.

4.9 *Groundwater Parameter Distributions*

The properties of the model layers, such as the top and bottom elevations, and the hydraulic conductivity, were assigned to each cell. Layer tops and bottoms were assigned based on the geometry of the hydrostratigraphic model (which closely follows the updated stratigraphic layers developed for this study). Initial estimates for hydraulic conductivity were made based on available hydrogeologic investigations and modelling studies. For all of the bedrock units, an equivalent porous medium (EPM) assumption was used to account for otherwise fracture-dependent hydraulic conductivity values.

Uniform hydraulic properties were initially assigned to each of the hydrostratigraphic units, except for the Weathered Bedrock unit. Figure 4.8 shows the hydraulic conductivity values for Layer 3 which represents Weathered Bedrock above and below the Niagara Escarpment made up of the most uppermost bedrock unit locally present. Table 4.3 lists the initial hydraulic parameters used in the model for each of the hydrostratigraphic units represented in the model.

Table 4.3: **Initial** model parameter values taken from the calibrated Shelburne Wellfield model (2022).

Hydrostratigraphic Unit	Layer	Hydraulic Conductivity [m/s]	Aniso-tropy Kh:Kz	Specific Yield[1]	Specific Storage [1/m]
Weathered till	1	$1x10^{-5}$	3:1	0.10	$1x10^{-4}$
Tavistock till	2	$5x10^{-7}$	8:1	0.05	$1x10^{-6}$
Weathered Bedrock	3	$6x10^{-5}$	2:1	0.10	$5x10^{-6}$
Guelph Formation	4	$9x10^{-5}$	2:1	0.05	$1x10^{-6}$
Ancaster/Niagara Falls	5	$1x10^{-7}$	25:1	0.01	$1x10^{-6}$
Gasport Formation	6	$1.8x10^{-5}$	2:1	0.05	$1x10^{-7}$
Cabot Head	7	$5x10^{-9}$	3:1	0.03	$1x10^{-6}$
Sand/Gravel outwash	1	$2x10^{-4}$	2:1	0.25	$1x10^{-4}$
Sand/Gravel stratified	1	$5x10^{-5}$	2:1	0.15	$1x10^{-4}$
Glaciolacustrine deposits	1	$3x10^{-5}$	2:1	0.20	$5x10^{-5}$
Alluvial deposits 1-8m thick	1	$1x10^{-5}$	2:1	0.10	$5x10^{-5}$
Organics and River Alluvium	1	$1x10^{-5}$	3:1	0.05	$1x10^{-5}$
Weathered Bedrock	3	$9x10^{-5}$	2:1	0.05	$5x10^{-6}$
Weathered Guelph Formation	3	$8x10^{-5}$	2:1	0.10	$5x10^{-6}$
Weathered Ancaster/Niagara Falls Formation	3	$2x10^{-4}$	2:1	0.10	$1x10^{-6}$
Weathered Gasport Formation	3	$1x10^{-4}$	2:1	0.10	$5x10^{-6}$
Weathered Cabot Head	3-7	$1x10^{-5}$	2:1	0.10	$1x10^{-6}$
Below Escarpment and Weathered Layer	3-8	$8x10^{-6}$	3:1	0.05	$3x10^{-6}$

[1] The porosities of the hydrostratigraphic units were assumed to be equal to the assigned specific yield values.

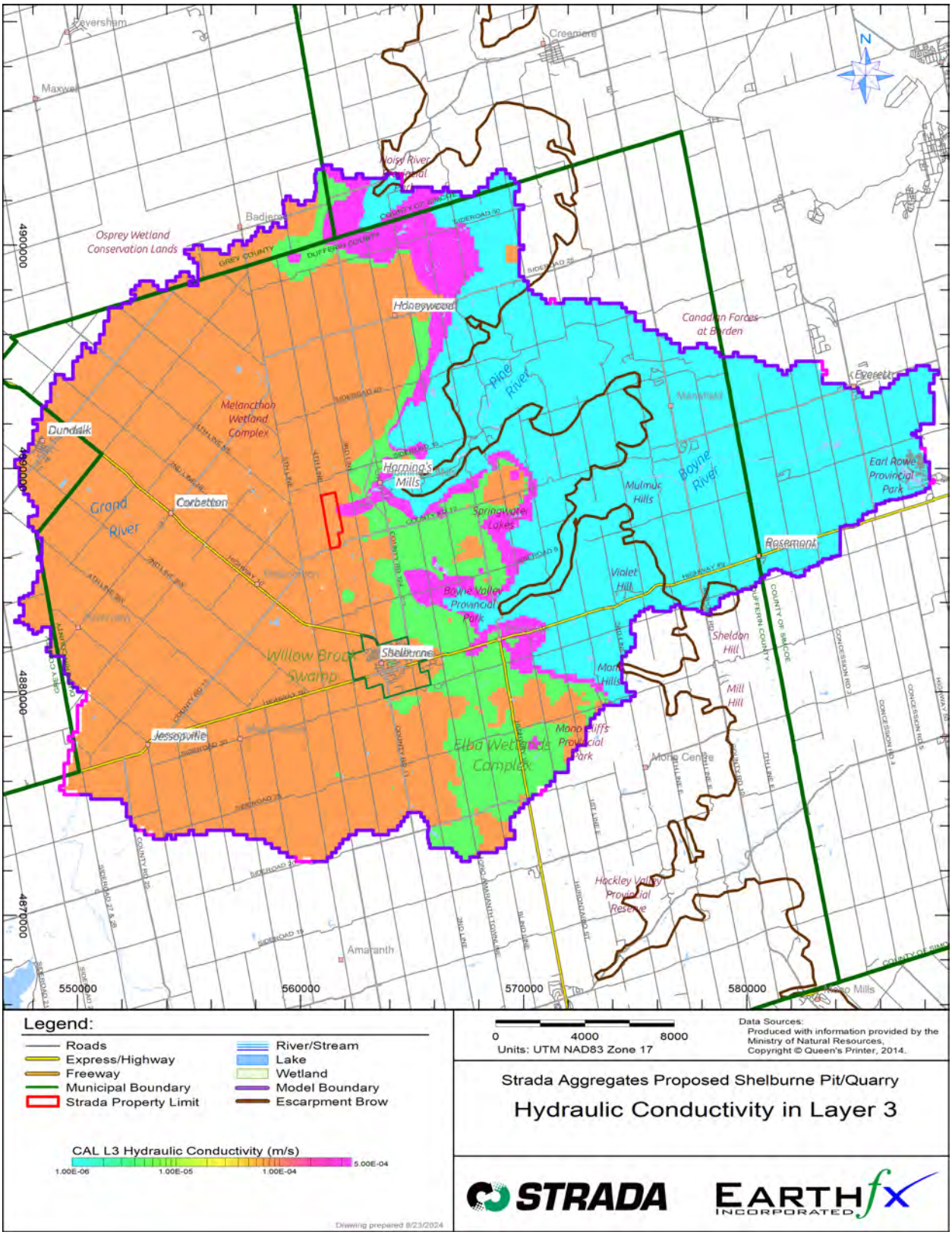


Figure 4.8: Hydraulic conductivity in Layer 3 representing Weathered Bedrock above and below the Niagara Escarpment.

4.10 *Groundwater Model Calibration*

4.10.1 Regional Groundwater Model Calibration to Observed Heads

Calibration of the steady-state groundwater model was conducted by adjusting the hydraulic properties assigned to the aquifers and aquitards until a good match was achieved between the simulated and observed water levels across the study area. Static water levels recorded in the MECP WWIS database served as a primary target for the regional-scale calibration. Numerous biases and errors are known to exist in the water well record data and an assessment of the intrinsic error and variation in this data set is discussed in Kassenaar and Wexler (2006). Despite the known data quality issues, the WWIS data set is this best available data and has a good regional coverage. These data were combined with the locally-collected water level data as part of Strada's monitoring programme. A total of 1,349 well locations made-up the final calibration dataset. The data were assigned to the model layers based on their screened/open-hole intervals. Comparisons were conducted by aquifer, where the simulated heads in model Layers 1, 3-4, and 6 were compared with the WWIS water levels assigned to the respective layers. The number of wells within each layer is provided in Table 4.4.

Three statistics were used to assess the quality of the regional model calibration: the mean error (ME), mean absolute error (MAE), and root mean squared error (RMSE). These are given by Anderson and Woessner (1992) as:

$$\text{Mean Error} = \frac{1}{n}\sum_{1}^{n}(h_o - h_s)_i \qquad \text{Eq. 5-5}$$

$$\text{Mean Absolute Error} = \frac{1}{n}\sum_{1}^{n}|(h_O - h_S)_i| \qquad \text{Eq. 5-6}$$

$$\text{Root Mean Squared Error} = \sqrt{\frac{1}{n}\sum_{1}^{n}(h_O - h_S)_i^2} \qquad \text{Eq. 5-7}$$

where:

h_o = observed head;
h_s = simulated head; and
n = number of observations.

Model calibration was done through a trial-and-error process with over 100 logged steady-state simulations to obtain the best statistics for each aquifer layer. The groundwater model mass balance error for the steady-state calibrated model was -1.86%. Calibration statistics for the simulated water levels are shown in Table 4.4. The near zero value for Mean Error (ME) indicates that there is no bias in the simulated values. The Mean Absolute Error and the Root Mean Squared Error (RMSE) provide a good estimate of the average magnitude of the difference and variance between observed and simulated values. It should be noted that the MECP well record data has a high intrinsic error (see Kassenaar and Wexler (2006)) and this impedes the ability to produce lower RMSE values.

In addition to intrinsic measurement error, the MECP water levels represent one-time measurements at a point taken at different times over a timescale spanning decades. Measurements could have been taken in different seasons and in wet or dry years. In contrast, a steady-state simulation

generates a temporally averaged water level condition for a particular location, eliminating the potential variability associated with seasonal changes in weather, historically dry and wet years, and more recently climate change. Therefore, greater disparities than the RMSE values should also be regarded as being potentially the result of variability in hydrological forcings.

The comparative analysis included in this steady-state groundwater calibration section is limited to observed data collected above the Niagara Escarpment as intermediate and deep hydrostratigraphic units below the Escarpment were not explicitly modeled.

Table 4.4: Calibration statistics for the groundwater model.

Unit	Number of Wells (n)	ME (m)	MAE (m)	RMSE (m)	Range in Observa-tions (m)	RMSE as Percent of Range (%)
Sand/gravel Outwash	60	2.75	3.72	5.28	119	4.4%
Weathered Bedrock/Guelph	1,071	-0.80	3.46	4.87	165	3.0%
Gasport	218	-2.27	5.19	6.59	148	4.5%
Composite of Above Units	1,349	-0.97	3.72	5.19	165	3.1%

4.10.2 Simulated Head Contour Maps and Residuals

Regional-scale maps were produced to present the results of the regional-scale model calibration. Local-scale maps are presented and discussed in Section 4.10.6. The contours in Figure 4.9 show the simulated heads in Layer 1 representing surficial sand and gravel outwash (and shallow weathered till) units at the regional scale. The sand/gravel outwash is limited to an area north of the Elba Wetlands Complex and the Town of Horning's Mills. The corresponding MECP static water levels are presented as colour-coded dots for comparison to the colour-shading for simulated heads. Differences between the colour inside and outside the dots indicate a deviation from the observations. A visual comparison of the observed and simulated values shows that a good match was achieved.

A positive value of the mean error in Table 4.4 indicates that the model is underestimating the observed water level values in that unit, which is the case for the sand and gravel outwash layer. Note, however, that there are actually very few (60) wells in the shallow aquifer, and that their spatial distribution is biased. In other aquifer units, the groundwater model tends to slightly over estimate water levels for the steady state condition.

The distribution of head residuals in Layer 1 with red circles and dark blue circles indicate that in and around the Strada property, a wide range of values has been historically recorded when compared to a steady-state average condition simulation. The steady-state simulation does slightly favor lower head values (i.e., blue circles) west to the Strada property, whereas near null residuals (very close match) are present to the south.

Simulated water level surfaces and contours for Layers 4 and 6 were compared to the observed water levels in the Guelph and Gasport Formations, respectively, and presented in Figure 4.10 and Figure 4.11.

The Weathered Bedrock unit, together with the Guelph Formation, where present, are a key source of groundwater within most of the study area above the Niagara Escarpment. The simulated and observed water levels from these units are similar, and only contours for the Guelph Formation are shown (Figure 4.10). They are the main source of water for the older Shelburne municipal wells located 5.4 km south of the Strada property. The Weathered Bedrock/Guelph Formations thin out closer to the Niagara Escarpment and its yield diminishes accordingly. Observed and simulated water levels for this hydrostratigraphic unit match well in the model area, a performance that it is maintained as the water level in these units slowly dips near the Escarpment.

Figure 4.12 shows the spatial distribution of the residuals on a map for Layer 1. Residuals are defined as the difference between observed and simulated values, where negative values (blue circles) represent underestimation in the simulated heads and red-colored circles are indicative of overestimation. Note that the average observed water level represents as few as one water level recorded in a water well record, or as many as thousands of data logger values recorded at an on-site monitor. The total period of record spans decades, and includes spring high water levels, and late summer lows, and both wet and dry years as well.

Figure 4.13 show the residuals in the Guelph Formation. They extend to the entire model domain with pale red and blue circles, indicating a close match, except for isolated locations where colors intensify. For wells intersecting the Guelph Bedrock Formation, the area east to the Strada site up to Springwater Lakes, located 6 km away, shows a dominance of red circles of various intensities. A similar cluster, this time of light and dark blue circles, are found west of the Strada property extending to the Bonnefield agricultural farm.

Wells completed in the Gasport aquifer are mostly located in a north-south band west of the Escarpment. Further west, the Gasport is too deep to be commonly used by private wells. The water levels in the Gasport Formation closely match observed values present in this band, as indicated in Figure 4.11. The residual map for the Gasport Formation (Figure 4.14) shows that simulated heads in the Strada site are very well matched, and that, across the model, a slight underestimation and overestimation are present to the north and south portion of the model, respectively.

A second visual comparison is presented in Figure 4.15 in which the simulated head contours in Layer 4 (Guelph Formation) are compared against the contours of the interpolated observed static water levels, estimated from shallow boreholes (i.e., generally less than 30 m below grade). Although the figure is busy near the Niagara Escarpment, a good agreement can be seen where the contours of equal water level overlap, indicating that the model matches the observed groundwater flow patterns as well as the magnitude of the water levels.

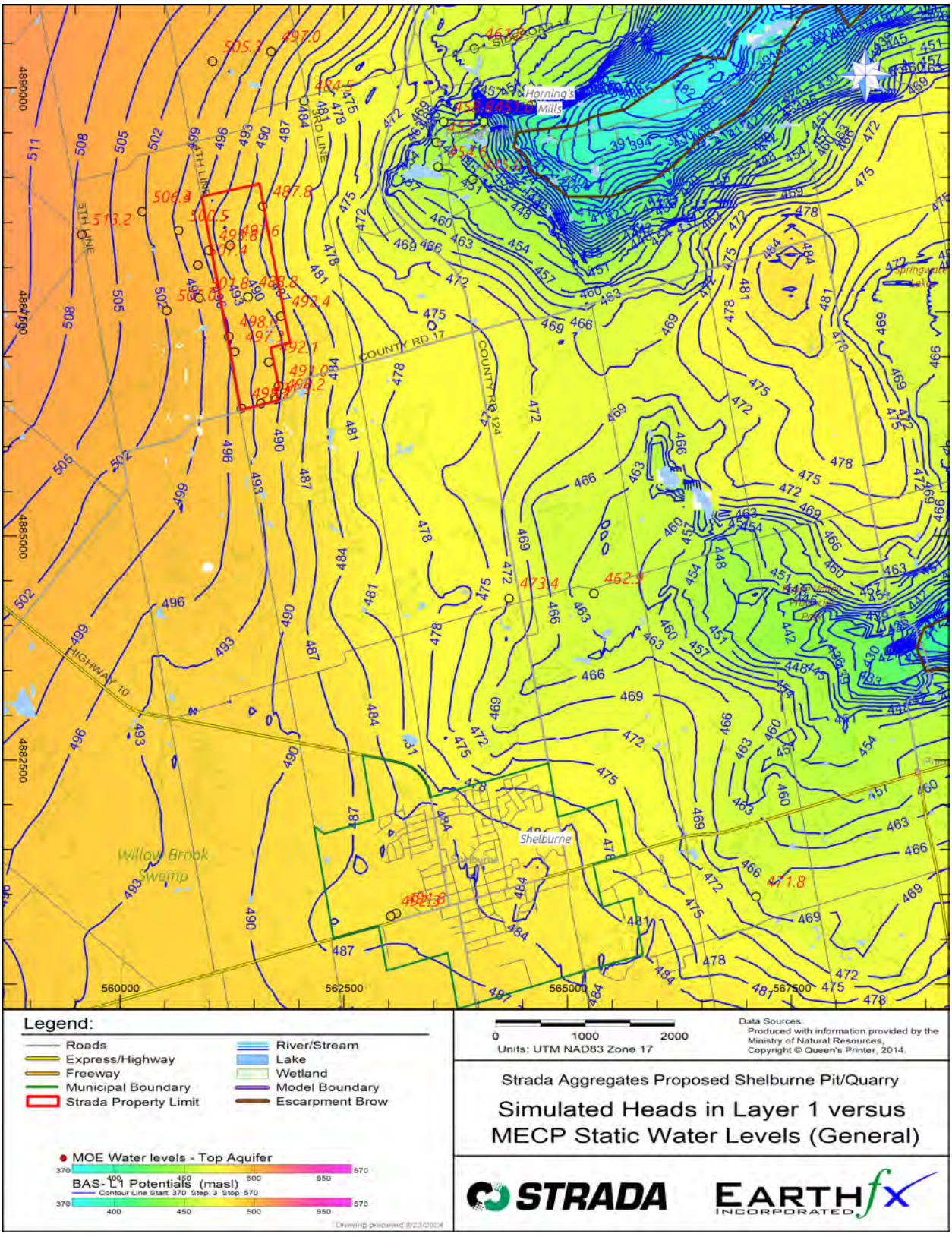


Figure 4.9: Simulated heads in Layer 1 (sand/gravel outwash and weathered till) versus the static water levels in respective boreholes (MECP WWIS data) – Regional Scale.

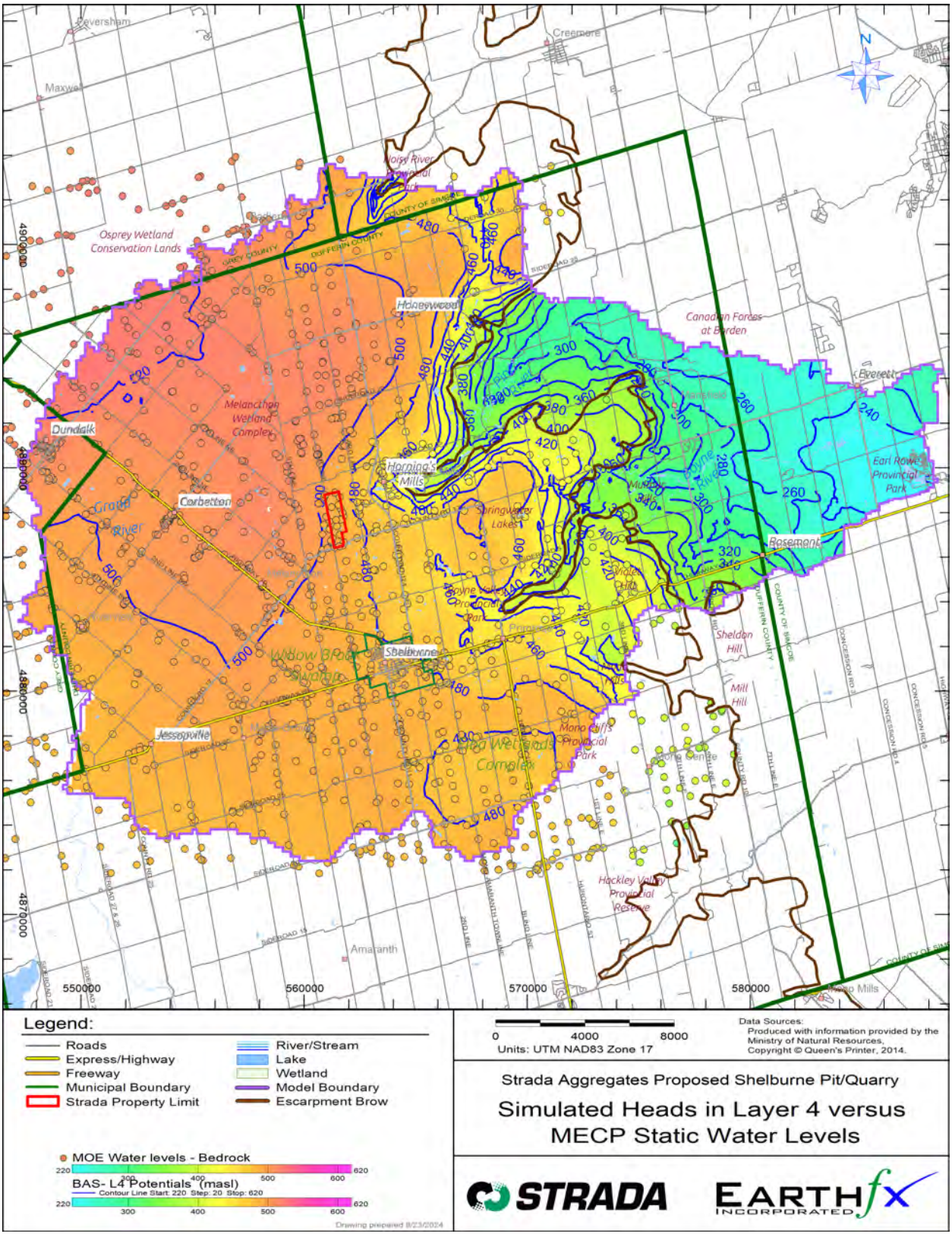


Figure 4.10: Simulated heads in Layer 4 (Guelph/Eramosa Formation) versus the static water levels in respective boreholes (MECP WWIS data).

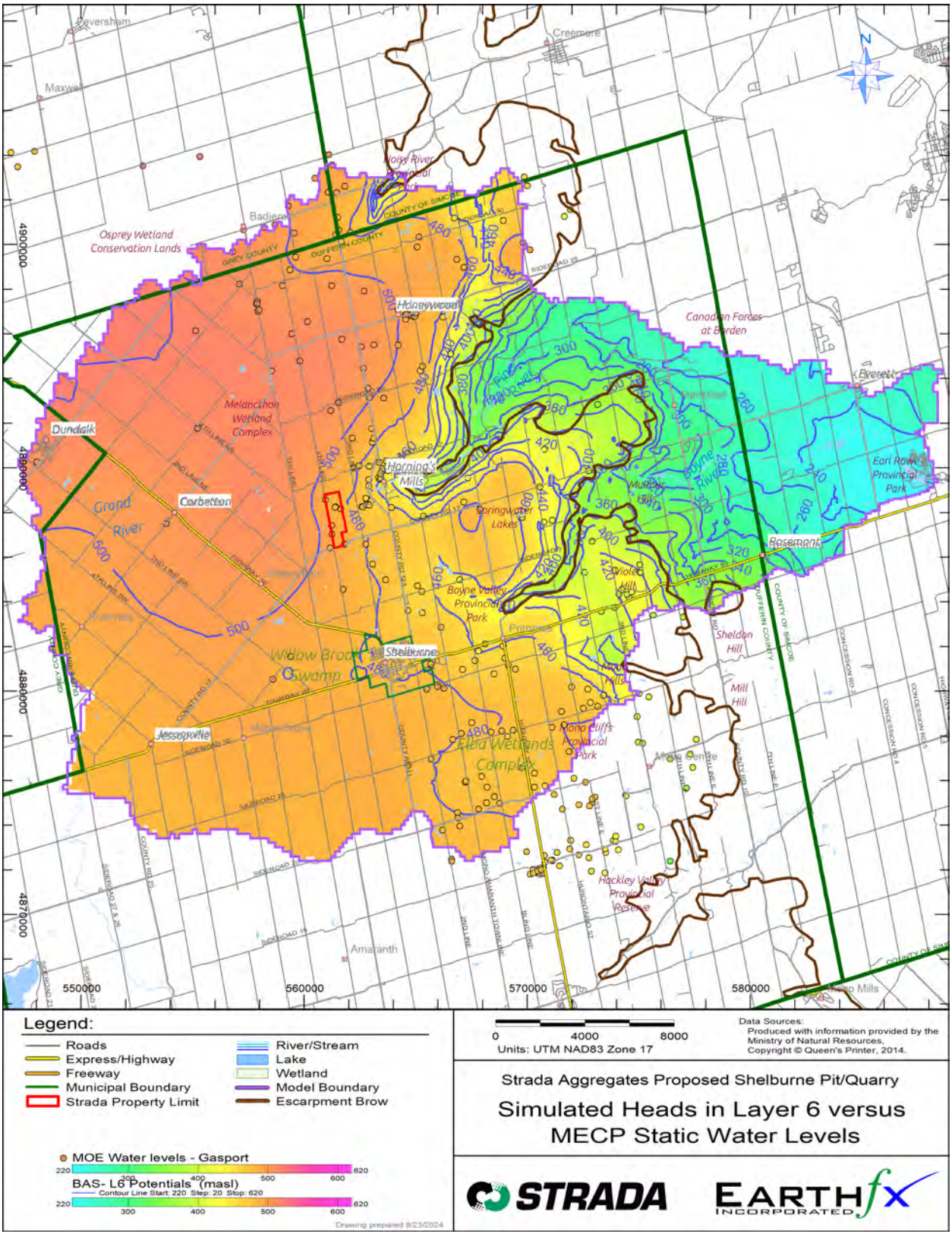


Figure 4.11: Simulated heads in Layer 6 (Gasport Formation) versus the static water levels in respective boreholes (MECP WWIS data)

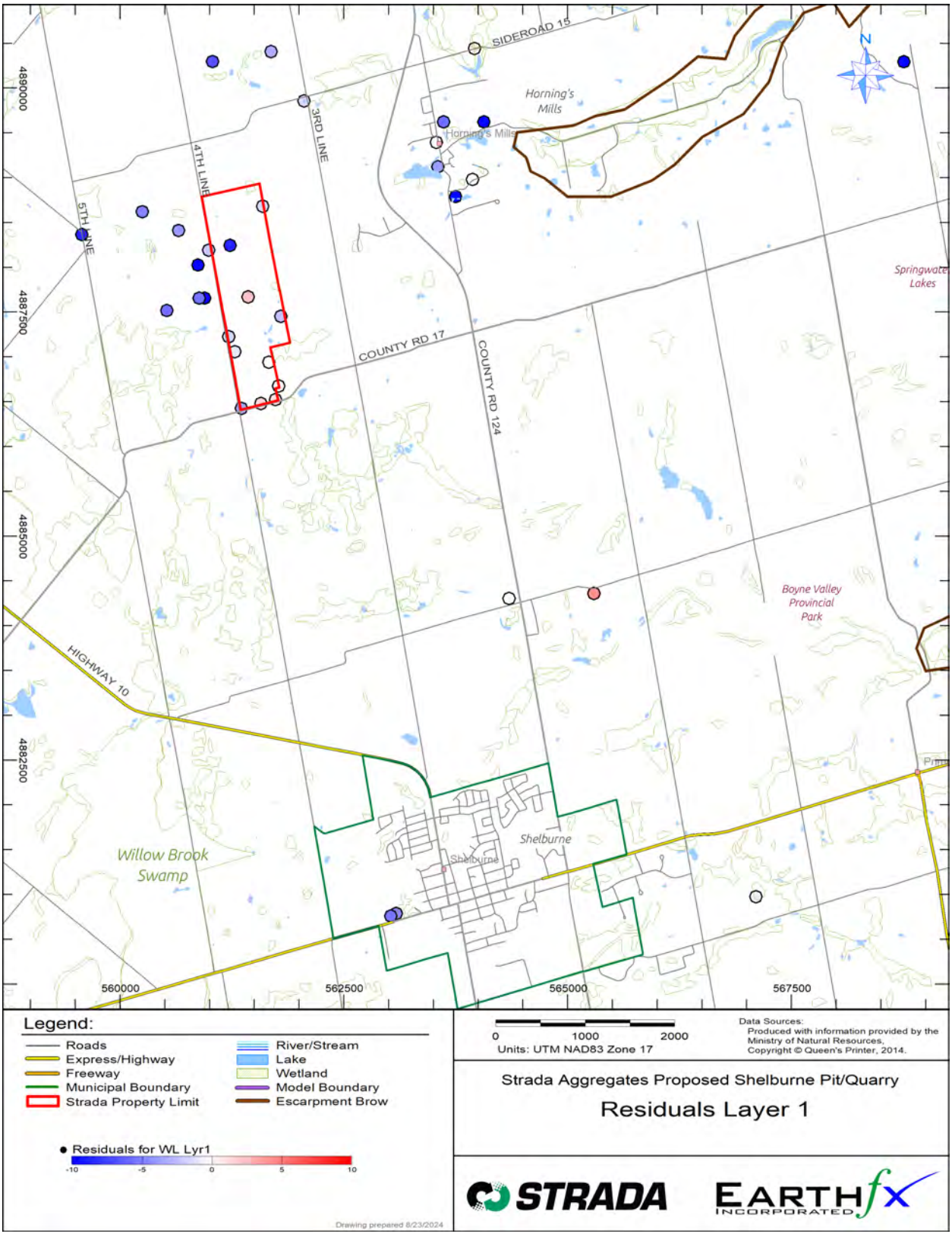


Figure 4.12: Observed-simulated residuals in the shallow overburden

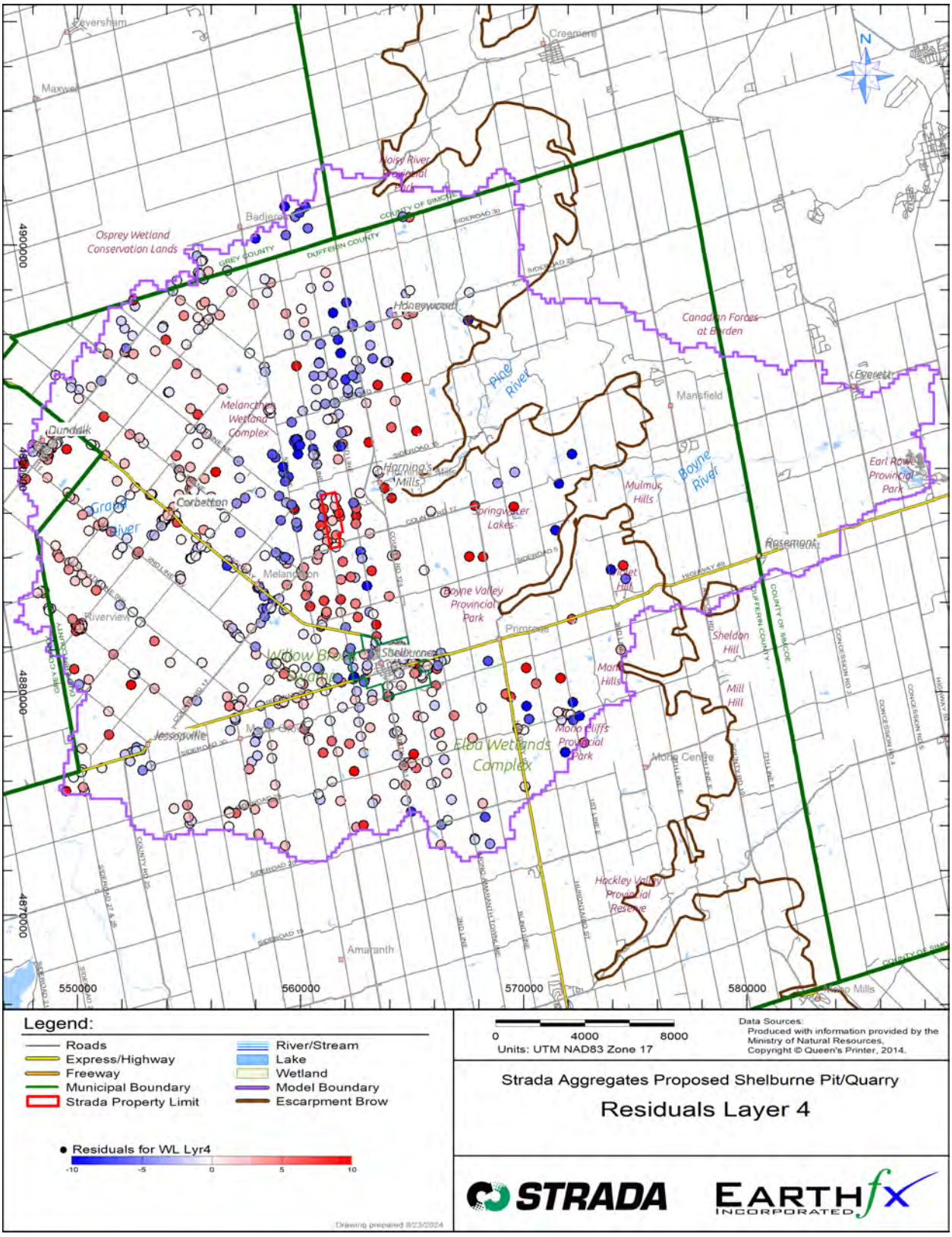


Figure 4.13: Observed-simulated residuals in the Guelph Formation.

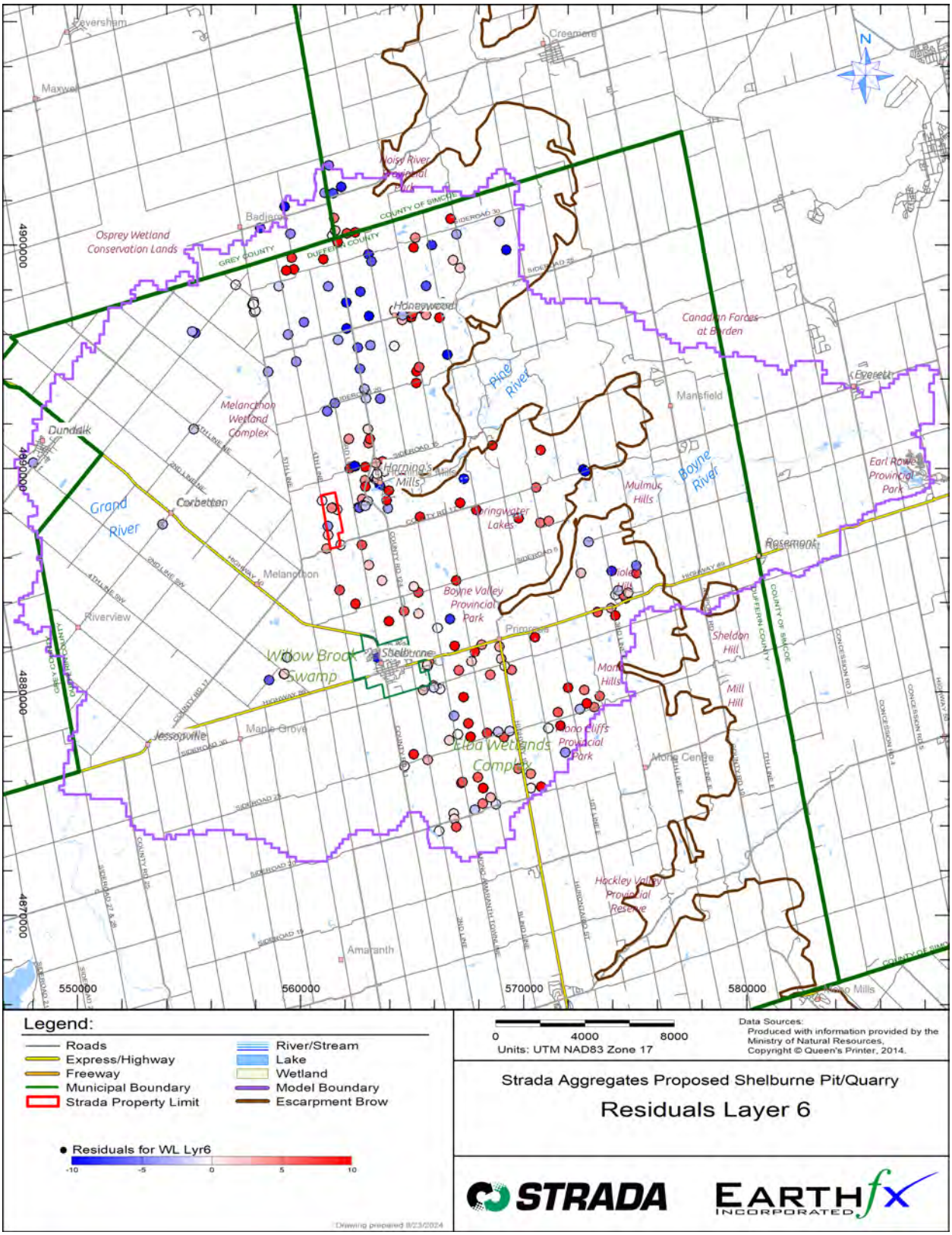


Figure 4.14: Observed-simulated residuals in the Gasport Formation.

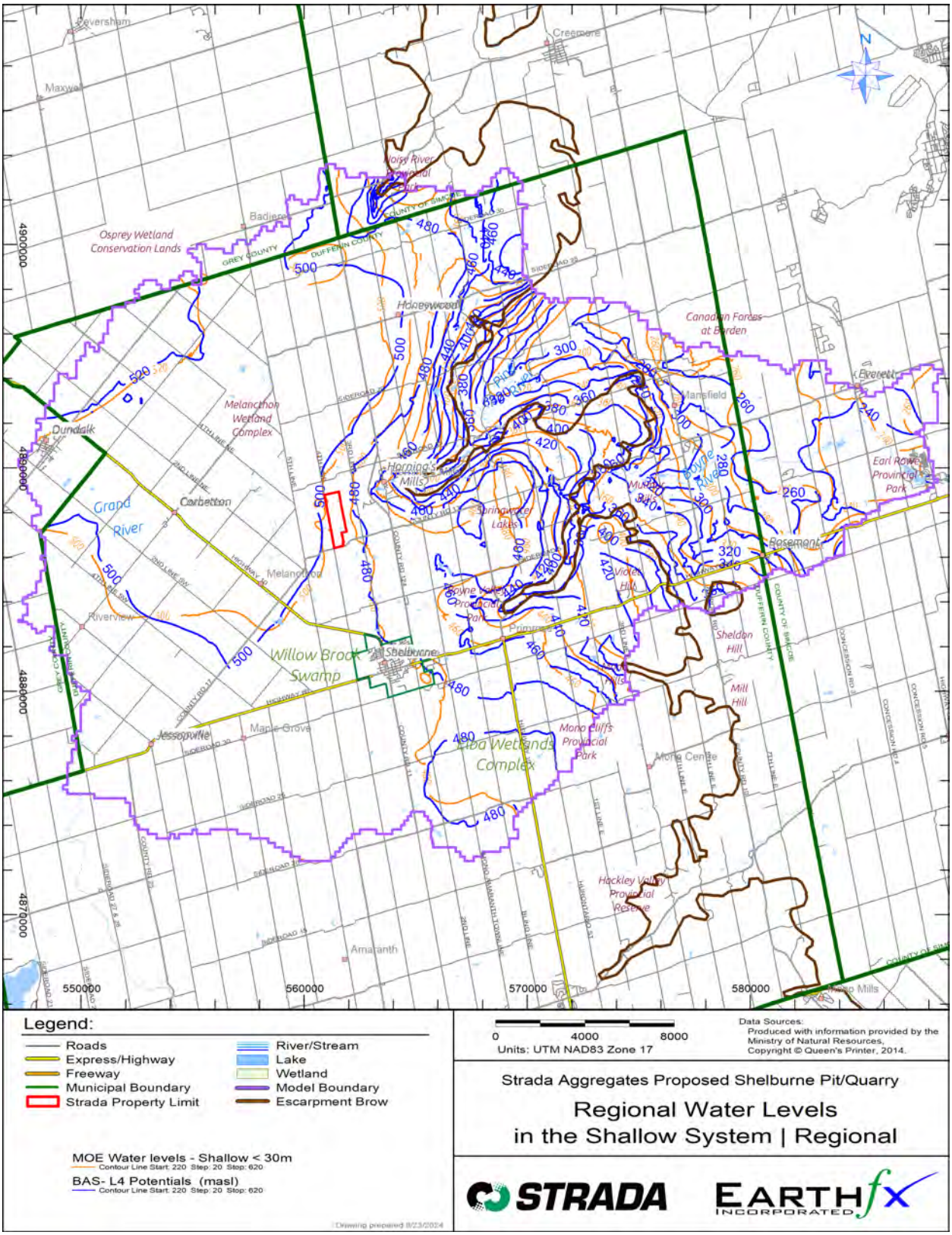


Figure 4.15: Comparison of simulated and observed regional water levels in the shallow system.

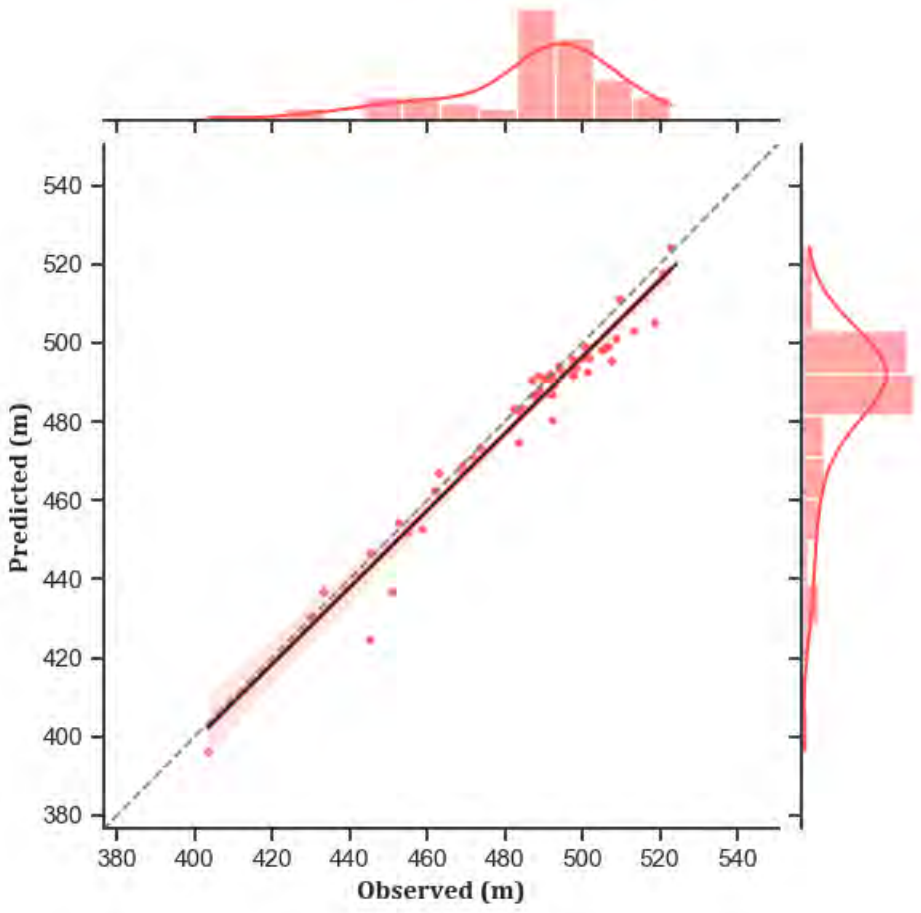
4.10.3 Observed vs. Simulated Scatterplots

A scatterplot comparing simulated heads, and the complete MECP and Strada's monitoring network static water levels is presented for each aquifer layer in Figure 4.16 through Figure 4.19. A summary of key statistics is attached next to each figure. A trend line with its respective 95% confidence intervals is also included for the scatter points to highlight potential deviations of the data from ideal behavior (i.e., the 1:1 line). The scatterplots also show the distribution of each dataset (i.e., observed and predicted) as a histogram. The histogram of the observed dataset is shown on the top, and that of the predicted values on the right side of the figure. The height of each bin indicates the density of water level values within that specific range, that is, the number of occurrences of either wells or cells with a water level value within that range. A smoothed distribution curve accompanies each histogram, which can be used as a comparative analysis tool between datasets. Ideally, the shape of these curves should match, as well as the height of each bin of the histogram. The difference between bin heights reflects the displacement of a predicted value to a lower or higher bin or range of head values.

Trend lines with slopes lower than unity suggest that predicted values tend to be higher at locations where the aquifer is present at lower ground elevations (i.e., below the Niagara Escarpment). This is true for the Weathered Bedrock/ Guelph and Gasport Formations (Figure 4.17 and Figure 4.18, respectively) and in Figure 4.19 as the composite dataset is dominated by the Weathered Bedrock/Guelph unit. In both cases, most of the data cloud is found in locations where the aquifer units are at a higher ground elevation, which favours achieving a greater degree of fitness provided by their statistics. The overburden aquifer's trend line is the closest to unity and falling slightly below the 1:1 line, suggesting the model slightly underestimates water levels regardless of their location in the watershed.

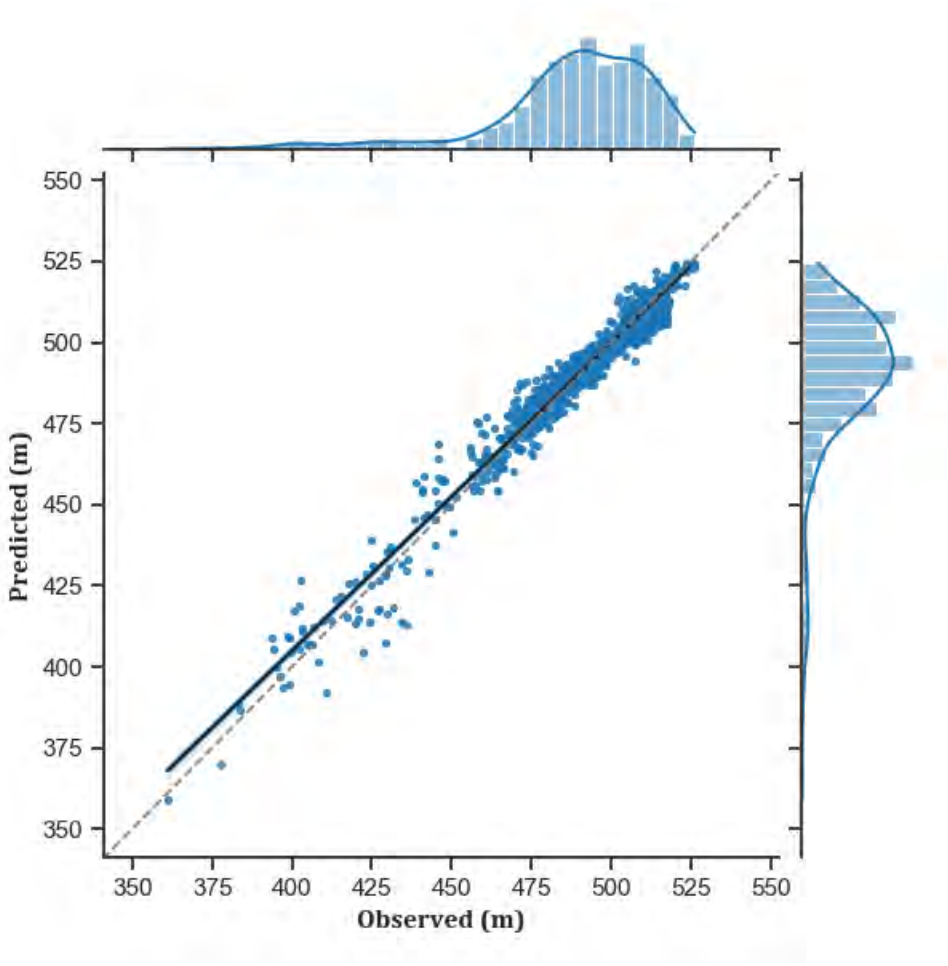
The most representative large-scale histogram is the Weathered Bedrock/Guelph scatterplot (Figure 4.17). This figure represents the most dominant regional unit, with the best spatial distribution and greatest number of wells, and shows excellent calibration statistics.

Among the errors in estimating water levels, the root mean squared (RMS) constitutes in the best measure of error if errors are normally distributed (Anderson and Woessner, 1992). Anderson and Woessner (1992) took the RMS statistic one step further by estimating the ratio of the RMS error to the total head loss in the system measured by the difference between the largest and lowest observed water level in the dataset. By keeping this ratio low, typically less than 5%, it ensures that the role of error is unimportant with respect to the movement of massive bodies of water across the watershed. By this measure of model performance, this ratio is below 5% for each dataset/aquifer units, as presented in Table 4.4. This demonstrates that the model achieves an acceptable level of calibration when compared to a published and commonly used performance measure.



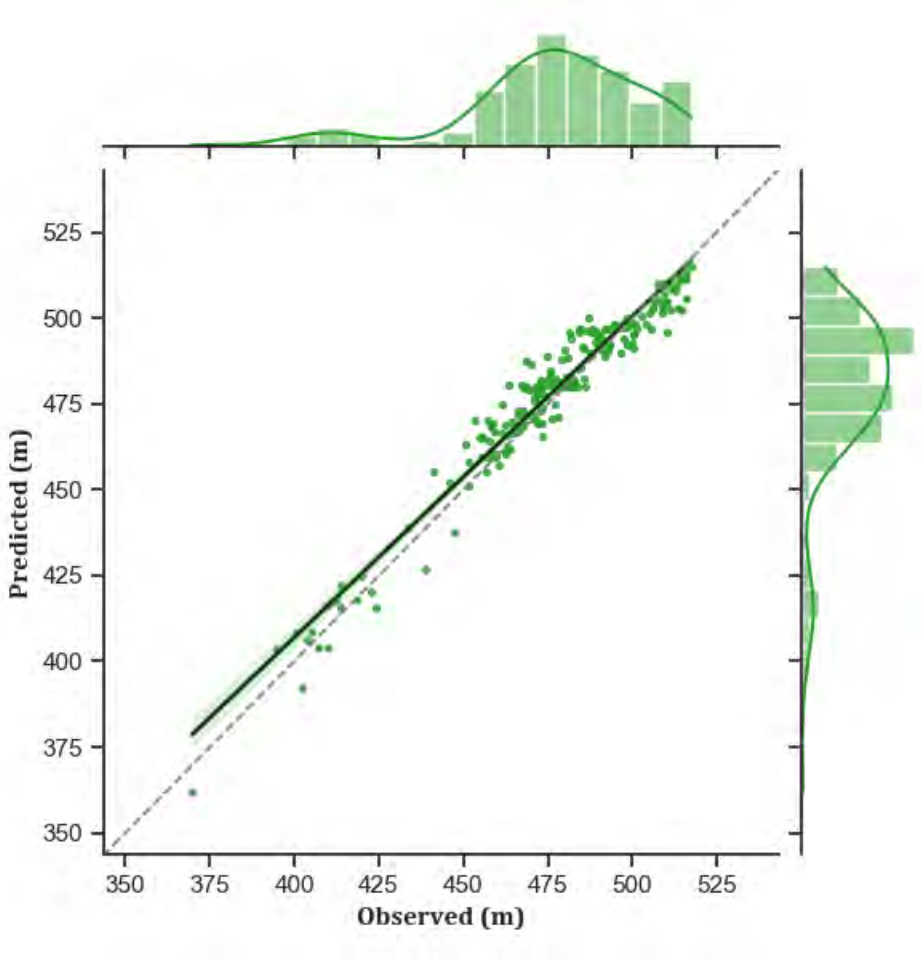
Number of points	: 60
Mean Error	: 2.75 m
Mean Abs. Error	: 3.72 m
RMS Error	: 5.28 m
R-Squared	: 0.95
Min Abs. Difference	: 0.05 m
Max Abs. Difference	: 20.10 m
Min Model value	: 396 masl
Max Model value	: 524 masl
Min Obs. value	: 403 masl
Max Obs. value	: 523 masl

Figure 4.16: Observed versus simulated water levels for Layer 1 (sands and gravel, weathered till).



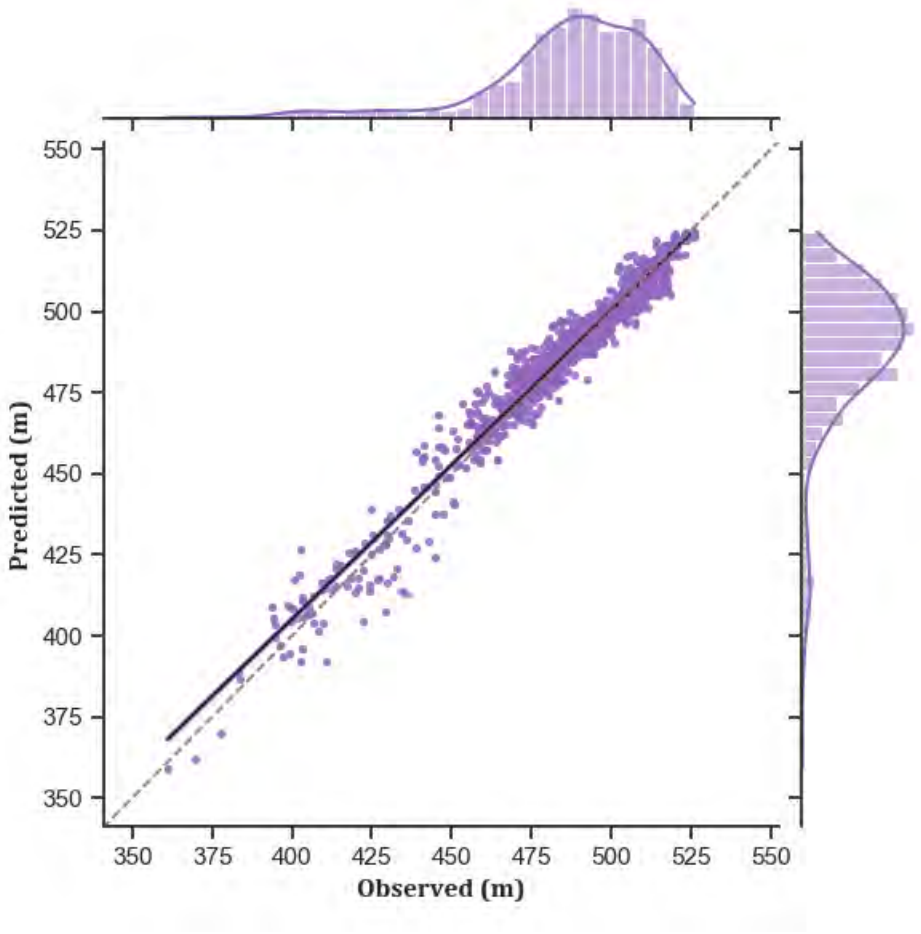
Number of points	:	1,071
Mean Error	:	-0.80 m
Mean Abs. Error	:	3.46 m
RMS Error	:	4.87 m
R-Squared	:	0.96
Min Abs. Difference	:	0.00 m
Max Abs. Difference	:	23.92 m
Min Model value	:	359 masl
Max Model value	:	525 masl
Min Obs. value	:	361 masl
Max Obs. value	:	526 masl

Figure 4.17: Observed versus simulated water levels for Layer 4 (Guelph/Eramosa Formation).



Number of points	:	218
Mean Error	:	-2.27 m
Mean Abs. Error	:	5.19 m
RMS Error	:	6.59 m
R-Squared	:	0.94
Min Abs. Difference	:	0.08 m
Max Abs. Difference	:	18.88 m
Min Model value	:	362 masl
Max Model value	:	515 masl
Min Obs. value	:	370 masl
Max Obs. value	:	517 masl

Figure 4.18: Observed versus simulated water levels for Layer 6 (Gasport Formation), including key statistics.



Number of points	:	1,349
Mean Error	:	-0.97 m
Mean Abs. Error	:	3.72 m
RMS Error	:	5.19 m
R-Squared	:	0.96
Min Abs. Difference	:	0.00 m
Max Abs. Difference	:	23.92 m
Min Model value	:	359 masl
Max Model value	:	525 masl
Min Obs. value	:	361 masl
Max Obs. value	:	526 masl

Figure 4.19: Observed versus simulated water levels for a composite dataset of available average values in all three aquifer units, compared here against the Guelph/Eramosa Formation model Layer 4, including key calibration statistics.

4.10.4 Transient Analysis – Pumping Tests

After completing the regional steady-state calibration, additional transient (time-dependent) simulations were conducted with the model to refine the calibration. Transient water levels provide information on the response of the groundwater system to changes in hydrologic forcings at both short and long temporal scales and within the different hydrostratigraphic units. A temporal analysis also looks into the celerity (speed) of the pressure response between aquifer units and provides insight into the storage properties of the aquifers and intervening aquitards. The vertical response through the hydrostratigraphic system takes into account the intensity of the stress, the timing, and the celerity of the hydrologic forcings as it moves through the units. A transient simulation demonstrates the capacity of the model to simulate the drawdown and recovery of water levels in the hydrogeologic units being tested, as well as the leakage across the intervening aquitards.

Groundwater monitoring started in the early 2000's at the Strada Aggregates site and the site database now spans nearly 20 years. Several transient data sources are available in and around the Strada property. From these available datasets, detailed in the Conceptual Model Report (Tatham and Earthfx, 2023), three aquifer tests (Figure 4.20) were selected to improve the calibration of the Strada groundwater model. Refinements were made to all hydrologic parameters, not only those associated with groundwater storage (i.e., porosity, specific storage, and specific yield) but also to the hydraulic properties (i.e., hydraulic conductivity) determined through the steady state simulations.

Packer testing available in and around the site was also collected and it use to inform transient calibration.

4.10.4.1 Operational Record of Strada's PW1

The groundwater level record for production well PW1, located near the centre of the Strada site, provided data used in the transient calibration of the groundwater model. The Strada's PW1 is a 48.8 m deep borehole, and was constructed as an open-hole well through the bedrock profile. Strada OW1, located 34 m from PW1, has similar well construction characteristics. Cross Section C in Figure 4.22, also shown in Figure 3.27 of Appendix C (Earthfx, 2024a): Conceptual Model Report (Earthfx, 2024), shows that PW1 and OW1 partially penetrate Gasport formation.

The PW1 time series spans from January 2008 to December 2012 and provides insight on seasonal changes in groundwater levels in addition to the water level fluctuations generated by daily pumping. Figure 4.24 shows the water level record at PW1 for 2009, together with simulated heads at the model cell located at row (R) 191 and column (C) 202 of the groundwater model. Of note is the recovery of wells when pumps are shut down at the end of the day, for the weekend, and for longer periods.

The transient simulation was divided in 10 periods of analysis, two per day, one of pumping during the day, and another for recovery at night. The pumping volume for PW1 during the period of transient analysis, which covered the first week of June 2009, was 138 m^3/d. This volume was applied to an 11-hr to 12-hr period of operational pumping per day. The actual pumping rate assigned to each active period ranged between 276 to 301 m^3/d.

No monitoring location within the Strada property exhibited a response to pumping, except for OW1 (34 m away), which trails the PW1 timeseries by 0.4 m. The fact that no response was observed in other monitoring locations, despite the open-hole well construction of PW1, suggests that much of the water for PW1 may be sourced from the deeper Gasport Fm. The entire pumping rate was then applied to Layer 6 of the groundwater model which represents the Gasport Fm.

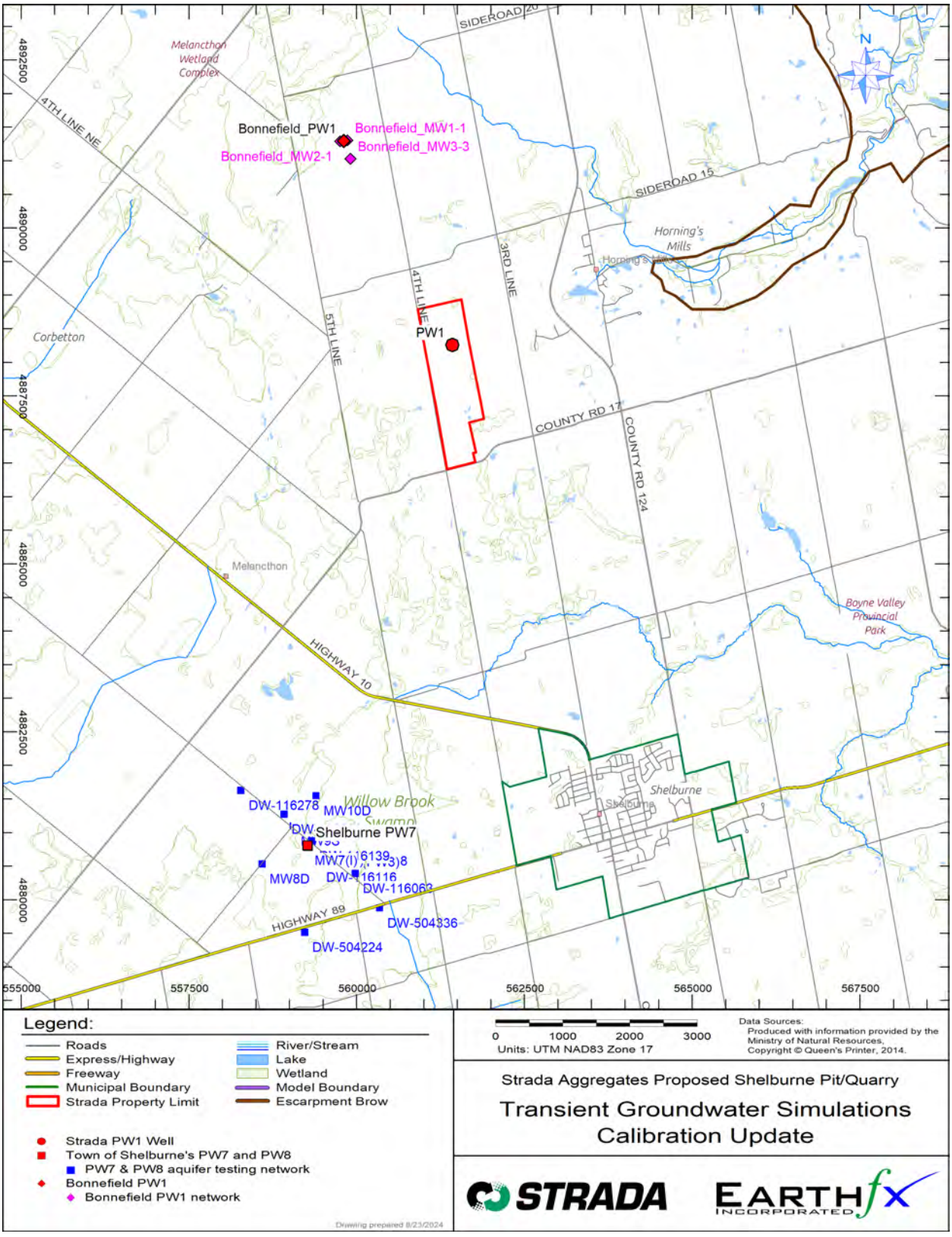


Figure 4.20: Location of wells with transient groundwater level data.

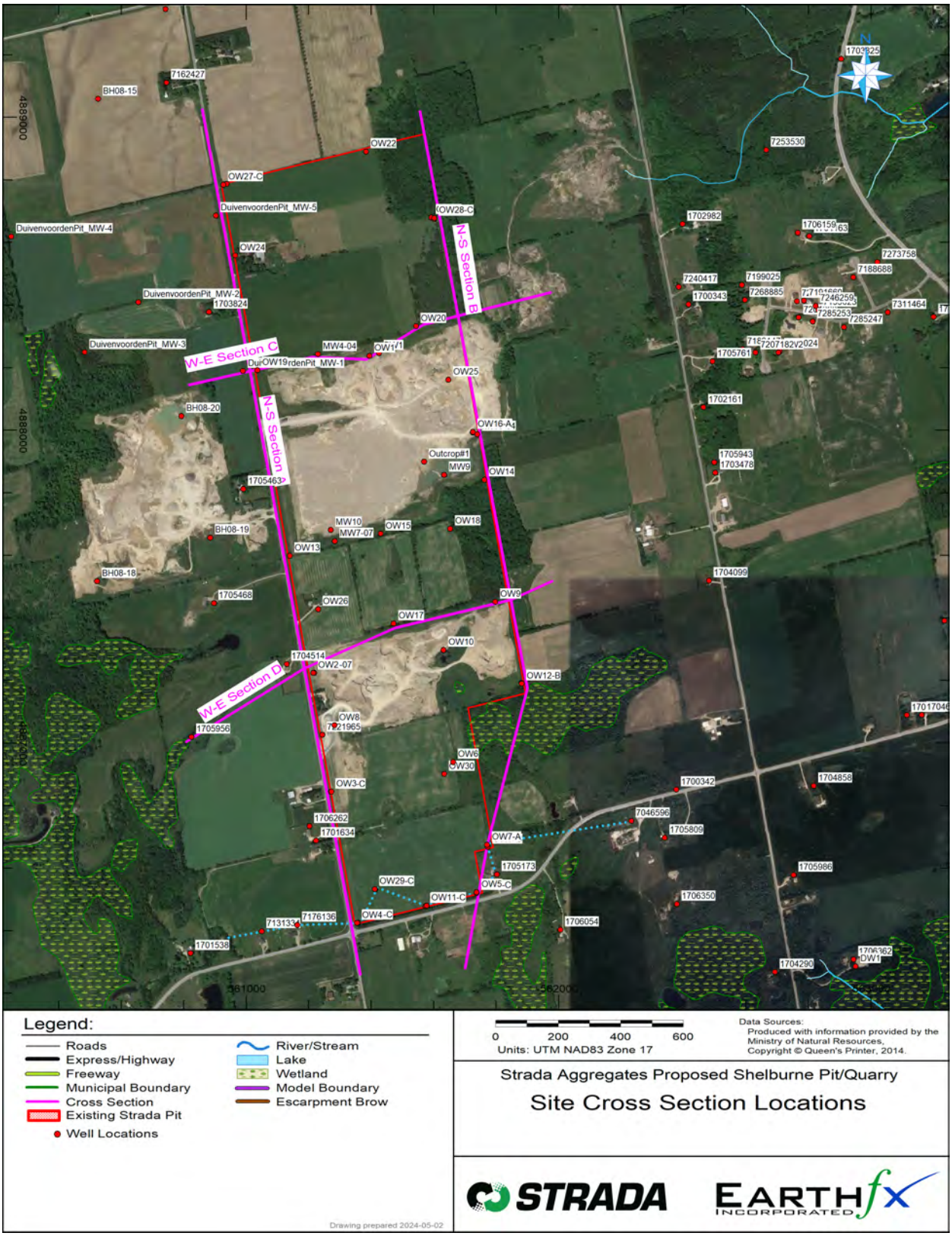


Figure 4.21: Cross section locations.

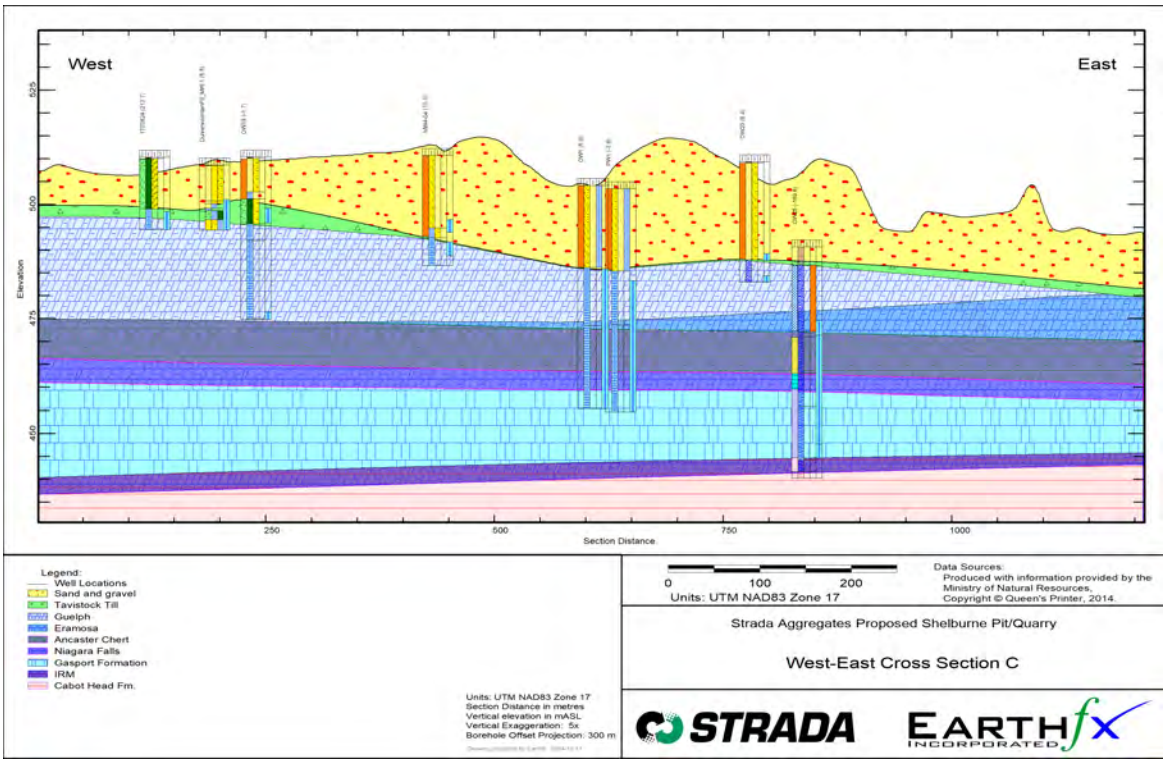


Figure 4.22: West-East Cross Section C

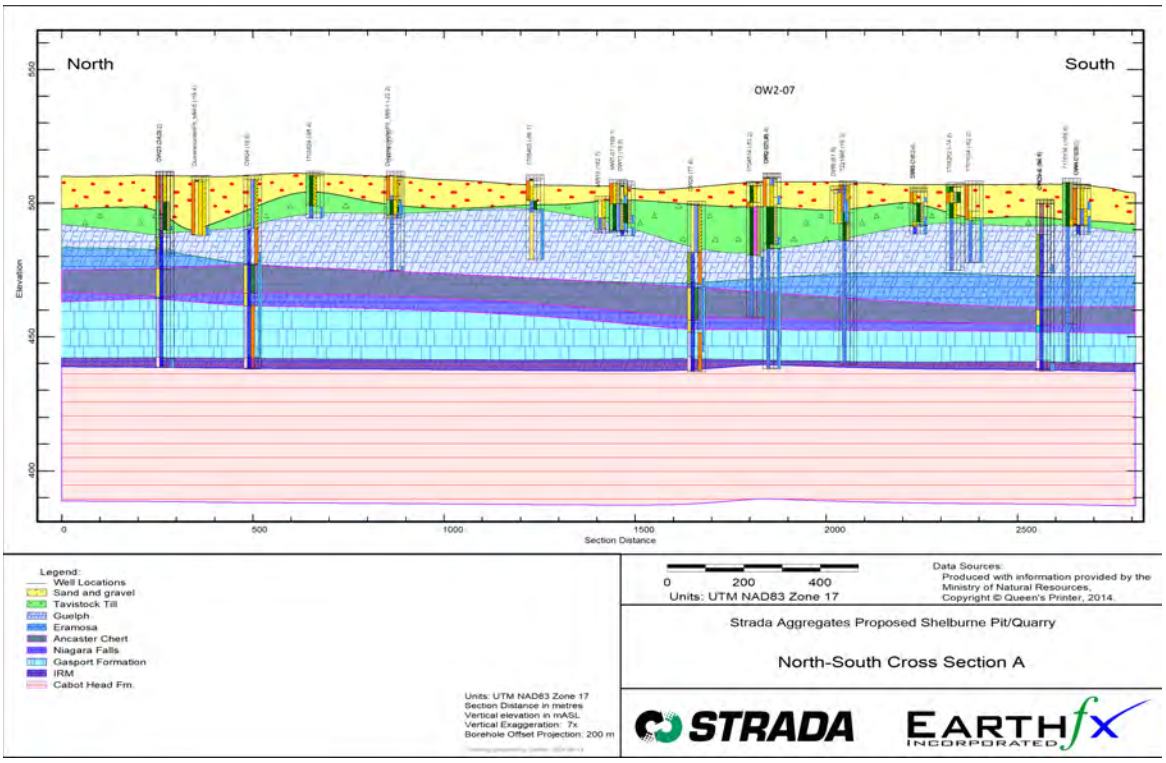


Figure 4.23: North-South Cross Section A

Calibration of the model to match observed well response was done primarily by adjusting the hydraulic conductivity and specific storage of the Gasport Fm., as well as the vertical leakage of the Niagara Falls aquitard unit, which is controlled by the sparse vertical fractures within the unit. This calibration effort, together with the water level data from the recently constructed Gasport Fm wells within the Strada property, led to the creation of a zone of higher conductive materials extending from the site vicinity to the Niagara Escarpment.

Even with the adjusted specific storage and vertical leakage parameters, matching the significant vertical leakage through the long open boreholes during a pumping cycle was not fully achieved as the simulated head seemed to show limited leakage and fast recovery. The drawdown is properly matched, as well as the overall static water level at this location. Wellbore storage, groundwater inflow from the upper aquifers, and vertical leakage down the wellbore, all of which cannot be simulated in the model, may be affecting the response at PW1. Overall, the model response is excellent.

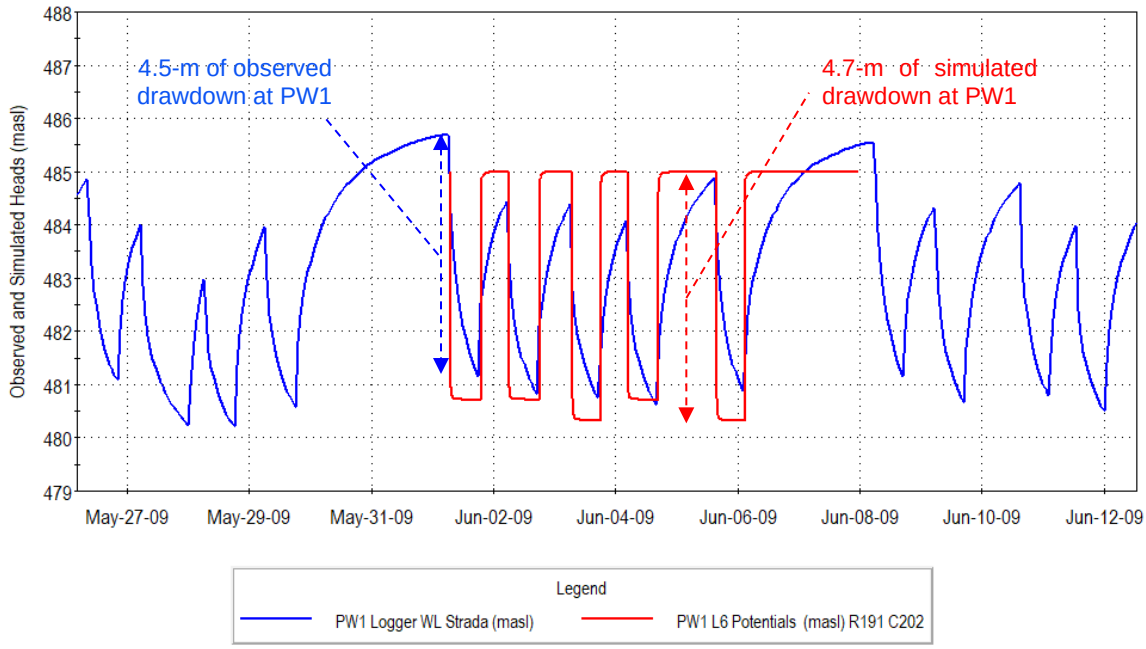


Figure 4.24: Observed and simulated heads during operational cycles of Strada Site's PW1.

4.10.4.2 Strada's OW2-07 Aquifer Test

Another potentially insightful data set was the pumping tested completed at OW2-07 (formerly known as MW2-07) on the Strada property in May 2007 (Goffco Ltd., 2007) (also see Appendix C, Earthfx , 2024a, Section 5.5.3). The pumping well is located approximately 1 km south of PW1 on the Strada property. Well OW2-07 is a 72 m deep open-hole well that intersects all the bedrock aquifer above the Cabot Head Formation. As such, it covers a significantly larger section of the bedrock than PW1. A cross section showing this borehole is included in Figure 4.23.

A drawdown of approximately 40 m was observed after 130 minutes of pumping at 28 L/min with a submersible pump installed at 61 mbgs (Figure 4.25). This drawdown is indicative of an extremely tight hydrogeological unit, typically associated with an aquitard. The report concludes that the well might achieve a sustainable rate of approximately 26 L/min.

In contrast, the Goffco test of PW1 (Goffco, 2005) concluded that the 2-year sustainable rate of PW1 might be 227 L/min or approximately 8.7 times the sustainable estimate for OW2-07. It is felt that local variability in hydraulic properties, rather than issues related to well construction, are responsible for the differences in the well production rates.

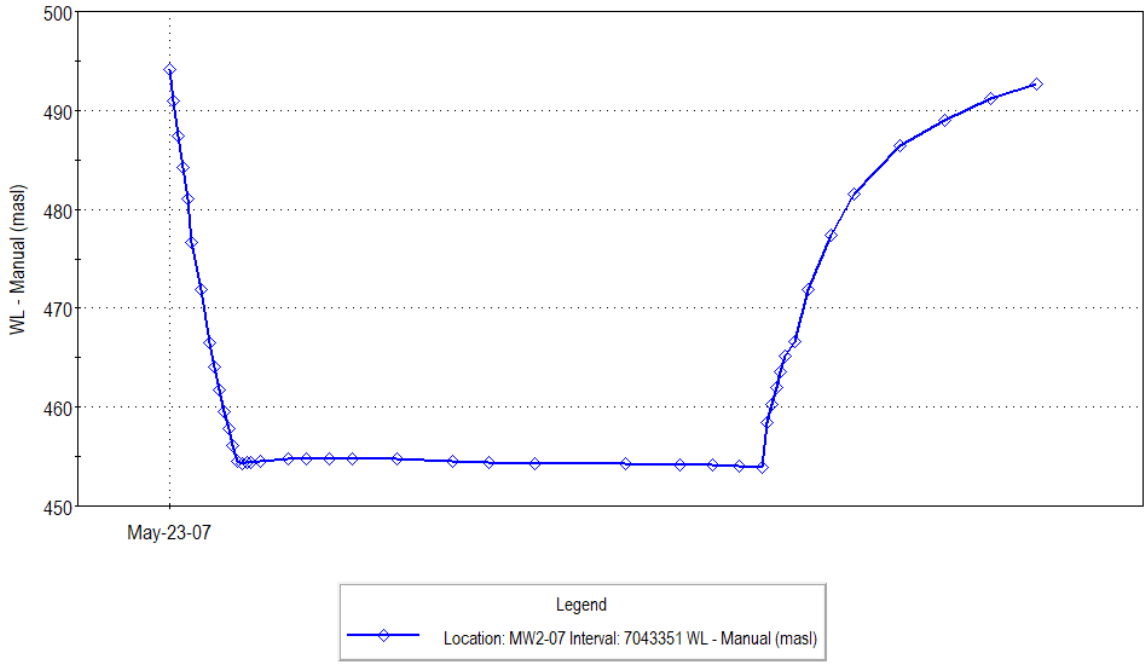


Figure 4.25: Recorded water levels during aquifer test at OW2-07.

The OW2-07 pump test confirms that aquifer properties on the site are variable, and potentially quite low. Packer testing has provided additional detailed insight. As a conservative assumption, the low response observed in OW2-07 was not directly simulated or used in the model.

4.10.4.3 Bonnefield GP III PW1 Operation

The operations schedule of the agricultural Bonnefield PW1 well provides pertinent information on the groundwater system response to pumping (Whitewater Hydrogeology, 2013). This well is located 2.5 km north of the Strada property. Water levels were also monitored at four neighboring sites during 2013. Bonnefield PW1 is an 88.4 m deep borehole. It was constructed as an open-hole well intersecting bedrock formations from the Guelph to the base of the Gasport Fm. There are natural differences in head between the monitoring wells due to differences in location, depth, and well construction; however, all responded to pumping at PW1 to varying degrees. The drawdown response was simulated with the model and used to assess the degree of local connectivity of the bedrock units.

Initial static levels for the monitoring locations were not available for this time period. They were extrapolated from another section of the time series where no active pumping was taking place. Considering that the major contribution of this dataset lies in the extent and magnitude of the drawdowns during pumping as measured at the monitoring locations, this extrapolation does not have an effect on the interpretation of the response.

The observed heads at Bonnefield PW1 and MW1-1, both deep boreholes, are shown in Figure 4.26. The response in the MW1-1 suggests that PW1 is sourced by the intermediate and deeper aquifer units. In the model, the pumping rate of 2,830 m^3/d was divided relative to the hydraulic conductivity of the Guelph and Gasport Formations (i.e., layers 4 and 6). Considering that the hydraulic conductivities are $3x10^{-5}$ and $2x10^{-5}$ m/s, their pumping rates were calculated as 1,887 and 943 m^3/d, respectively.

The drawdown timeseries suggests that a constant pumping rate was not maintained through the 4-day period of pumping. However, an approximate drawdown of 16 m was observed at the Bonnefield PW1 well, whereas a simulated drawdown of 13.7 m in both the Gasport Fm (red line) and in the Guelph Fm (dashed-cyan line) was obtained.

The observed drawdown at PW1 suggests that vertical leakage through the units, or more likely in the long open borehole, is a factor during pumping. The simulated heads, on the other hand, exhibit two behaviours in regards to vertical leakage during pumping: limited leakage for the Gasport Fm, and a greater vertical leakage than that observed in the Guelph Fm. A composite simulated head for an open-hole well might look as that observed; however, the model is not capable of determining a composite drawdown for the different units.

Water levels at MW1-1, located 55 m away, is affected by the pumping at PW1. A drawdown of 9.5 m is observed. The model, at this location (row (R) 68, column (C) 118), predicts a water level drop of 4.5 m instead (dashed-orange line). This potentially could indicate that either a greater pumping rate should be applied to Layer 4 or that the hydraulic conductivity of this layer is lower than the current value in the model.

This transient simulation helped in refining the hydraulic conductivity values used for the Guelph and Gasport Formations after correlating these results with recent water level data collected at both formations in the Strada's monitoring network.

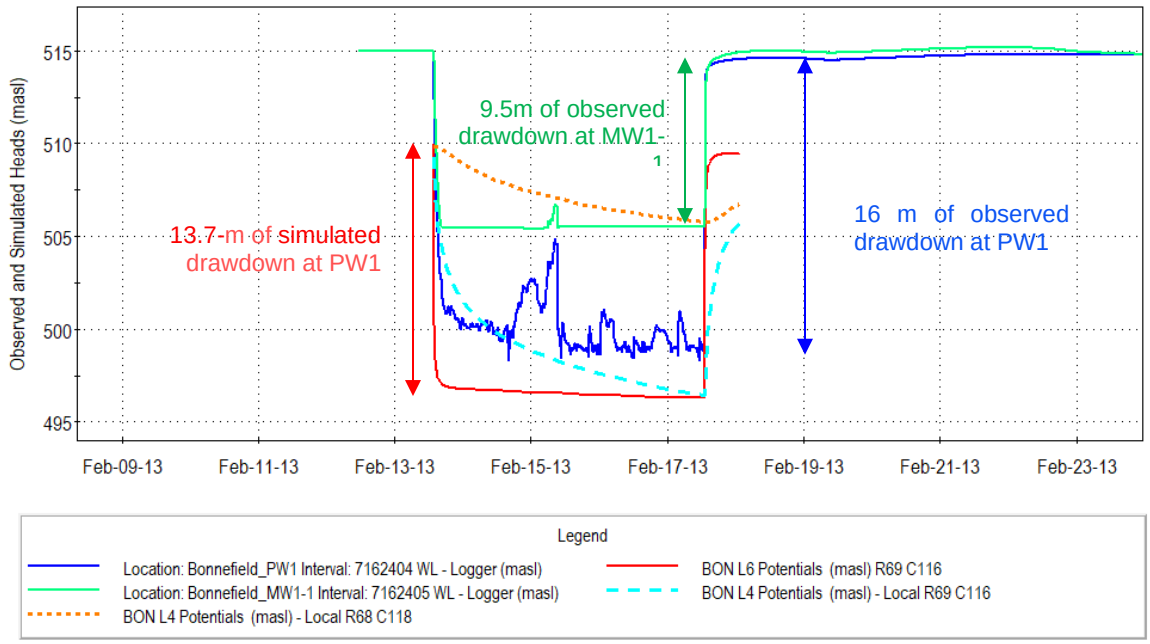


Figure 4.26: Observed and simulated heads during operational cycles of Bonnefield PW1 during February, 2013. (Note: the BON prefix refers to the simulated heads.)

4.10.4.4 Shelburne PW7 & PW8 Aquifer Testing

Earthfx was retained in 2022 to update the wellhead protection areas (WHPAs) for the Town of Shelburne's wellfield (Earthfx, 2022). As part of that effort, the Town carried out a multi-level aquifer test for a period of 7 days with the deeper wells, Shelburne PW7 and PW8, pumping at maximum permitted capacity. The observed multi-level response and the results of a transient model simulation are presented in more detail in that report. A significant head gradient across the Niagara Falls aquitard was observed at this location during pumping (Figure 4.27). Under normal operating conditions, the head loss between the Goat Island and the Gasport is approximately 13 m, but at maximum permitted capacity for both PW7 and PW8, the head loss increased by an additional 23 m. During shut-off times, the head loss recovered to half a metre. This great variability is representative of an aquitard with some vertical fractures. During periods of no stress, heads equilibrate rapidly, while during stressed conditions, the effects of a leaky confined aquifer become evident.

Shelburne's PW7 and PW8 were drilled to depths of 86.5 and 86.6 mbgs, respectively, with a steel casing extending to depths of 47.2 and 45.7 mbgs, followed by 39.4 and 40.9 m of open hole to target the deeper Gasport aquifer unit. Testing of PW7 by Golder and Banks (2013) indicated that the well was capable of providing a sustained flow of approximately 18.9 L/s (1,635 m^3/d).

During the test, both production wells were pumped at capacity: 1,634 m^3/d, sourcing the water from the Gasport Fm. (Layer 6 in the groundwater model). The transient simulation was divided in three stress periods that included: shutting off the pumps half-a-day before starting the aquifer test, followed by the pumping of both wells at capacity for 7 days, and finishing the test with a 3-day recovery period.

A total drawdown of 40 m and 15 m were measured in the Gasport and Goat Island units during the test, respectively. The latter drawdown was measured at MW7, located 7 m from PW7, and in the same model cell as PW7. The observed data show a 25 m head gradient across the Niagara Falls aquitard at this location, during pumping at capacity, whereas without pumping the head difference is diminished to 0.5 m. This defines the Niagara Falls as an aquitard, where flow through the sparse fractures is exceeded during stress, but after recovery there is long-term equalization in heads.

The Strada groundwater model, which is built for a different purpose and focus area, does not have the same cell resolution as the Earthfx (2022) Shelburne Wellfield model. Cell size in the Shelburne model wellfield area is 12 m, while cells in this portion of the Strada model are as much as 200 m in size. This results in the Strada model underestimating the drawdown during the transient simulation. The Strada model simulation underestimates drawdowns at 25 m, as compared to observed drawdown of 40 m (Figure 4.27).

Overall, however, the Strada calibration and analysis of the Shelburne PW7 wellfield response confirms that the Niagara Falls is a significant regional aquitard, and also confirms the hydraulic properties of the Guelph, and in particular, the Gasport aquifer system.

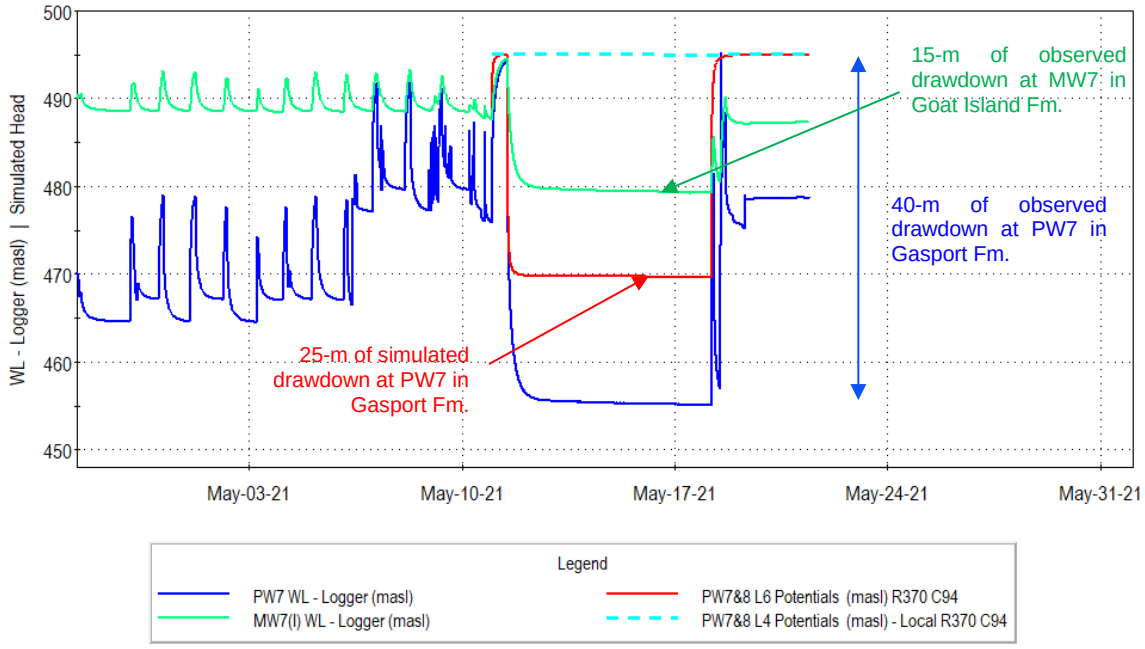


Figure 4.27: Observed and simulated heads during the 7-day aquifer test at Shelburne PW7 and PW8 wells, in May 2021 (note: the PW7&8 prefix refers to simulated heads).

4.10.4.5 Hydraulic Testing

On site packer testing was done to supplement the two on site pump tests, long term pumping well operation analysis, and numerous off site pump tests and packer testing. While specific simulations were undertaken to assess the larger pump tests, the packer test data was used to guide conceptual development, model input parameter assignments and refinement of the model calibration.

The following is a summary of extensive hydraulic testing in and around the Strada site.

Strada hydraulic testing and operational analysis:

- One pumping and observation well nest with over 5 years of flows and levels
- Two wells with pumping tests
- Three wells with dozens of detailed packer tests

Highland Quarry hydraulic testing summary:

- 5 monitor nests with long term pumping tests
- 20 boreholes with hundreds of packer tests
- 32 cores with hydraulic conductivity estimates from particle size analysis

Shelburne Wellfield hydraulic testing and operational analysis:

- Multiple pumping tests and long-term monitoring

Bonnefield Wellfield hydraulic tests:

- 2 pumping tests available

In summary, there are hundreds of hydraulic measurements spanning

- Every spatial scale from core to wellfield scale
- On-site and off-site locations
- Time scales from minutes to years of pumping.

Test results were used across all aspects of conceptual model development to detailed transient calibration.

4.10.4.6 Transient Calibration Conclusions

Collectively, the two regional pumping tests, together with the two on-site tests and the Lugeon packer tests, provide important information about response of the aquifer units to significant hydrogeologic stress. The model matches the response well, with some caveats owing to the fact that this is a fractured bedrock aquifer system, and some of the test and observation wells are from long, open-hole, boreholes that span the hydrogeologic units. Most important, the tests cover both the site and the local area of potential impact.

4.10.5 Local Model Refinement Zones

A review of the new data and other local-scale water level data suggested some small refinements to the model properties might be warranted. Local refinement in layer properties must be justified by both field observations and conceptual insights. In addition to the model layer geometry refinements, new water levels were collected at the seven new deep Gasport monitoring wells as the wells stabilised after drilling. Simply adding "K-zones" to locally improve the calibration, without both data and conceptualization, adds no predictive benefit to the model.

The following field evidence supported a possible local refinement:

- Water levels through the central portion of the site appear generally lower than observations to the north and south.
- Transient analysis of PW1 and OW1, as discussed above, suggests a more permeable zone in the central portion of the site. The effects of pumping at PW1 are not observed at any other monitor except OW1, suggesting that the drawdowns are localized to a central zone. Further, testing at OW2-07 supported the observation that the bedrock profile was of lower permeability south of this zone.
- Personal communications with the peer reviewer, who provided an interpretative map dated April 8, 2010, suggested that there might be a subsurface karst flow zone through the central portion of the site.
- At the sub-regional scale, water levels appear to converge on the Pine River Valley. While this is expected given the topographic profile, it may also suggest a zone of enhanced permeability related to the geologic structure of the valley.

The field evidence noted above, together with the conceptualization of a zone of enhanced permeability emanating from the Pine River re-entrant (valley), was used to refine the model properties as discussed below.

This information, together with numerous steady state and transient calibration refinement simulations, resulted in the delineation of hydraulic conductivity zones within the Weathered Bedrock, Guelph, and Gasport units, as shown in Figure 4.28 through Figure 4.30, respectively.

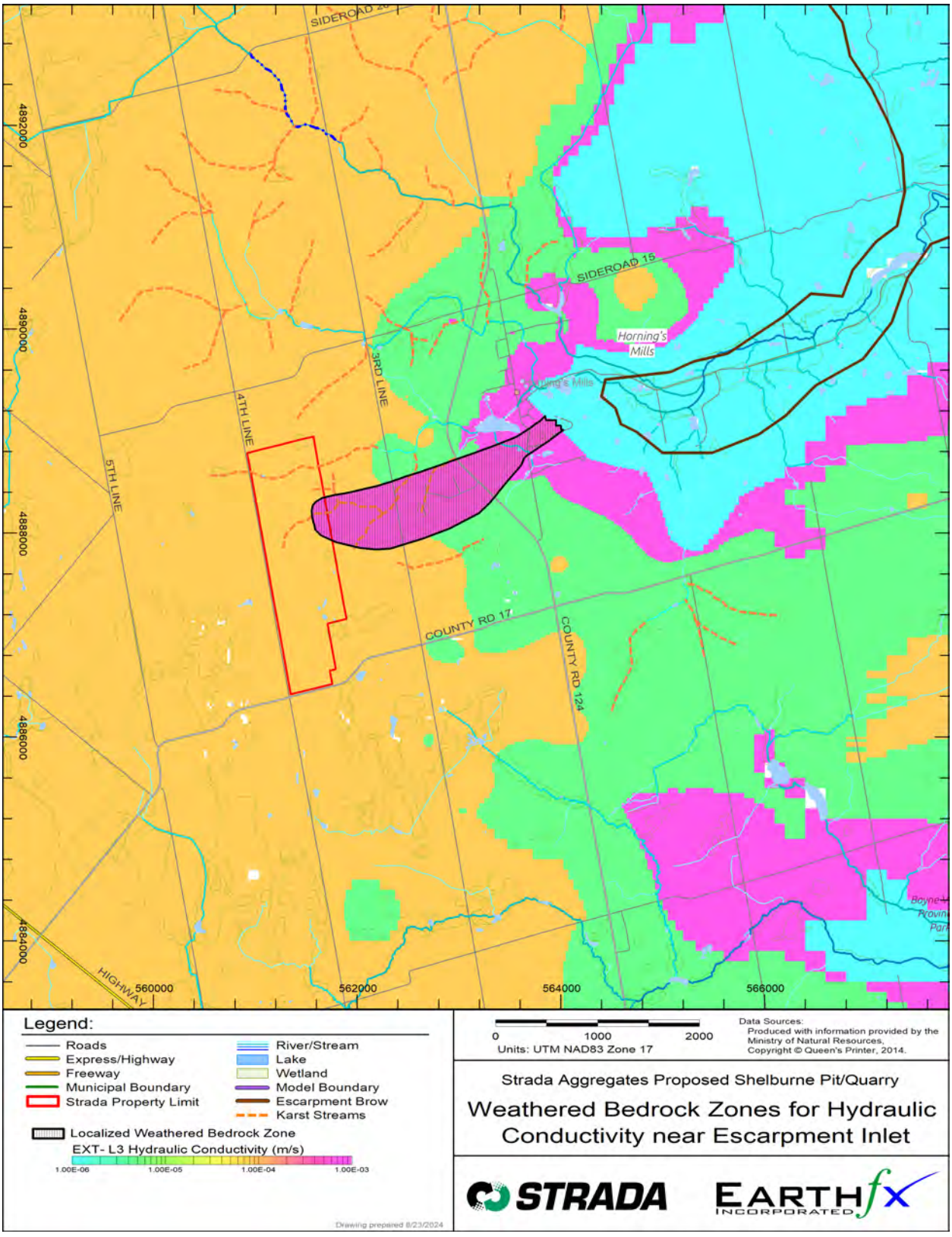


Figure 4.28: Weathered bedrock hydraulic conductivity zone near the Niagara Escarpment re-entrant.

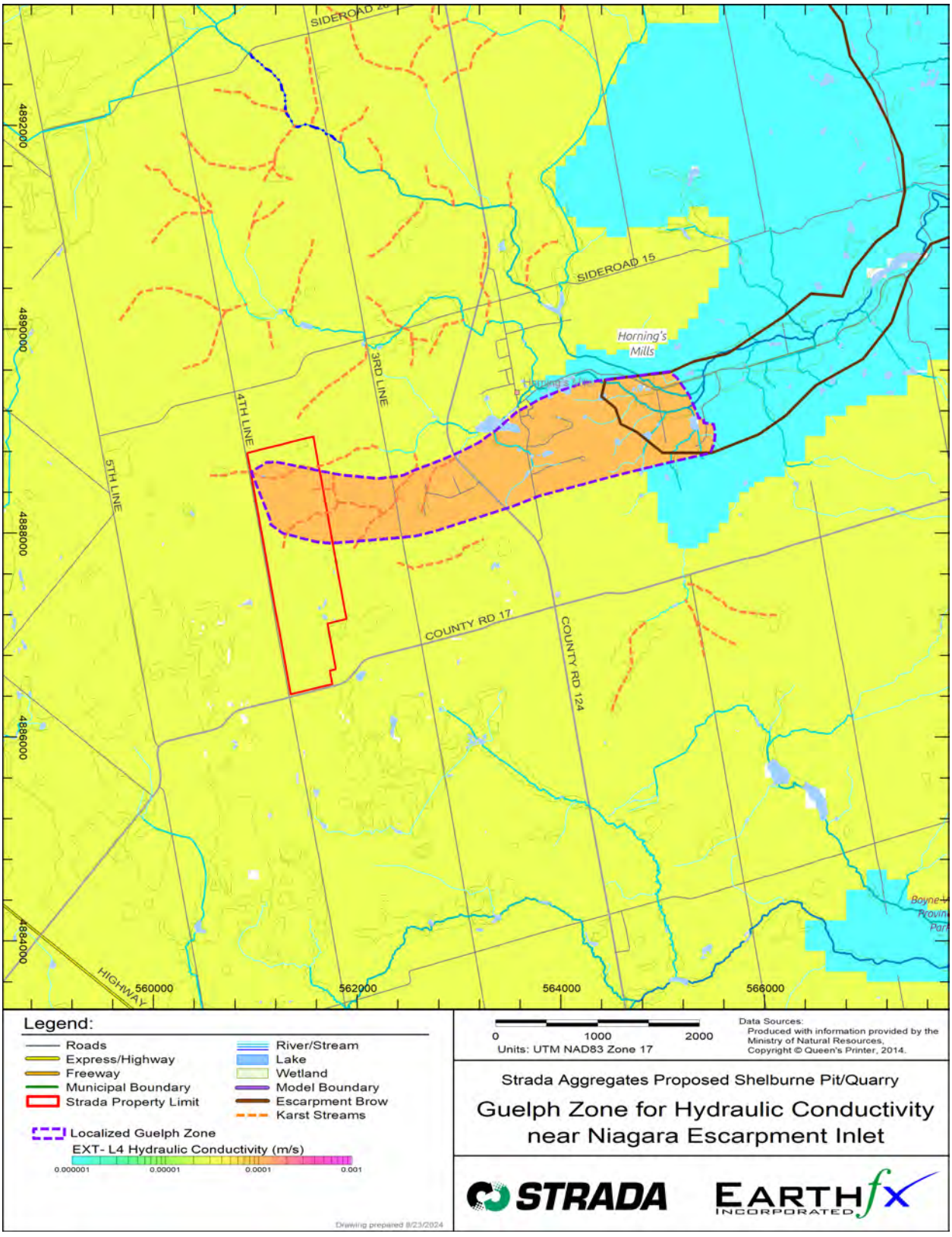


Figure 4.29: Guelph Fm. hydraulic conductivity zone near the Niagara Escarpment re-entrant.

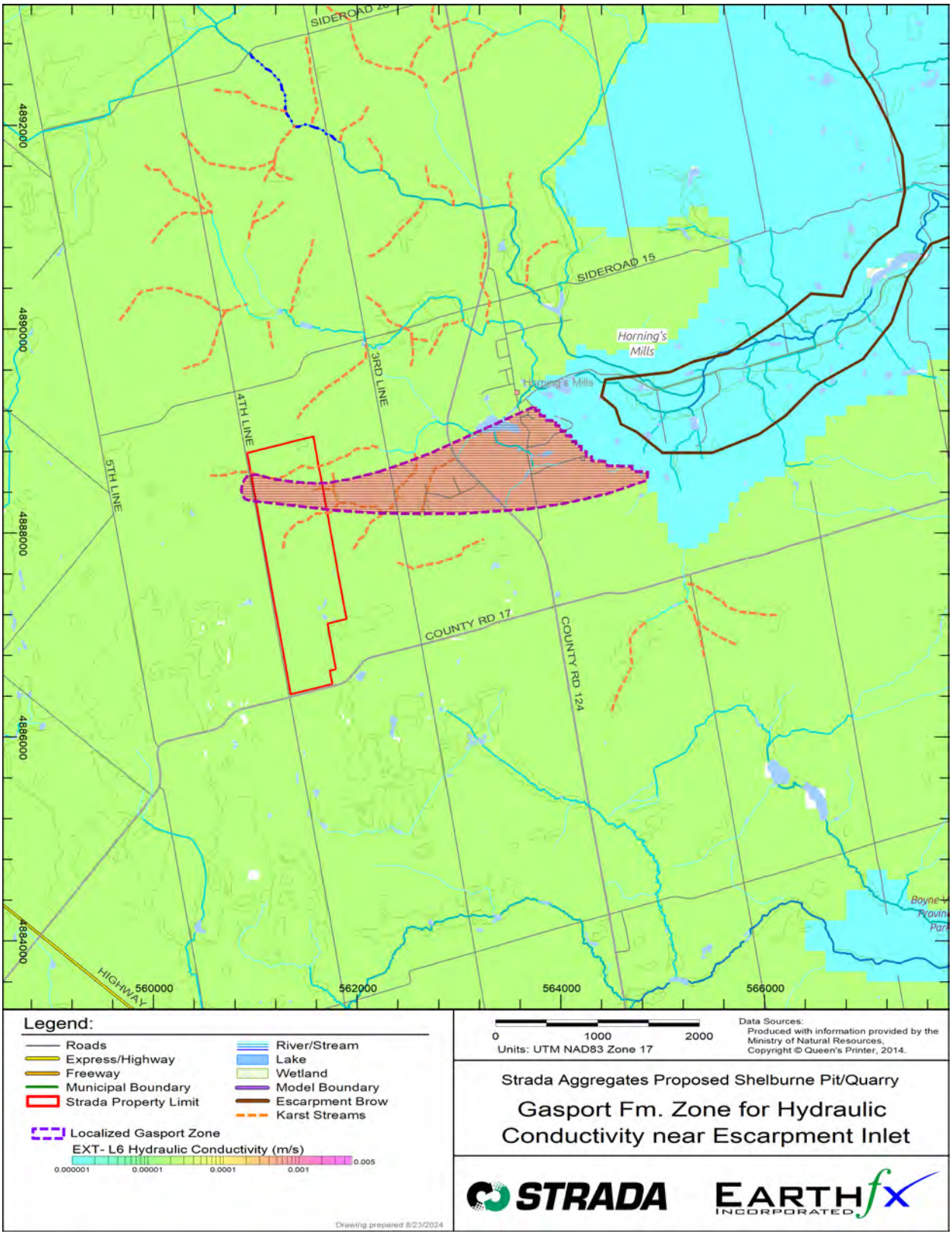


Figure 4.30: Gasport Fm. hydraulic conductivity zone near the Niagara Escarpment re-entrant.

4.10.6 Calibrated Water Levels at Local Scale

The groundwater model was updated with the features outlined in the previous sections as part of the model calibration and refinement process. The overall goal was to locally refine the calibration at both the site scale and local area of impact scale.

Simulated water levels from the calibrated model are presented along with interpolated MECP WWIS static water levels averaged in Figure 4.31 through Figure 4.33 for the Overburden, Weathered Bedrock/Guelph Formation, and Gasport aquifers, respectively. Five-metre water level contours are shown to facilitate comparison between the estimates, which is the purpose of the calibration.

Static MECP water levels were interpolated using a kriging technique for the local scale area. Analysis of the variogram nugget was undertaken to identify local-scale variability and noise in the data. The variogram nugget is a measure of the intrinsic variability in water levels between closely-spaced data points. The nugget represents multiple sources of systemic error in the water level data, including one-time measurements taken in different seasons (and in different years), elevation errors, location errors, in-borehole measurement errors, transcription errors, and the fact that the water level in the well may not have fully recovered from drilling before measurement. It is very useful to compare the nugget, a measure of intrinsic variability and error in the data, with the model calibration error. The model calibration RMS error cannot be less than the nugget, for it is impossible to build a model that is more accurate than the error in the model input data.

In addition to the nugget analysis, kriging variance error analysis was used to identify uncertainty in the kriging process and screen the results based on the kriging variance. Variance values of 80, 100 and 180 m^2 were chosen as thresholds for each of these three aquifer units to limit contour display.

In the Overburden aquifer (Figure 4.31), simulated and observed contours plot close to each other, particularly across the Strada site where they follow both concave and convex patterns as they move north to south. The area with available data is the most constrained for this aquifer compared to the others, and is limited to a relatively close distance from the Strada property (note that the blue contour lines are clipped). The nugget estimated from water level variogram analysis was less than 1 m, indicating a low level of systemic error associated with the measured water levels in the overburden aquifer near the site.

As was noted earlier, a set of karst streams (see Section 4.5) was added to the model to represent the suspected connection among swales and surface water streams around the site. The karst streams delineation was made available to Earthfx by Hunter and Associates and it is the result of their local knowledge of the area. The contours of the simulated heads in Figure 4.10 are affected by these Karst streams somewhat lowering the heads locally, at the north side of the Strada property.

In the Weathered Bedrock/Guelph Formation aquifers (Figure 4.32), the observed groundwater level contours were only truncated by the variance error threshold near the Escarpment, northeast from the Strada site, and to the southwest corner of the local-scale area. The simulated contours deviate slightly (both plus and minus) compared to the observed data contours of the same value showing a good agreement across the local scale, especially in the vicinity of the Strada property. This figure highlights the groundwater flow pattern that trends from the southwest of the property in a northeast direction towards Horning Mills and the Pine River valley. The karst streams also exhibit an effect on the head contours in the Weathered Bedrock unit, as indicated by the v-shaped patterns n the contour lines. The nugget for the Weathered Bedrock/Guelph Formation water levels was estimated at 2.7 m, indicating a greater systemic error in the observed data for this intermediate aquifer.

Given the limited number of deep wells that intersect the Gasport Formation to the west of the local area; contours in this area were truncated due to high variance (Figure 4.33). The observed water level contours are smoother, partly because this is a deep, confined aquifer and may be subject to less seasonality, but also because of data sparsity in the MECP WWIS data set. Cones of influence caused by pumping from the Shelburne Wellfield can be observed. The nugget value for this dataset, however, is 5.6 m, but may be influenced by prevalence of deep, open boreholes that may intersect more than one aquifer.

Scatter plots of observed and simulated groundwater levels are shown in Figure 4.34 through Figure 4.37, for each aquifer unit and for a composite dataset. Similar to the nugget value determined from the semivariogram analysis of the observed datasets, the local scale root mean square (RMS) also increases with the depth of the unit: 4.1 m, 4.6 m, and 5.7 m, respectively. Interestingly, the nugget and the RMS values for the Gasport Formation are very close, suggesting that a significant portion of the discrepancy between simulated and observed water levels can be attributed to systemic error.

Another measure of model calibration is the ratio of RMS error to the range of observed values in the local study area. The most representative measure of this statistic comes from the Weathered Bedrock/Guelph Fm dataset, which has a reasonable number of wells and spatial distribution in the local area. The ratio of RMS error to the range of observed values is 3.4%. Spitz and Moreno (1996) indicate that an error of less than 10% of the range indicates an acceptable calibration. The ratio of RMS to observed range of measurements for the Overburden is 6%, for the Gasport aquifer is 7%, and for all wells overall is 3.5%. All of these are within the acceptable range as noted by Spitz and Moreno (1996).

4.10.7 Local Area Calibration Conclusions

The calibration details and refinements presented in this section address the site and local scale conditions in the area of impact. Together, the new data and conceptualization support the addition of a small zone of refinement through the center of the site and Horning's Mills. Overall, the model RMS calibration statistic is consistent with the intrinsic error in the data, as delineated by variogram nugget analysis.

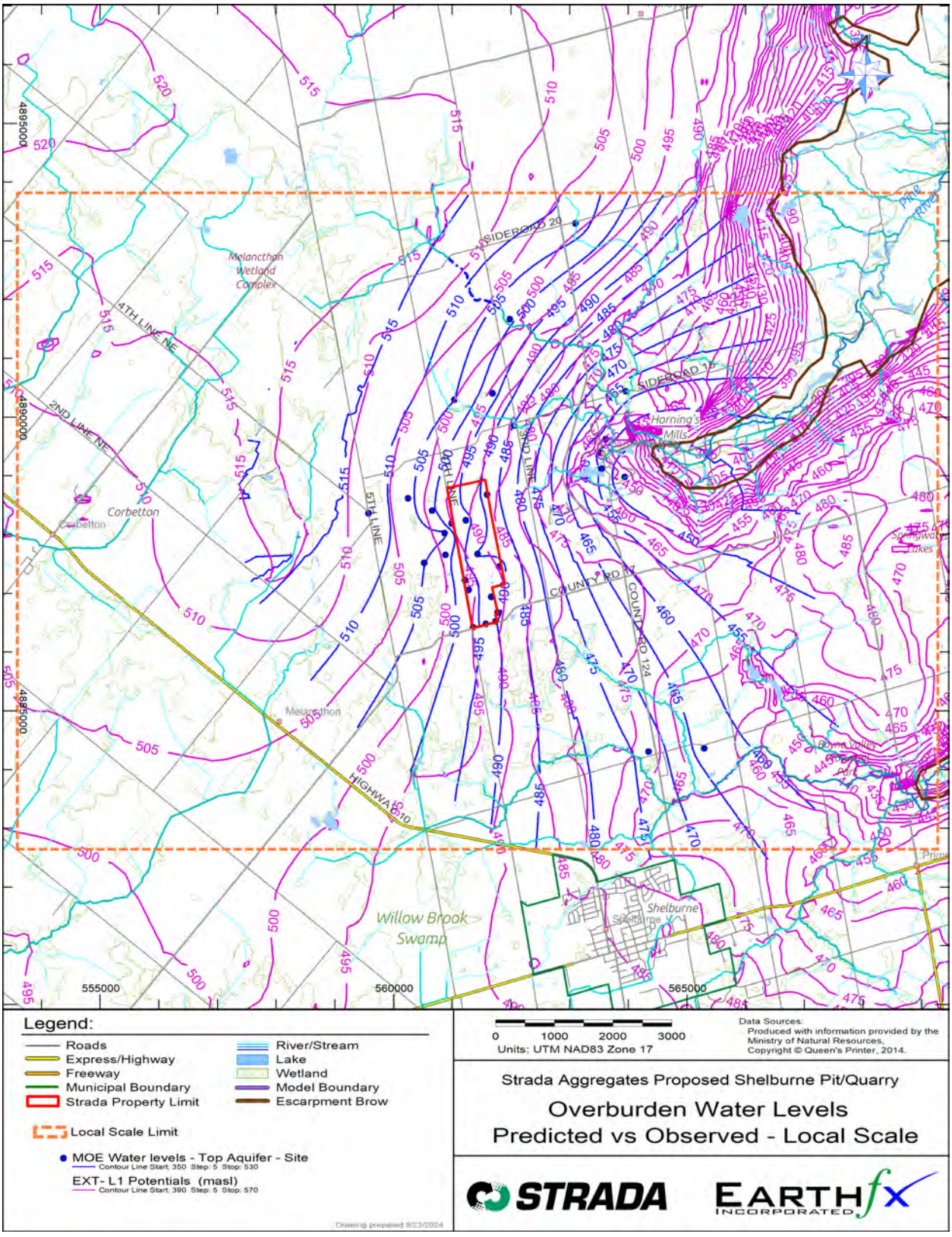


Figure 4.31: Simulated and observed local groundwater levels in the Overburden aquifer.

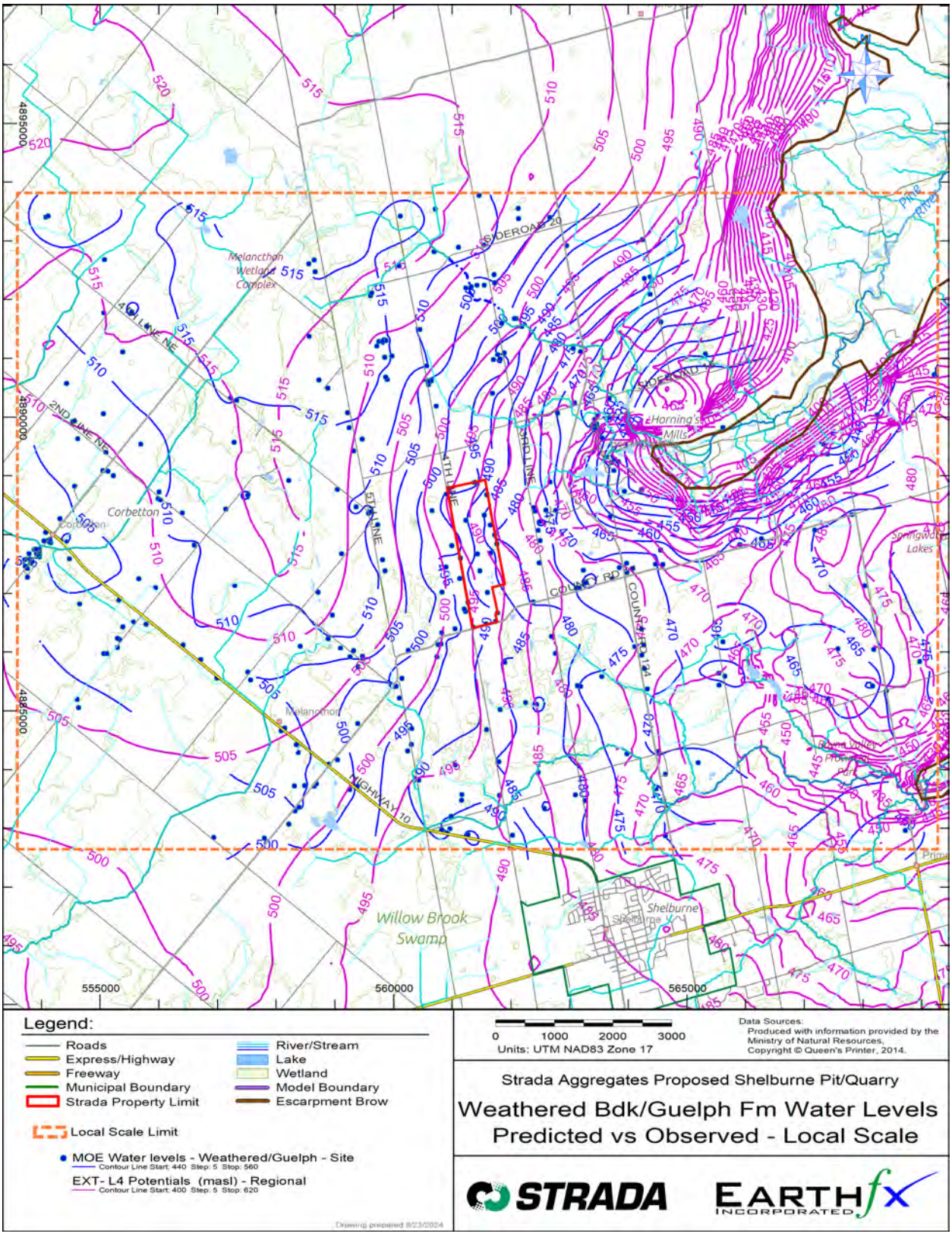


Figure 4.32: Simulated and observed local groundwater levels in the Weathered Bedrock/Guelph Fm aquifers.

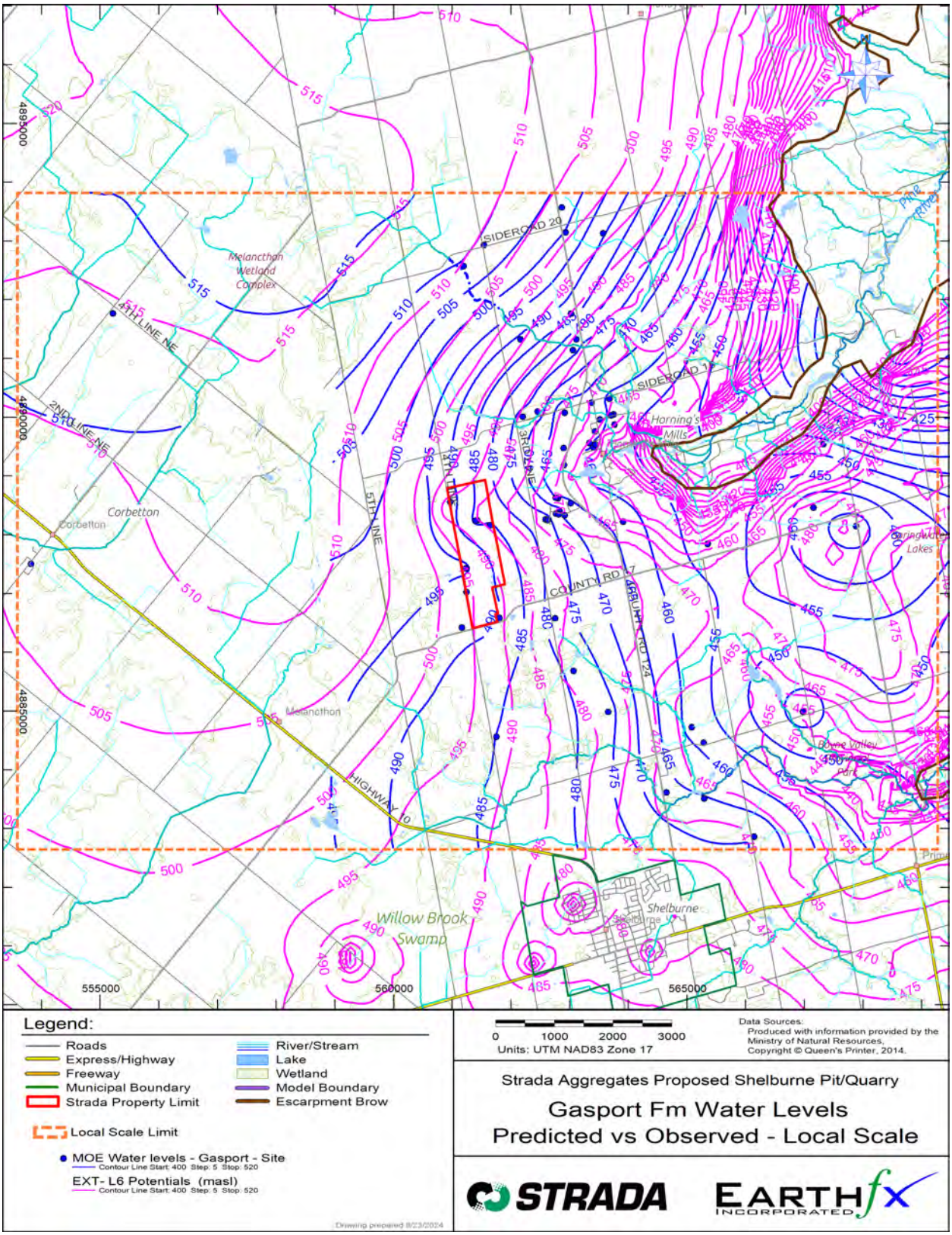
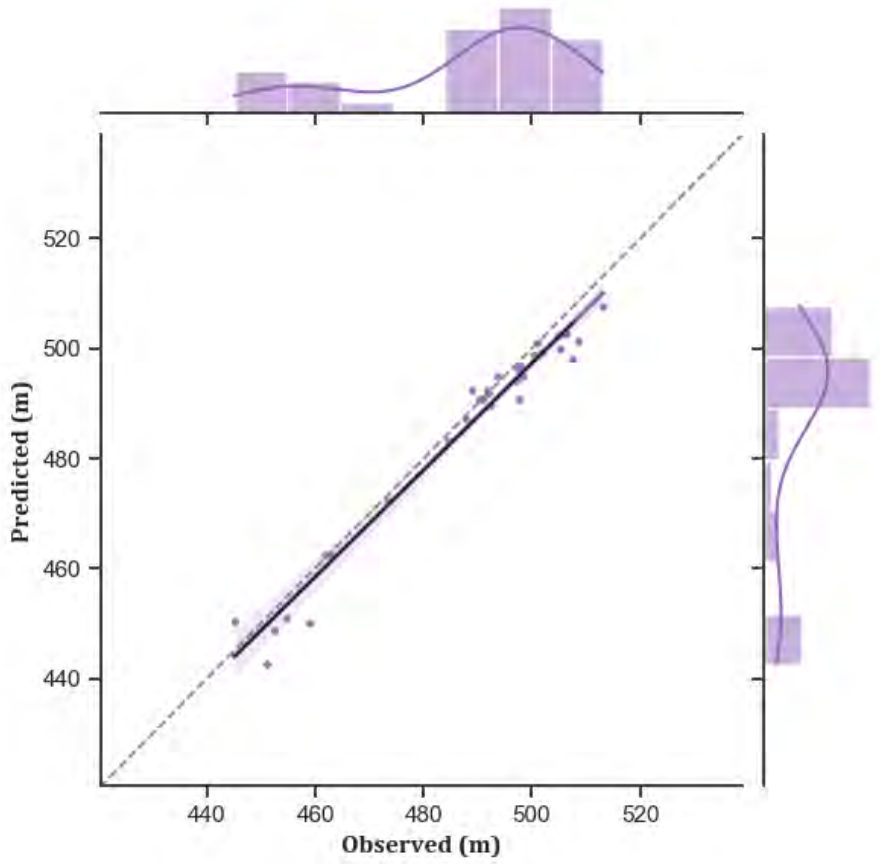
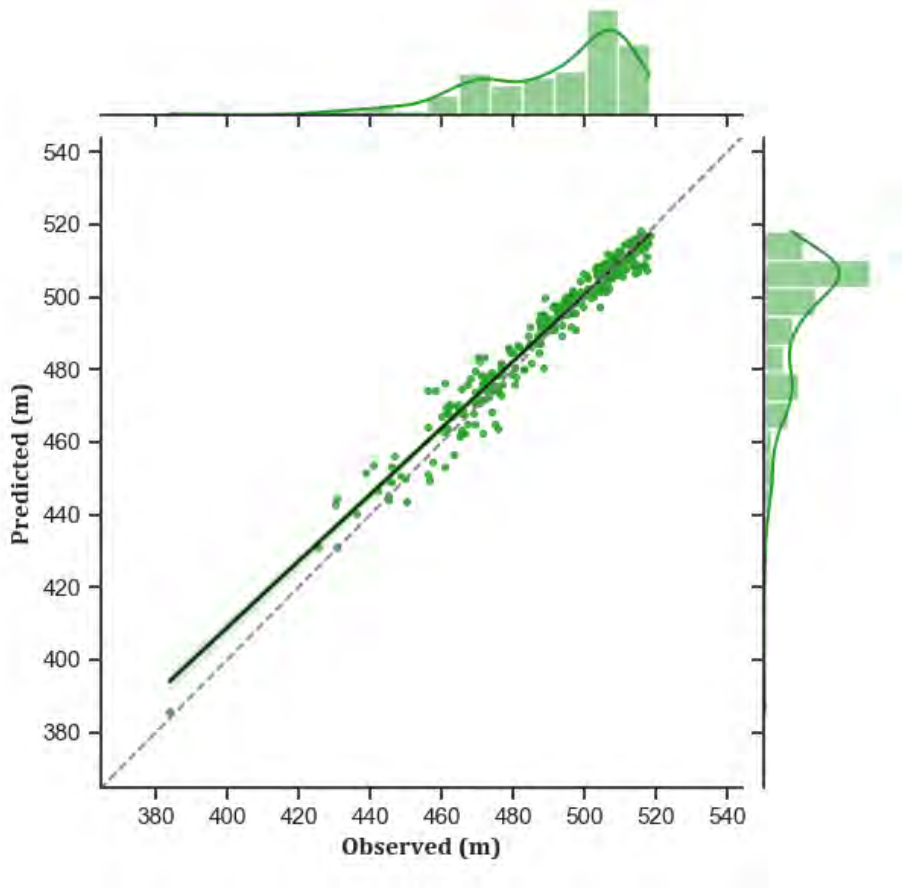


Figure 4.33: Simulated and observed local groundwater levels in the Gasport aquifer.



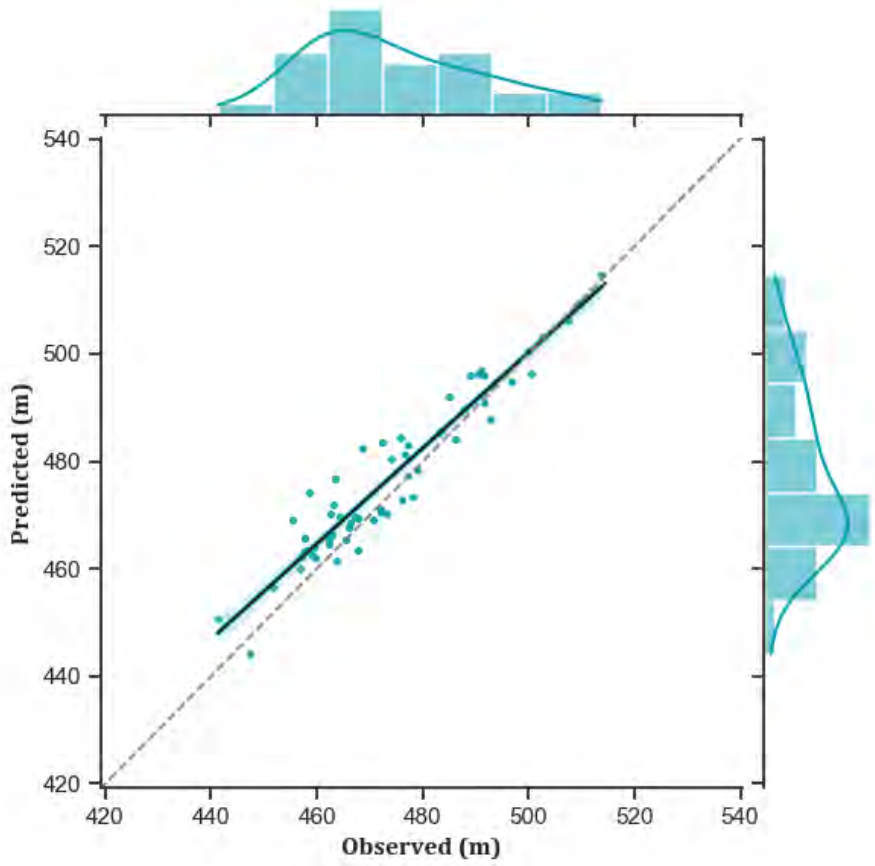
Number of points	33
Mean Error	2.35 m
Mean Abs. Error	3.12 m
RMS Error	4.07 m
R Squared	0.95
Min Abs. Difference	0.12 m
Max Abs. Difference	9.35 m
Min Model value	442.6 m
Max Model value	507.8 m
Min Obs. value	445.0 m
Max Obs. value	513.2 m
RMS/Range OBS	6%

Figure 4.34: Scatter plot for local water levels and its statistics for the Overburden aquifer.



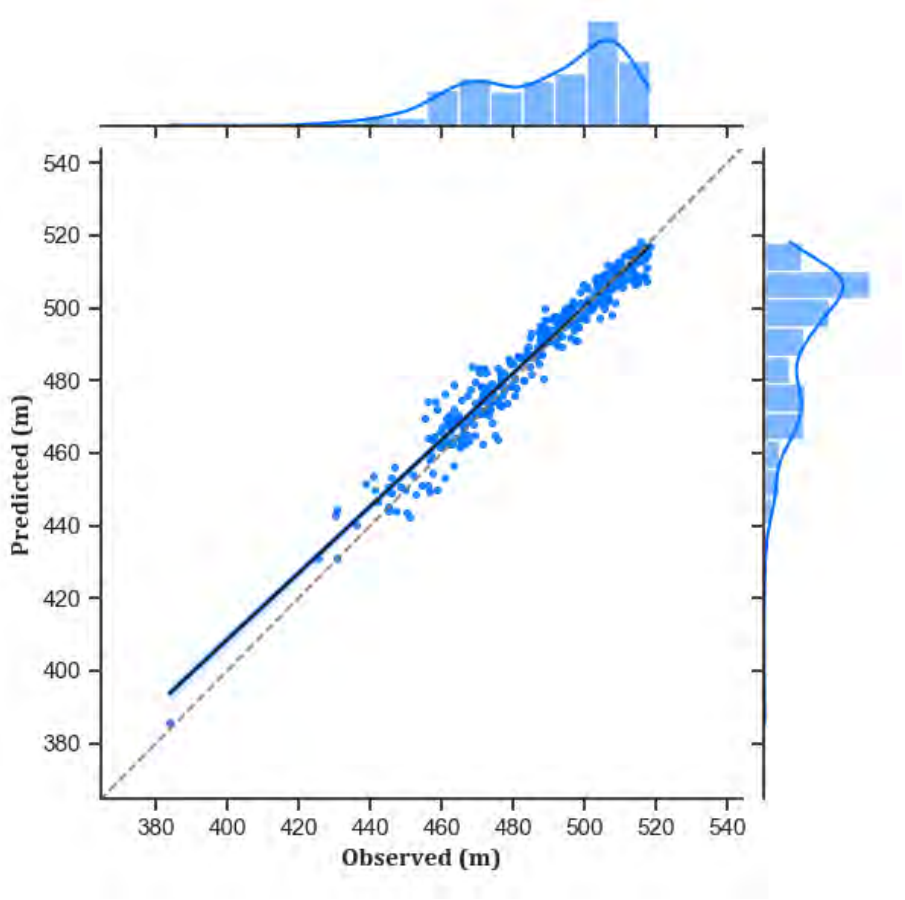
Number of points	350
Mean Error	-1.26 m
Mean Abs. Error	3.37 m
RMS Error	4.55 m
R Squared	0.95 m
Min Abs. Difference	0 m
Max Abs. Difference	18.26 m
Min Model value	385.7 m
Max Model value	518.1 m
Min Obs. value	383.8 m
Max Obs. value	518.1 m
RMS/Range OBS	3.4%

Figure 4.35: Scatter plot for local water levels and its statistics for the Weathered Bedrock and Guelph Fm aquifers.



Number of points	60
Mean Error	-3.06 m
Mean Abs. Error	4.39 m
RMS Error	5.71 m
R Squared	0.88
Min Abs. Difference	0.07 m
Max Abs. Difference	15.66 m
Min Model value	444.2 m
Max Model value	514.6 m
Min Obs. value	441.3 m
Max Obs. value	513.8 m
RMS/Range OBS	7.5%

Figure 4.36: Scatter plot for local water levels and its statistics for the Gasport aquifer.



Number of points	443
Mean Error	-1.27 m
Mean Abs. Error	3.47 m
RMS Error	4.68 m
R Squared	0.95 m
Min Abs. Difference	0 m
Max Abs. Difference	18.26 m
Min Model value	385.7 m
Max Model value	518.1 m
Min Obs. value	383.8 m
Max Obs. value	518.1 m
RMS/Range OBS	3.5%

Figure 4.37: Scatter plot for local water levels and its statistics for Composite dataset of all aquifers.

5 References

Anderson, M.P. and Woessner W.W., 1992, Applied Ground Water Modelling -- Simulation of flow and advective transport. Academic Press, USA.

Annable, W.K., 1996, Database of morphologic characteristics of watercourses in southern Ontario: published by Credit Valley Conservation Authority and Ontario Ministry of Natural Resources.

Chiew, F.H.S. and McMahon, T.A., 1993, Assessing the adequacy of catchment streamflow yield estimates, Australian Journal of Soil Research, 31: 665-680.

DeWalle, D.R., and Rango, A., 2008, Principles of snow hydrology: Cambridge University Press, Cambridge, U.K., 410 p.

Dickinson, W.T., Whiteley, H.Q., 1970, Watershed areas contributing to runoff: International Association of Hydrologic Sciences Publication 96, p. 1.12-1.28.

DWCo. (Dufferin Water Co.) Ltd., 2023, Mansfield water system – Annual Summary Report for 2022. Prepared for: the Township of Mulmur. 13 p.

Earthfx Incorporated, 2010, Water Balance Analysis of the Lake Simcoe Basin using the Precipitation-Runoff Modelling System (PRMS): prepared for the South Georgian Bay - Lake Simcoe Source Protection Region, October 2010, 106 p.

Earthfx Incorporated, 2022, Updated wellhead protection area delineation, vulnerability scoring, and threats assessment for the Town of Shelburne, Ontario. Prepared for: S. Burnett and Associates, June, 2022. 309 p.

Earthfx Incorporated, 2024a. Proposed Strada Aggregates Shelburne Pit/Quarry Conceptual Model Report (Application Appendix C), October 2024, 118 p .

Earthfx Incorporated, 2024b. Proposed Strada Aggregates Shelburne Pit/Quarry Impact Assessment Report (Application Appendix E), October 2024, 242 p.

Environment and Climate Change Canada, 2021, High resolution deterministic precipitation analysis system (CaPA-HRDPA). https://collaboration.cmc.ec.gc.ca/cmc/cmoi/product_guide/docs/lib/technote_capa_hrdpa_e.pdf

Freeze, R.A. and J.A. Cherry, 1979, Groundwater; Prentice-Hall Inc., 604p.

GENIVAR, 2011, Proposed Melancthon Quarry Hydrogeologic and Hydrologic Assessment. Prepared for: The Highland Companies 477476 Third Line, R.R. #2 Shelburne, Ontario. Genivar Project No. 082032.05, volumes 1 through 4.

GOFFCO Ltd, 2005, Hydrogeology report in support of an application for a permit to take water from a well and pond for aggregate washing purposes, West Half of Lot 13, Concession 3 Township of Melancthon, Dufferin County, prepared For Strada Aggregates Inc.

GOFFCO Ltd, 2007, Report on a preliminary pumping test for monitoring well MW2-07 near the Shelburne Pit Lot12, Concession 3, Melancthon Township. June 28th, 2007. 14 p.

Golder Associates and Banks Groundwater Engineering, 2013, Long Term Well for Additional Water Supply Project, Environmental Assessment/Environmental Impact Statement: prepared for the Town of Shelburne, September 2013.

Gwyn, Q.H.J. 1972. Quaternary Geology of the Dundalk area Southern Ontario. Ontario Department of Mines and Northern Affairs. Preliminary Map P.727 Geological Series Scale 1:50,000

Harbaugh, A.W., 2005, MODFLOW-2005, The U.S. Geological Survey modular ground-water model—the Ground-Water Flow Process: U.S. Geological Survey Techniques and Methods 6-A16.

Hargreaves, G.H. and Samani, Z.A., 1982, Estimating potential evapotranspiration. Journal of Irrigation and Drainage Engineering, 108, 223-230.

Hoffman, D. W. and Matthews B. C. 1964. Soil Survey of Dufferin County, Ontario. Repot Number 38. Ontario Agricultural College R. E. Wicklund Soil Research Institute

Hunt, R., Walker, J., Selbig, W., Westenbroek, S., and Regan, R., 2013, Simulation of climate-change effects on streamflow, lake water budgets, and stream temperature using GSFLOW and SNTEMP, Trout Lake Watershed, Wisconsin: U.S. Geological Survey Scientific Investigations Report 5159, U.S. Dept. of the Interior, Reston, Va.

Huntington, J.L., and R.G. Niswonger, 2012, Role of surface-water and groundwater interactions on projected summertime streamflow in snow dominated regions -- An integrated modeling approach: Water Resources Research 48(11): doi: 10.1029/2012WR012319.

Hydrology Consultants Limited, 1979. Report on the construction and testing of production Well 5

Kassenaar, D., 2013. VIEWLOG (version 4). Microsoft Windows. Toronto, ON: VIEWLOG Systems Inc.

Leavesley, G.H., Litchty, R.W., Troutman, B.M. and Saindon, L.G., 1986, Precipitation-Runoff Modeling System: User's Manual. Water Resources Investigations Report 83-4283. USGS. Denver Colorado.

Markstrom, S.L., Niswonger, R.G., Regan, R.S., Prudic, D.E., and Barlow, P.M., 2008, GSFLOW: Coupled ground-water and surface-water flow model based on the integration of the Precipitation-Runoff Modeling System (PRMS) and the Modular Ground-Water Flow Model (MODFLOW-2005): U.S. Geological Survey Techniques and Methods 6-D1, 240 p.

Markstrom, S. L., Regan, R. S., Hay, L. E., Viger, R. J., Webb, R. M., Payn, R. A., and LaFontaine, J. H., 2015, PRMS-IV, the precipitation-runoff modeling system, version 4: U.S. Geological Survey Techniques and Methods, book 6, chap. B7, 158 p., http://dx.doi.org/10.3133/tm6B7.

Merritt, M.L., and Konikow, L.F., 2000, Documentation of a computer program to simulate lake-aquifer interaction using the MODFLOW groundwater flow model and the MOC3D solute-transport model: USGS Water-Resources Investigations Report 00-4167, 146 p.

Nash, J.E. and J.V. Sutcliffe, 1970, River flow forecasting through conceptual models, Part I - A discussion of principles. Journal of Hydrology 10, p. 282-290.

Natural Resource Solutions Inc. (NRSI), 2024. Strada Pit/Quarry Natural Environment Assessment, Prepared for Strada Aggregates Inc. Project No.2473A, 597 p.

Niswonger, R.G. and D.E. Prudic, 2005, Documentation of the Streamflow-Routing (SFR2) package to include Unsaturated Flow beneath Streams- a modification to SFR1; U.S. Geological Survey Techniques and Methods 6-A13, p. 50.

Niswonger, R.G., Prudic, D.E., and Regan, R.S., 2006, Documentation of the Unsaturated-Zone Flow (UZF1) Package for modeling unsaturated flow between the land surface and the water table with MODFLOW-2005: U.S. Geological Survey Techniques and Methods, Book 6, Chapter A19, 62 p.

Niswonger, R.G., Panday, Sorab, and Ibaraki, Motomu, 2011, MODFLOW-NWT, A Newton formulation for MODFLOW-2005: USGS Techniques and Methods 6–A37, 44 p.

Ontario Ministry of Agriculture and Food, Ontario Ministry of Rural Affairs, 2003, Soil Survey Complex [Computer File]. Guelph, ON (Accessed October 2014)

Ontario Geological Survey, 2010, Surficial geology of southern Ontario: Ontario Geological Survey, Miscellaneous Release – Data 128 revised, digital compilation of southern Ontario surficial geological mapping.

Ontario Ministry of Natural Resources [MNR], 2008. Southern Ontario Land Resource Information System (SOLRIS). Phase 2 – Data Specification Version 1.2, April, 2008. 17 p.

Ontario Ministry of Natural Resources [MNR], 2012, OHN Watercourse Coverage [Computer File]. Peterborough, ON (Accessed September 2014).

Spitz, K. and Moreno, J., 1996, A Practical Guide to Groundwater and Solute Transport Modeling, John Wiley & Sons Inc: New York.

Southwestern Ontario Orthoimagery Project (SWOOP), 2010 [computer file], Land Information Ontario, Ministry of Natural Resources.

Tatham and Earthfx, 2023. Proposed Strada Aggregates Shelburne Quarry Data Compilation Report (Application Appendix A and B). Memo report prepared for Strada Aggregates, June 29, 2023

Tanvir Hassan, S.M., M.W. Lubczynski, R.G. Niswonger, and Z. Su, 2014, Surface-groundwater interactions in hard rocks in Sardon catchment of western Spain -- an integrated modeling approach: Journal of Hydrology: doi: 10.1016/j.jhydrol.2014.05.026.

Torrance, J.K. 2009. The Honeywood Soil Series and Potato Production in Dufferin County, Ontario

United States Department of Agriculture: Soil Conservation Service, 1985, National Engineering Handbook, Section 4 - Hydrology: USDA-SCS, Washington, D.C.

United States Department of Agriculture, Soil Conservation Service, 1986. Urban hydrology for small watersheds. Technical Release, 55, 2{6.

WSP Canada Inc., 2014, Town of Shelburne 2013 permit to take water annual monitoring report, Report 101-17080-00, 129 p.

Whitewater Hydrogeology, 2013, Category 3 PTTW Application: 3191574 Nova Scotia (Downey Farms). Prepared for the Ministry of the Environment, Environmental Assessment and Approvals Branch, 2 St. Claire Avenue West, Floor 12A Toronto ON

Appendix E: Impact Assessment Report

Strada Aggregates Proposed Strada Pit/Quarry

Appendix E
Impact Assessment Report

Prepared for:



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Prepared by:



January, 2025

Strada Aggregates
Proposed Strada Pit/Quarry

Appendix E
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Proposed Strada Aggregates Shelburne Pit/Quarry Impact Assessment Report

1 Introduction

1.1 *Objectives*

The following tasks are covered in this Appendix E: Impact Assessment Report:

- Simulation and analysis of the likely changes to groundwater and surface water flows and levels under different phases of the proposed pit/quarry operation and closure;
- Simulation and evaluation of measures to minimize the effects of the pit/quarry on nearby private wells;
- Simulation of site conditions under a range of seasonal and inter-annual climate conditions, and
- Quantitative evaluation of the hydrologic and hydrogeologic water budget under current and future scenarios. This includes simulation of all on-site water management, and detailed, feature-based wetland water budgets that quantify surface water and groundwater effects.

1.2 *Study Approach*

The study approach is based on the development of both a Conceptual Model interpretation of the field data, and the further use of an integrated surface water and groundwater model to evaluate resources issues in a comprehensive and quantitative manner. This approach addresses the entire hydrologic cycle, with 100% water budget accounting, and can address the effects of groundwater development on surface water and wetland resources.

Another important aspect of this approach is that it includes the evaluation of both long-term average conditions and seasonal transient variability. The effects of seasonal processes, such as spring snowmelt or summer drought, are fully evaluated.

The numerical modelling approach used in this study is based on a similar approach to that used by Earthfx Incorporated for a recent Source Water Protection (SWP) study of the Town of Shelburne wellfield (Earthfx, 2022).

1.2.1 Level 2 Development Impact Assessment and Mitigation Measures

The Level 2 impact assessment is included in Section 3 of this report. Each of the major development phases of pit/quarry and rehabilitation is simulated and compared to the baseline flows and levels on both an average and monthly basis. “Baseline Conditions” represent conditions in and around the site once the gravel extraction operations are complete as per the current pit operating license, and are described in Section 2.2. In this way, the results of future development scenarios can be directly compared to baseline conditions and thereby provide insight into the effects of the proposed development on a monthly, seasonal, and inter-annual basis.

1.2.2 Long-Term Management and Mitigation Plan

An extensive program of monitoring and private well protection and management has been undertaken in conjunction with local agencies. This program is described in Section 4.

The numerical model was also used to identify the available drawdown in the aquifer under baseline and future conditions. Results indicated that groundwater resources would remain sustainable under these conditions, as discussed further on in this report.

1.3 *Stream, Wetland, Pond and Lake Model Representations*

The graphical presentation and use of the term “ditches”, “wetlands”, “ponds”, “lakes”, “rivers” and “streams” on figures and in the text of this report refers to features that are represented in the numerical model. These terms do not imply that the feature is considered an officially classified hydrologic feature by the regulatory agencies (including MNR). For example, in some figures presented below, stream segments (blue lines) are shown on the maps to represent streams, roadside ditches and surface drainage swales in the model. These lines represent overland runoff drainage pathways mapped from the digital elevation model (DEM), but they may not correspond to MNR mapped (and classified) streams. The MNR does not classify roadside ditches, for example.

Similarly, there are model representations and discussions of dugouts, wetlands, ponds and lakes that represent depressions in the DEM, but they may not correspond to an MNR mapped wetland or water body. For example, man-made ditches and ponds are simulated and assessed but not considered key hydrologic features or key natural heritage features.

A set of Priority Natural Features (hereafter referred to as NAT complexes) were identified by NRSI as part of their impact assessment (NRSI, 2024, Section 1.1). These “natural features” (wetlands) are discussed in Section 2.6. While wetlands of all classes are identified on the basemap legend, NAT wetlands are labelled as NAT-XX on the maps, hydrographs and water budget bar charts.

Another example is the numerical model representation of subsurface karst conduits (personal communications with peer reviewer, Map dated April 8, 2010). The subsurface portion of the stream conduit is, in some figures, interpreted and illustrated as a dashed blue or orange line, but that does not imply that the feature exists on surface and is a MNR classified stream. In these cases, the model is representing the routing of water through an inferred subsurface conduit.

1.4 *Maps and Model Datum*

In late September, 2023 the Province of Ontario released detailed LiDAR ground elevation survey data covering the entire Strada study area (CGVD2013 Datum). This datum was used for the model ground surface representation. Map projection is UTM NAD 83 Zone 17. Basemap information is provided by the Ministry of Natural Resources and may be Copyright, 2014 Queen’s Printer. The accuracy of basemap information reflects the various government data sources and should not be used for purposes beyond this impact assessment.

Map figures in this report have been prepared as high-resolution images suitable for detailed on-screen review, zoom and analysis. Figures are presented in a portrait letter orientation to allow consistent scrolling without page size and orientation changes. All figures are hyper-linked to the text discussion to facilitate switching between the text and figures.

Model row and column numbers refer to the grid described in Section 4.3 of Appendix D (Earthfx Inc., 2024).

2 Level 1/2 Baseline Condition Analysis

2.1 *Introduction*

The delineation of current site conditions and baseline conditions for impact assessment are two important aspects of the assessment process.

"Current conditions" represent the observed site conditions as measured from the monitoring network. Current conditions are documented and discussed in detail in Appendix A through D.

It is important to note that site conditions will change as extraction progresses within the currently approved license area and permitted pumping for aggregate wash operations occurs. The on-going pit operations will result in changes in runoff and infiltration in and around the site.

2.2 *Baseline Conditions*

"Baseline Conditions" represent conditions in and around the site once the gravel extraction operations are complete as per the current pit operating license. As defined here, Baseline conditions are not current but near future conditions. The current License Area, highlighting the primary remaining area of future extraction, is shown in Figure 2.1.

The numerical model was used to estimate Baseline conditions. Changes to the land use, topography and layer geometry were made, and the Precipitation Recharge Modelling System (PRMS) model was used to estimate the changes in recharge and runoff patterns. The final land surface topography at full pit extraction is shown in Figure 2.2. The estimated water levels, streamflows, and wetland interactions under baseline conditions are shown in the following sections.

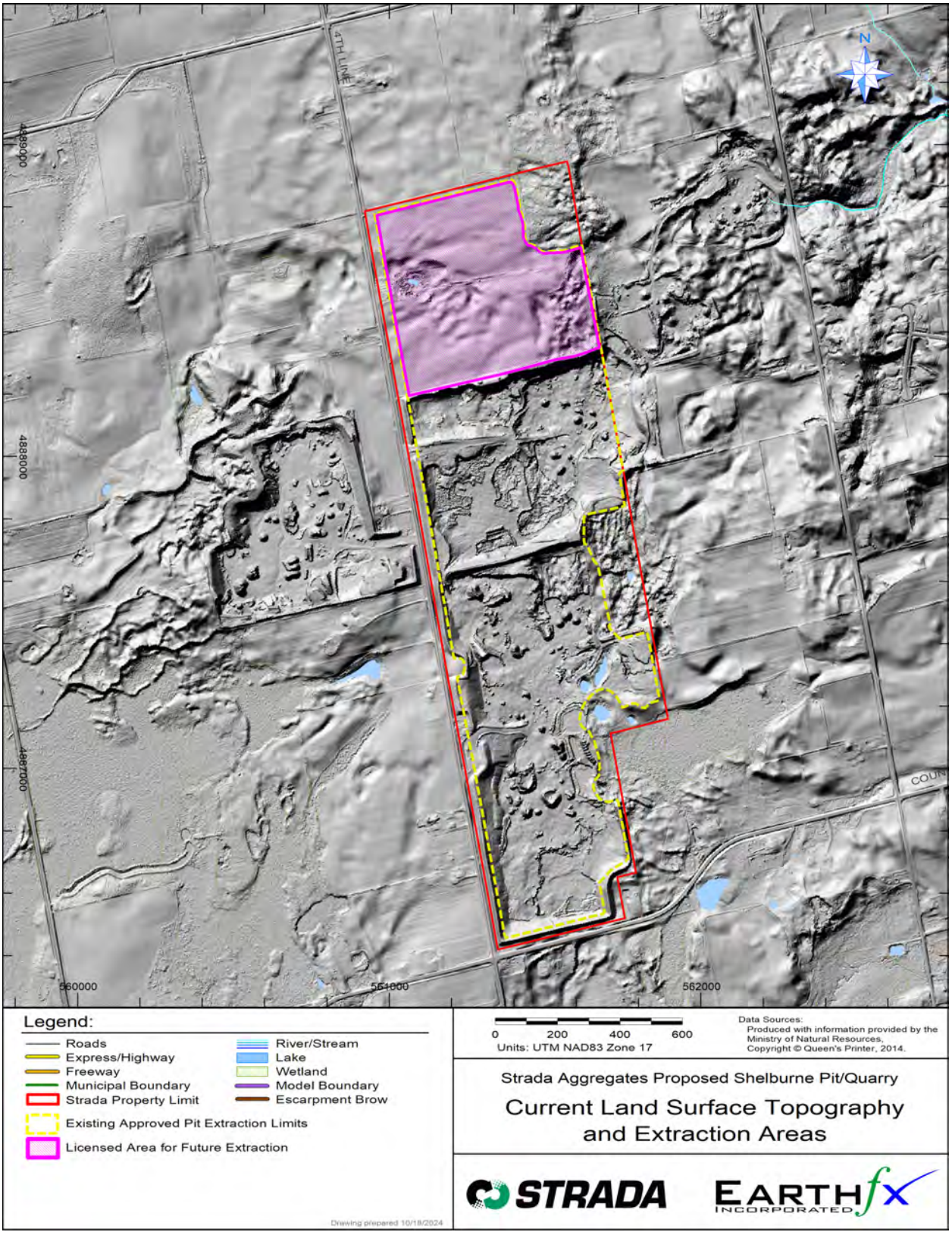


Figure 2.1: Current Surface Topography, License area and primary remaining area for extraction.

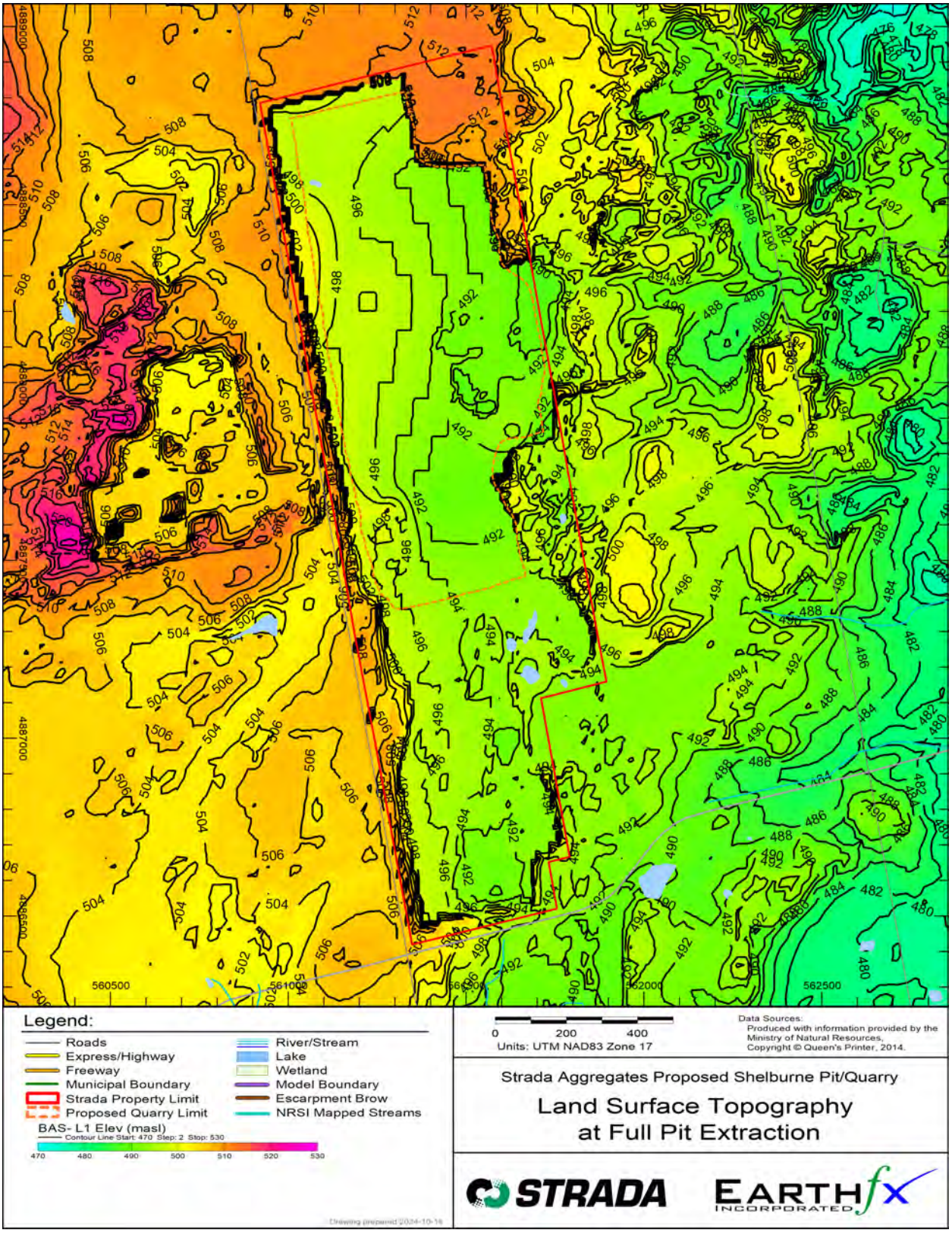


Figure 2.2: Land Surface Topography at Full Pit Extraction

2.3 *Time Period*

The numerical model was run in two modes. First, the model was run to "Steady state" or long-term average conditions. Second, the model was run in transient mode for the period of October 1, 2015 to April 1 2024. The steady-state average results were used to assess long-term change in conditions, while the transient assessment was used to evaluate seasonal and inter-annual variation in flows, water levels and wetland conditions. Transient results are referenced on maps and hydrographs with the "GSE" (GSFLOW Extended) prefix in the legend.

2.4 *Groundwater Levels*

The baseline water level in the shallow system (water table) is shown in Figure 2.3. Water levels slope to the east, with flow converging on Horning's Mills and the Pine River valley. Similarly, water levels in the upper bedrock Guelph formation are shown in Figure 2.4, and follow a similar pattern. Finally, average water levels under Baseline Conditions in the confined Gasport formation (Figure 2.5) also slope towards the Pine River valley, and the model suggests that there might be upward gradients from the Gasport aquifer near Horning's Mills (See discussion of GWP-6 hydrograph, below in Figure 2.17).

The water levels are shown on a West – East Cross Section in Figure 2.6 and Figure 2.7.

The limestone aquifers in the study area exhibit very good water supply potential. The "available drawdown" for wells in the area can be estimated by calculating the difference between the water table elevation and the top of the Cabot Head shale. This is shown in Figure 2.8, and illustrates that there is significant available drawdown through much of the area. Near the escarpment the available drawdown above the Cabot Head is reduced because of a gradual rise in the Cabot Head formation, which results in a thinning of the aquifer units (Bedrock strata in southwestern Ontario dip shallowly at 3 to 6 m/km southwestwards (Armstrong and Carter, 2010, Page 19). Note the pinching of the Guelph formation at section distance 4400 m on the cross section in Figure 2.7. This pinching results in groundwater discharge and upward gradients from Layer 6 (Gasport) to Layer 4 (Guelph) at Section Distance 5600 m on Figure 2.7. These gradients produce a more reliable and steady water level due to reduced seasonal variability in the water levels (See discussion of GWP-6 hydrograph, below in Figure 2.17). The current available drawdown in the wells will be checked during the well inspection. Additional drawdown would be available by deepening the well if the well does not reach the top of the Cabot Head. The current and total available drawdown will be checked against the predicted drawdown at that time.

An additional 8-10 m of aquifer thickness (and available drawdown) is provided by the Manitoulin and Whirlpool aquifers that exist below the Cabot Head. For example, MECP well 1701065, located at the edge of the escarpment in Horning's Mills, is drilled through the Cabot Head and into the Manitoulin Dolostone which is 8.5 m thick at that location. While the Cabot Head has been represented in the model, aquifers beneath this unit have not been analyzed and are not needed or utilized for this development application. (Gwyn (1972), notes that "field exposures were examined in which there were two and three tills", collectively referred to as the Tavistock Till in this report.)

The average depth to the water table is shown in Figure 2.9. This indicates that some of the wetlands may be partially or fully in contact with the water table, while others may be perched above the water table (or vernal pools). The model predicts areas where the water table discharges to wetlands. This is referred to as "surface discharge" (or surface leakage), and the discharge is shown spatially in Figure 2.10. Seasonal variation in surface discharge is discussed in more detail in the next sections.

The model provides transient groundwater levels over the period of 2015-2024. A set of groundwater assessment points were selected for the Baseline and future conditions comparative analyses. Ground Water Program (GWP) Assessment point locations are shown on Figure 2.11, and represent a range of distances from the proposed quarry (Representative stream assessment locations (STR) are also shown and discussed in the next section). Groundwater hydrographs from the GWP assessment locations are shown in Figure 2.12 through Figure 2.17. Transient water level hydrographs from each of the three aquifer zones are shown, and in some cases (east of the Strada site) there are upward gradients (as discussed above) from the deeper system.

2.4.1 Map and Hydrograph Legend Abbreviations

Throughout this report some abbreviations are use to improve readability and prevent legends and figure captions from becoming too long.

Model Row and Column numbers:
Note that GWP and STR locations and accompanying model row and column numbers on maps and hydrographs refer to the model grid cells as described in Section 4.3 of Appendix D (Earthfx Inc., 2024). The GWP and STR naming is easier to remember than the row and column number, but the row and column are a more precise description of the model result.

Model Layer Number:
The results from model layers are presented in an abbreviated form as:

- "L1" for Model Layer 1 (Shallow overburden across the entire model area)
- "L4" for Model Layer 4 (Guelph Eramosa formation *above the escarpment*)
- "L6" for Model Layer 6 (Gasport Formation *above the escarpment*)

Model layers are discussed in more detail in Section 4.3 of Appendix D (Earthfx Inc., 2024). Note that model layers above and below the escarpment represent different geologic units, so the reporting of the layer number is necessary.

Scenario Name:
The abbreviation "BAS" on model figures and hydrographs refers to "Baseline" simulation scenario results. Additional abbreviations for other scenarios (such as P1 for extraction Phase 1) are described in Section 3.4.

Simulation Type:
As noted in Section 2.3, both long-term steady state and transient simulations were completed. Steady state results are described as "average" conditions on maps. Transient GSFLOW simulation results, usually presented as hydrographs (of water levels or flows), are referred to with the "GSE" prefix.

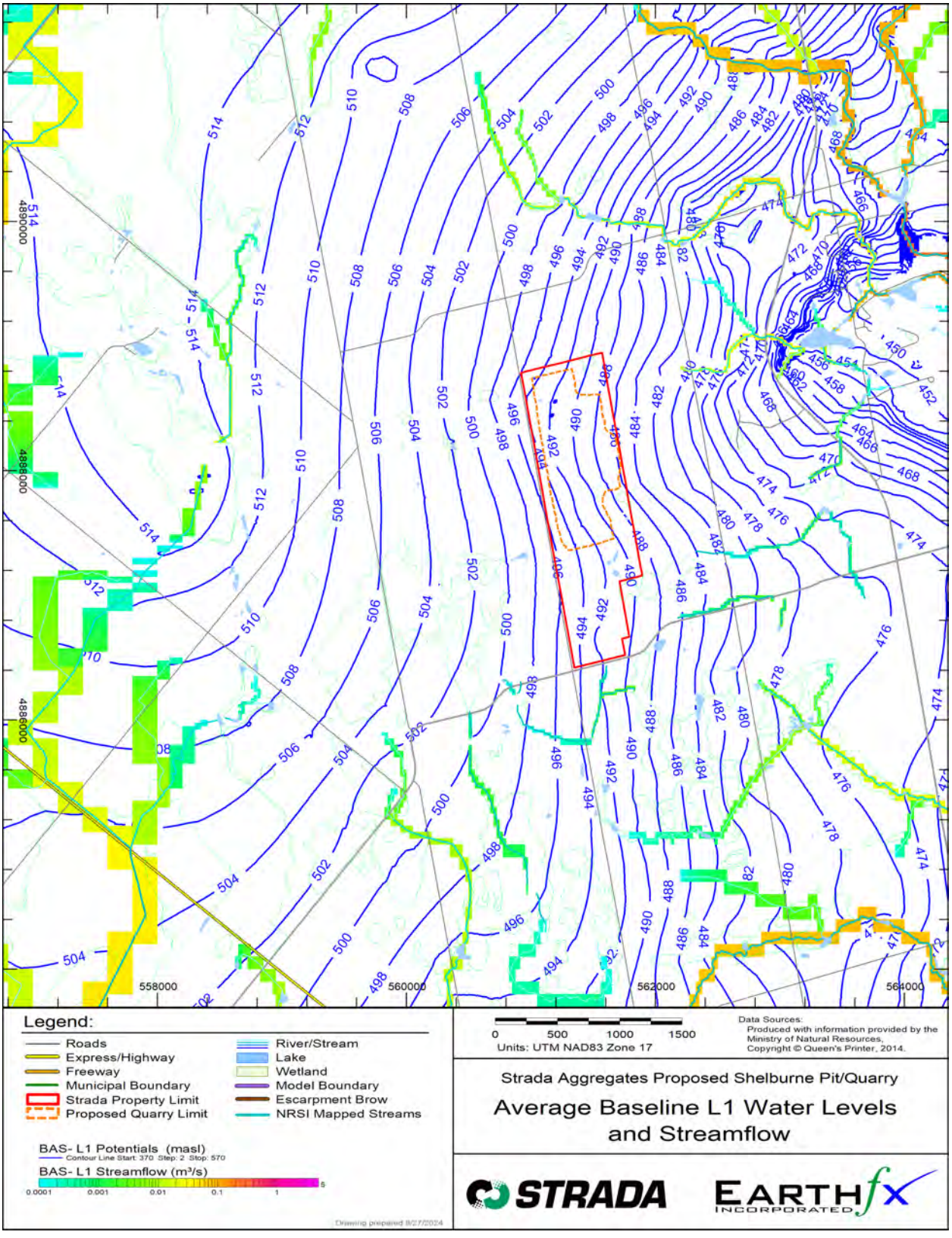


Figure 2.3: Average Baseline Layer 1 Water Table and Streamflow

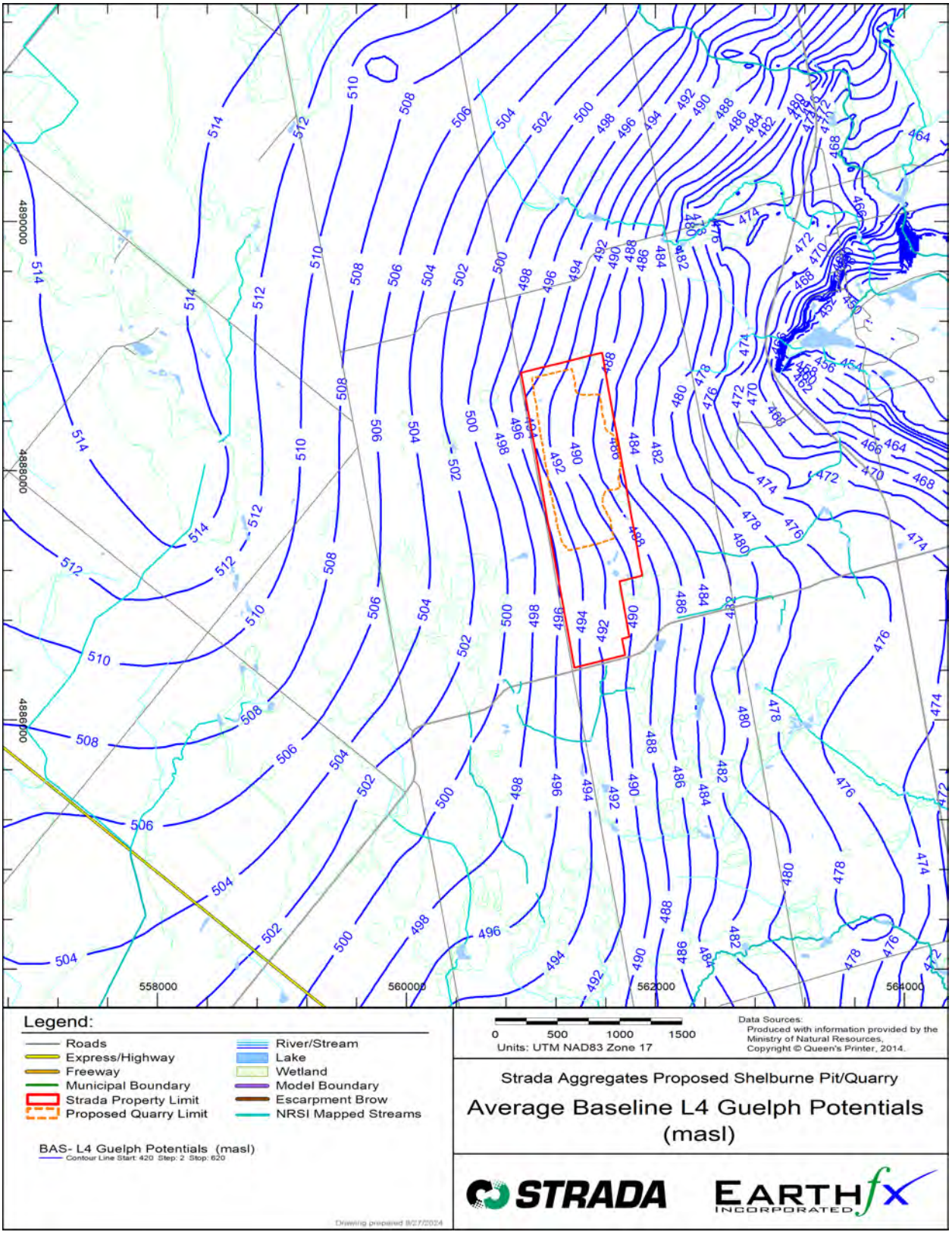


Figure 2.4: Average Baseline Guelph Formation Water Levels

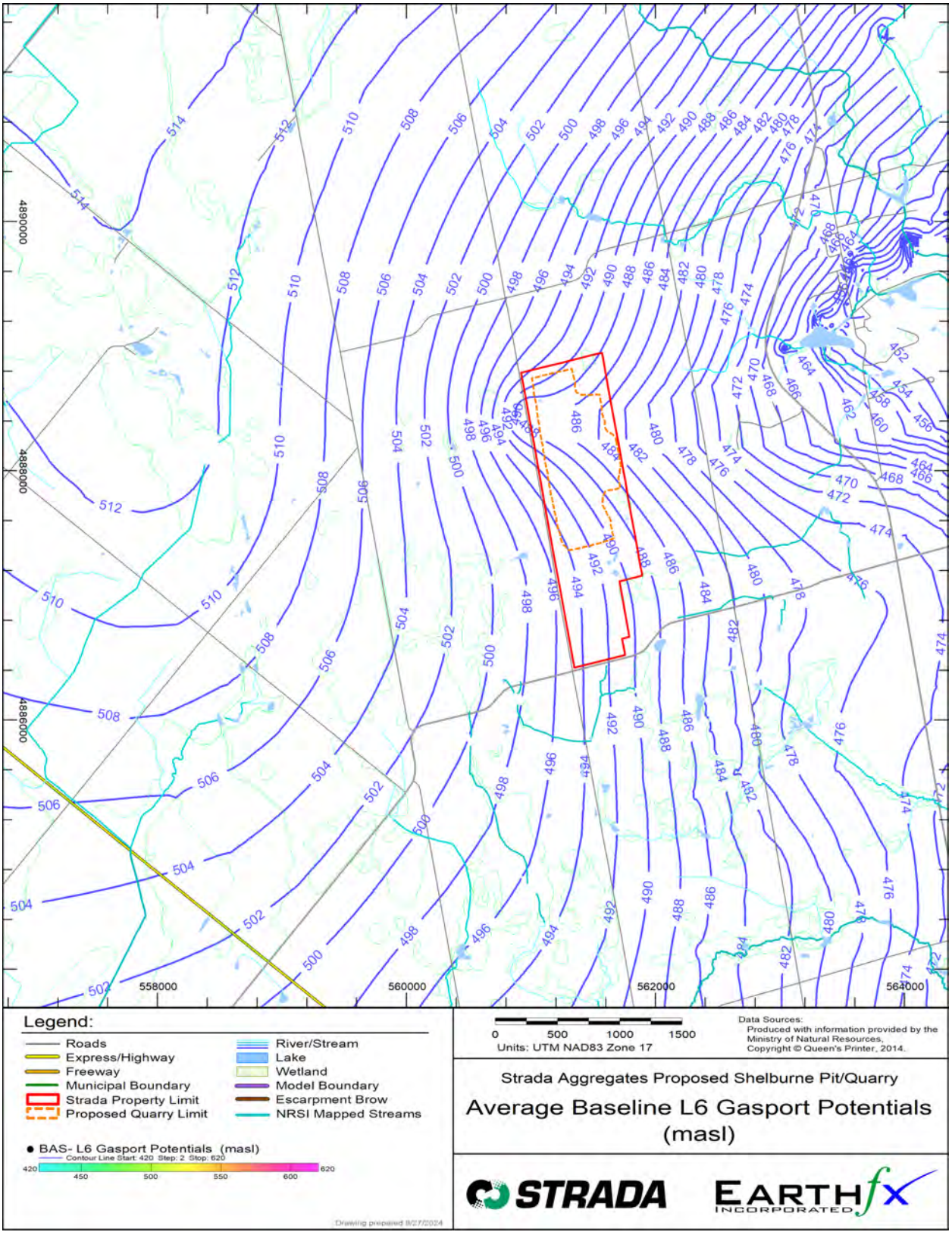


Figure 2.5: Average Gasport Formation Water Levels

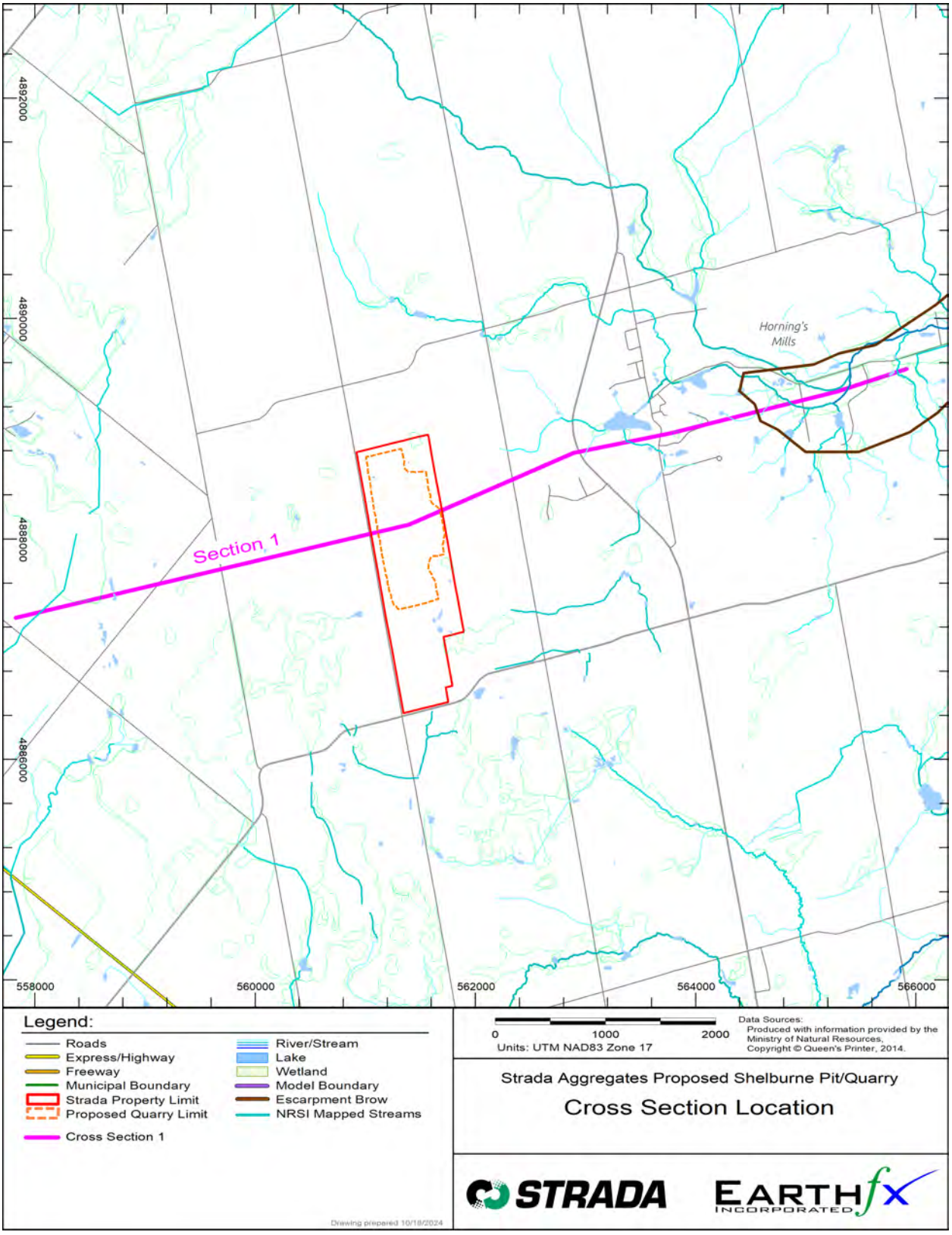


Figure 2.6: Cross Section Location

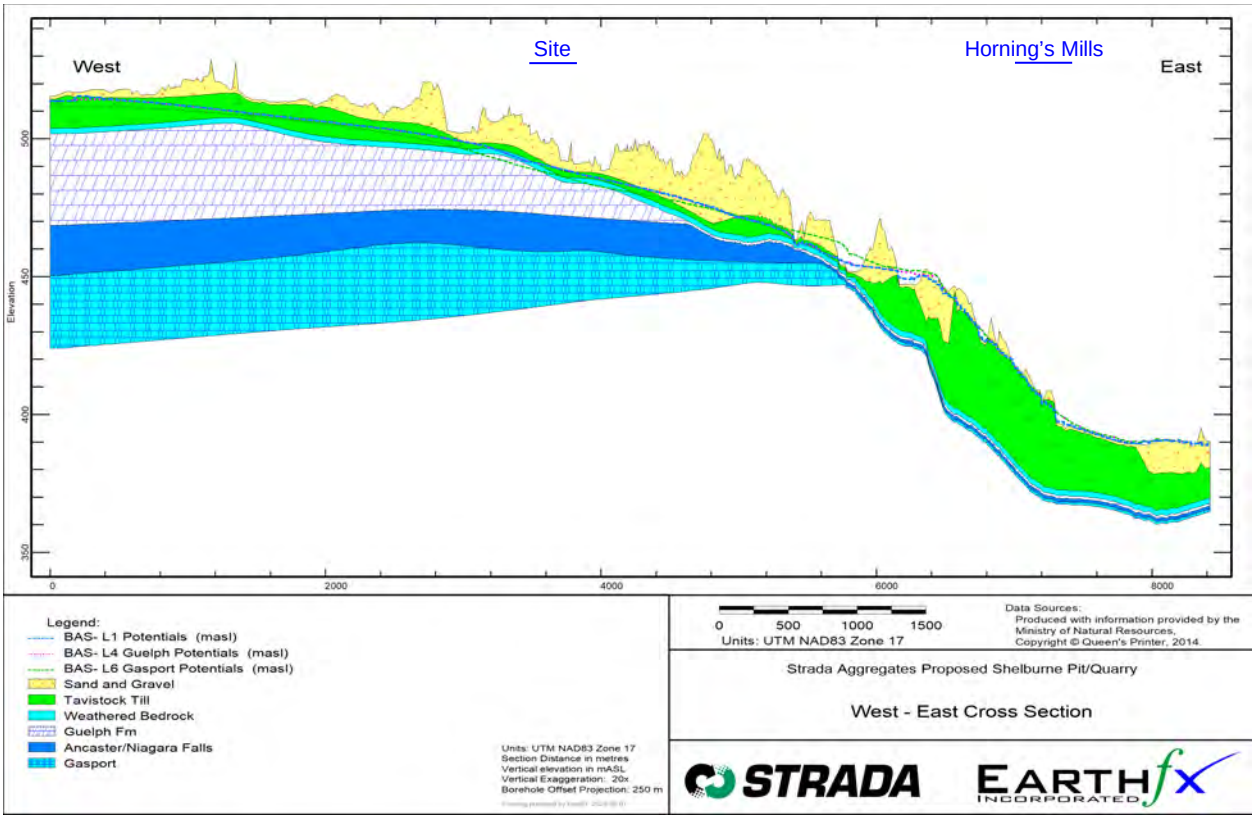


Figure 2.7: West - East Cross Section with Baseline Water Levels

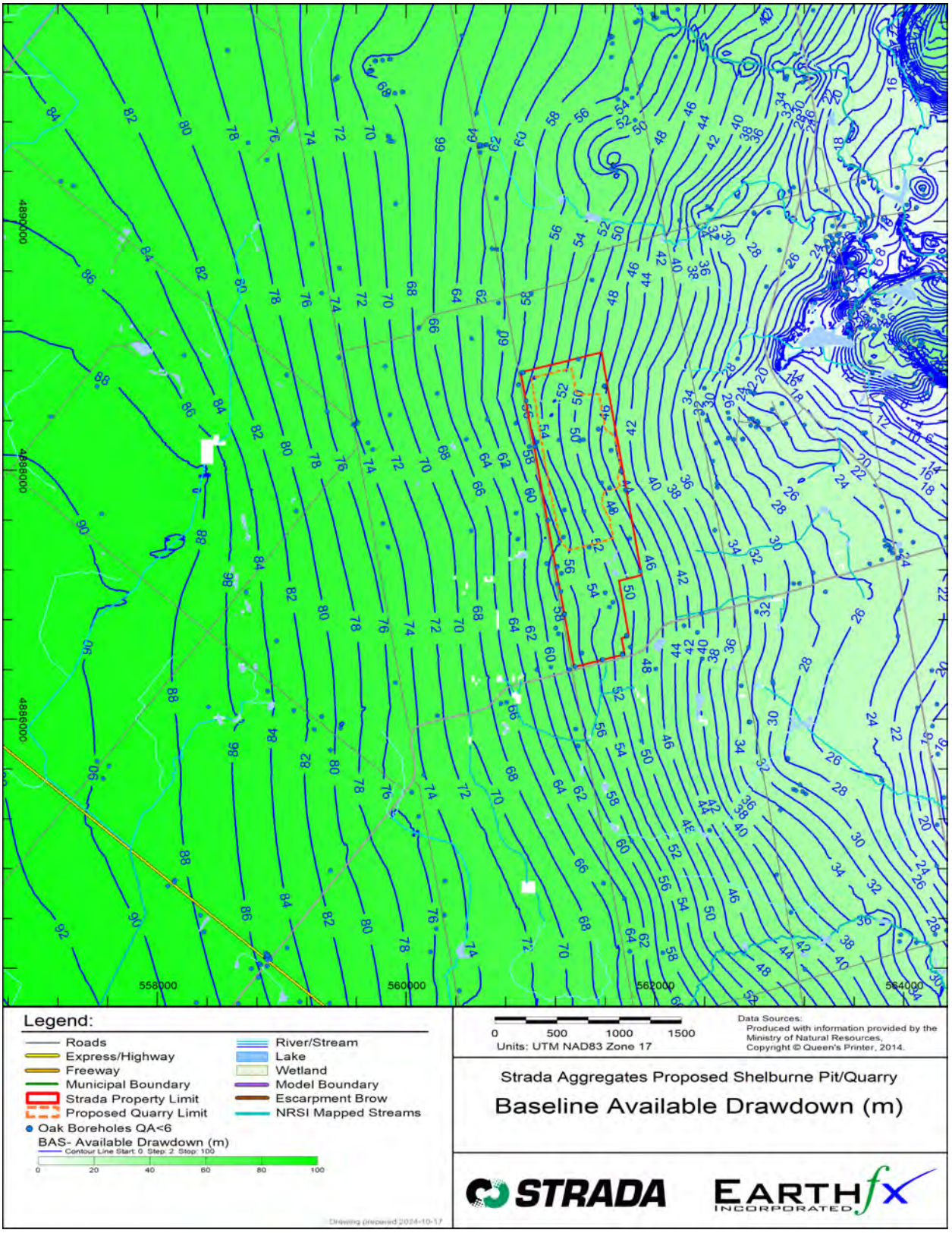


Figure 2.8: Baseline Available Aquifer Drawdown (m) above the Cabot Head formation (Note: only MECP boreholes with a QA accuracy code of less than 6 are shown)

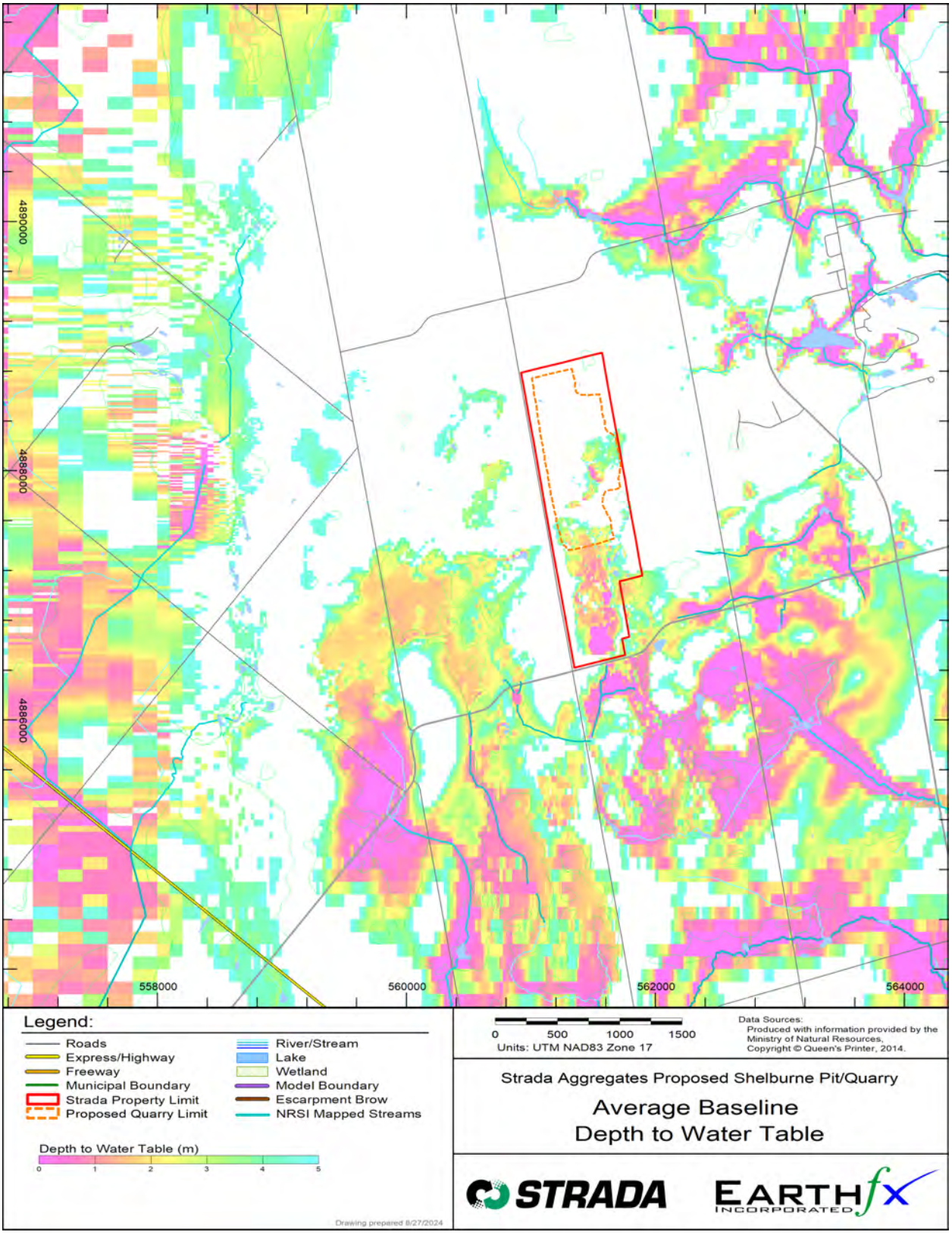


Figure 2.9: Average Baseline depth to Water Table (White is > 5 m to water table)

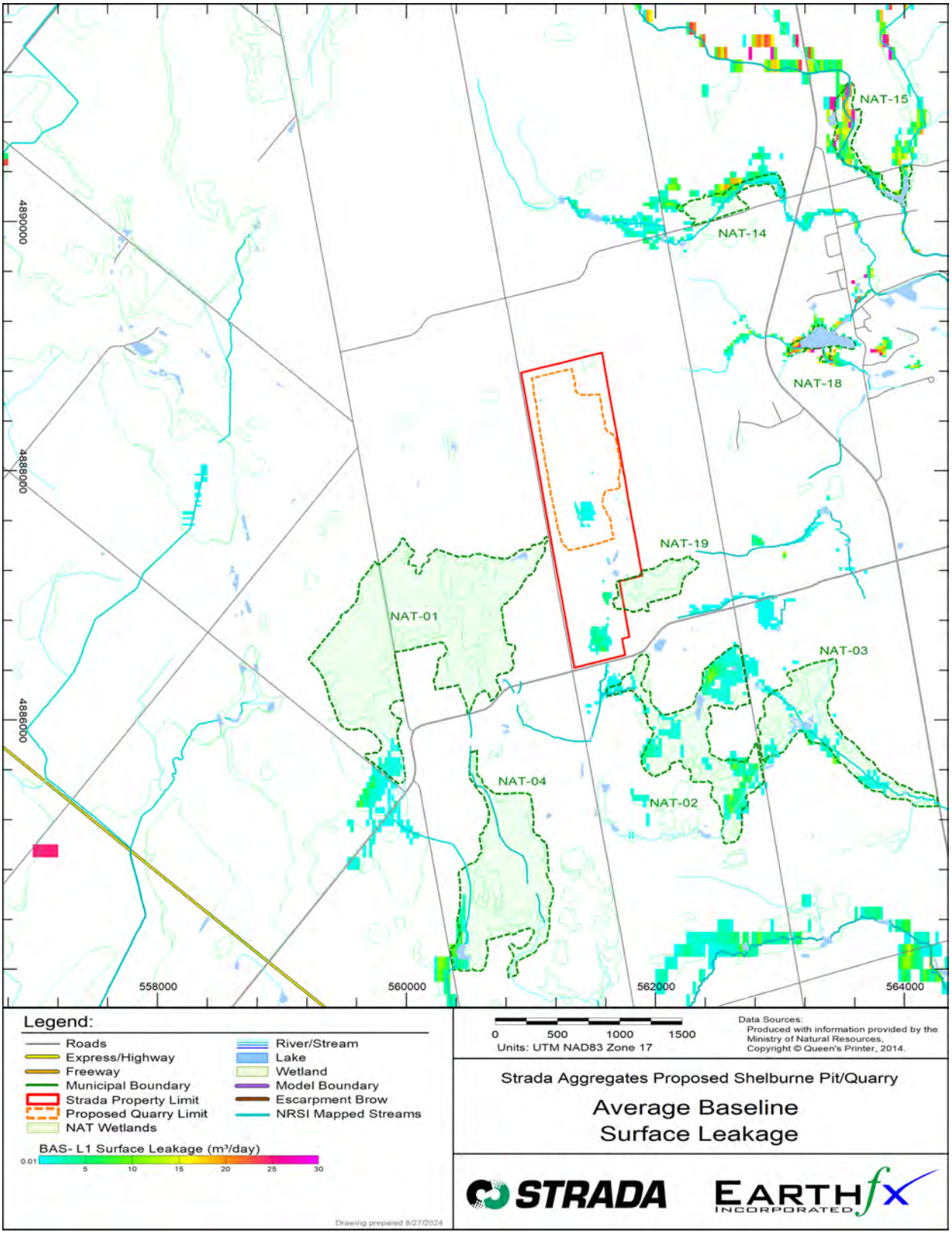


Figure 2.10: Average Baseline Groundwater seepage to surface wetlands.

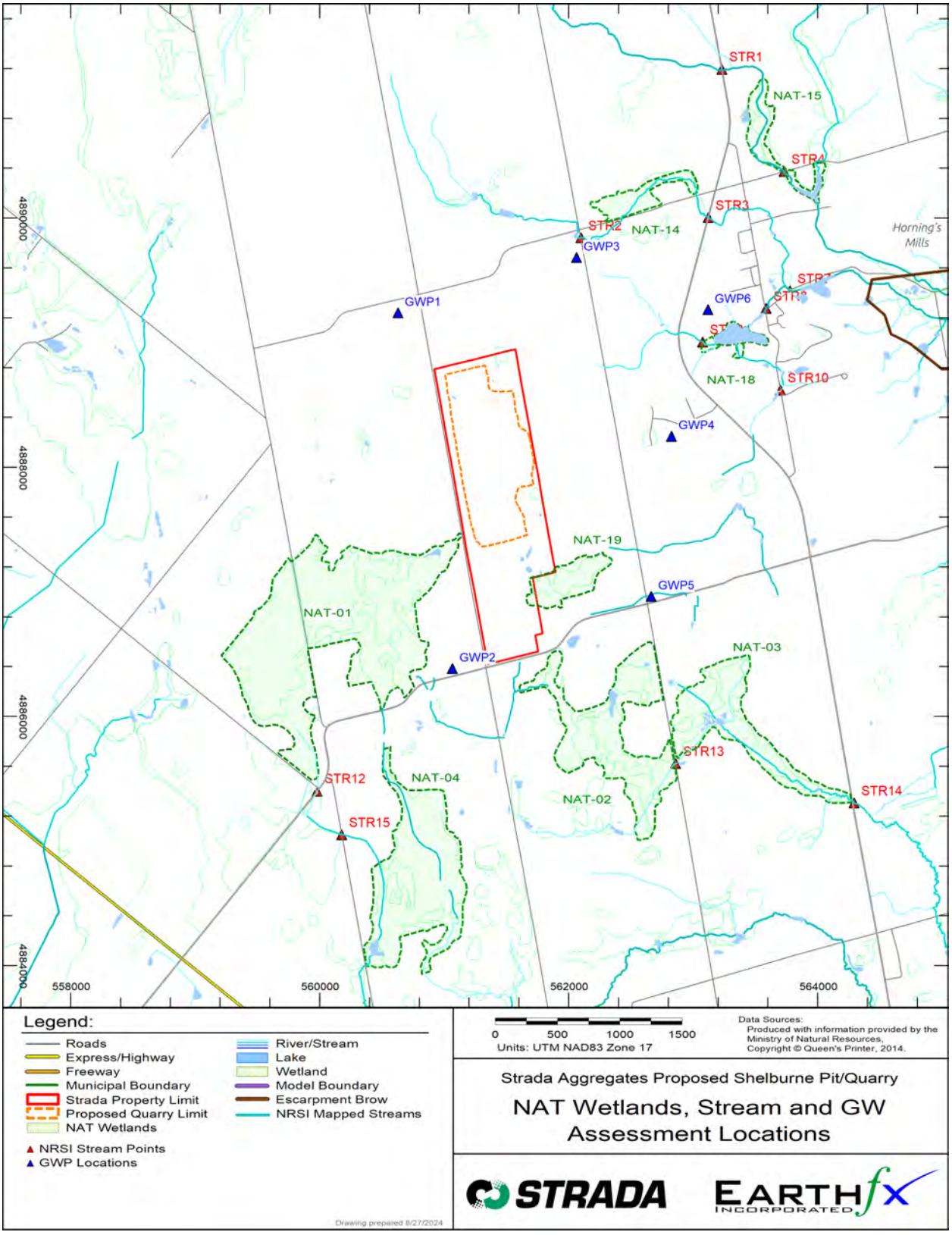


Figure 2.11: NAT Wetlands, NRSI Stream Points (STR) and Groundwater Assessment points (GWP)

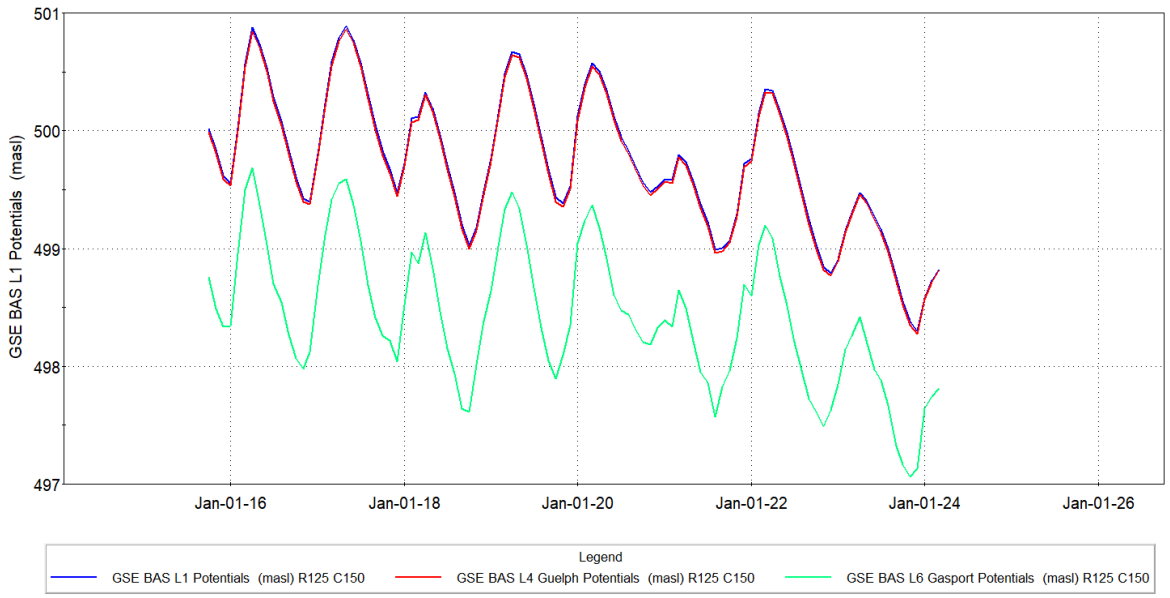


Figure 2.12: GSFLOW Baseline (GSE BAS) water levels at location GWP1 (Model Row 125 and Column 150) for Overburden (L1), Guelph (L4), and Gasport (L6) aquifer units.

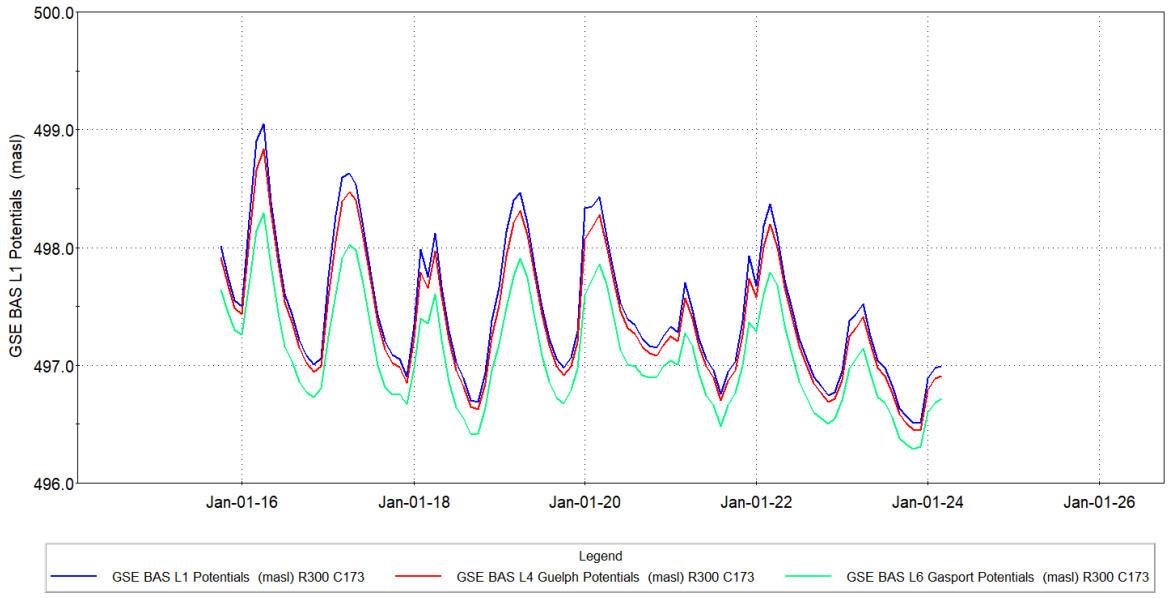


Figure 2.13: Baseline water levels at location GWP2 for Overburden (L1), Guelph (L4), and Gasport (L6) aquifer units.

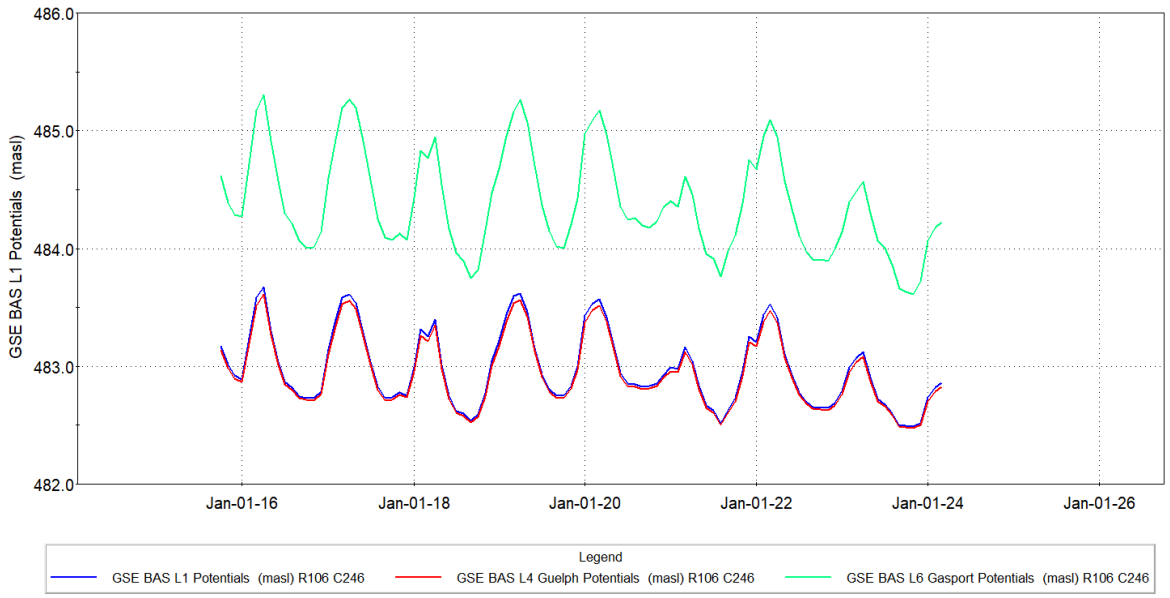


Figure 2.14: Baseline water levels at location GWP3 for Overburden (L1), Guelph (L4), and Gasport (L6) aquifer units.

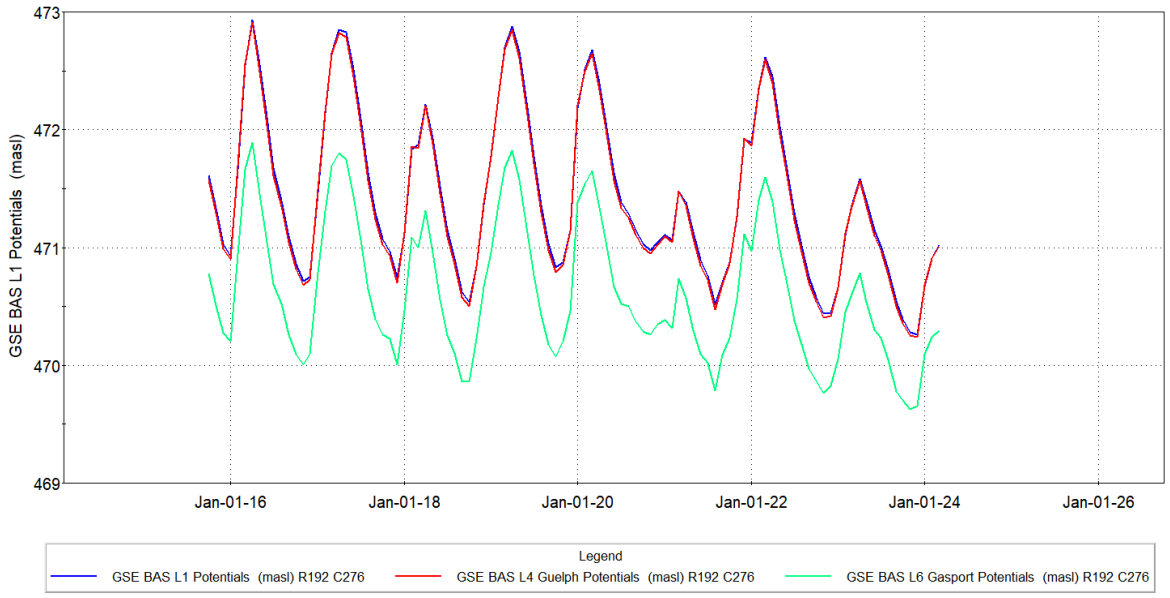


Figure 2.15: Baseline water levels at location GWP4 for Overburden (L1), Guelph (L4), and Gasport (L6) aquifer units.

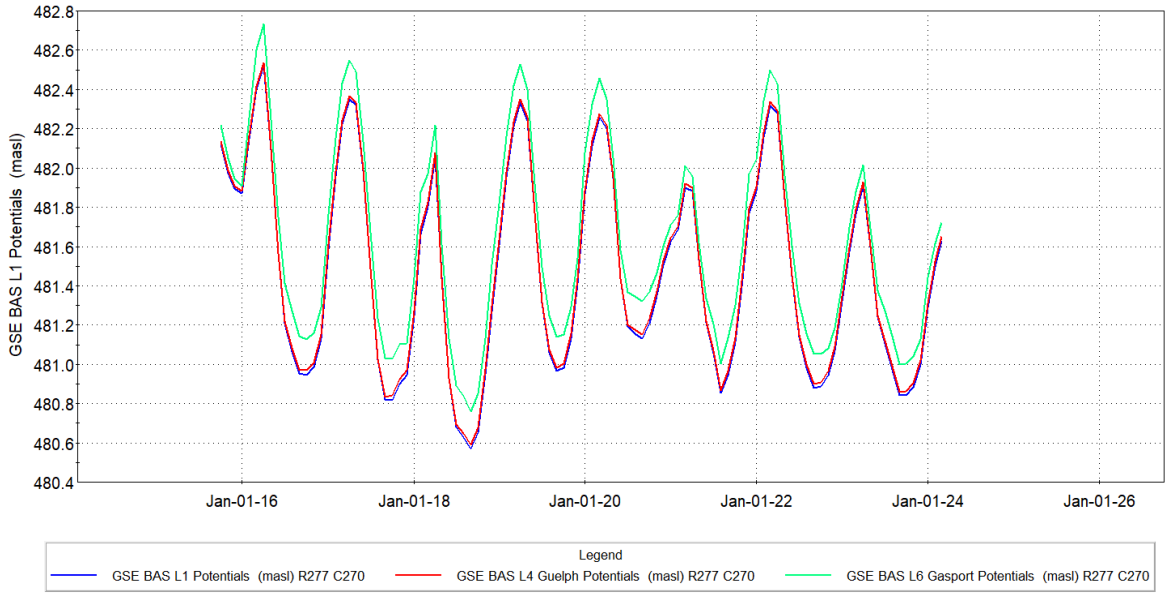


Figure 2.16: Baseline water levels at location GWP5 for Overburden (L1), Guelph (L4), and Gasport (L6) aquifer units.

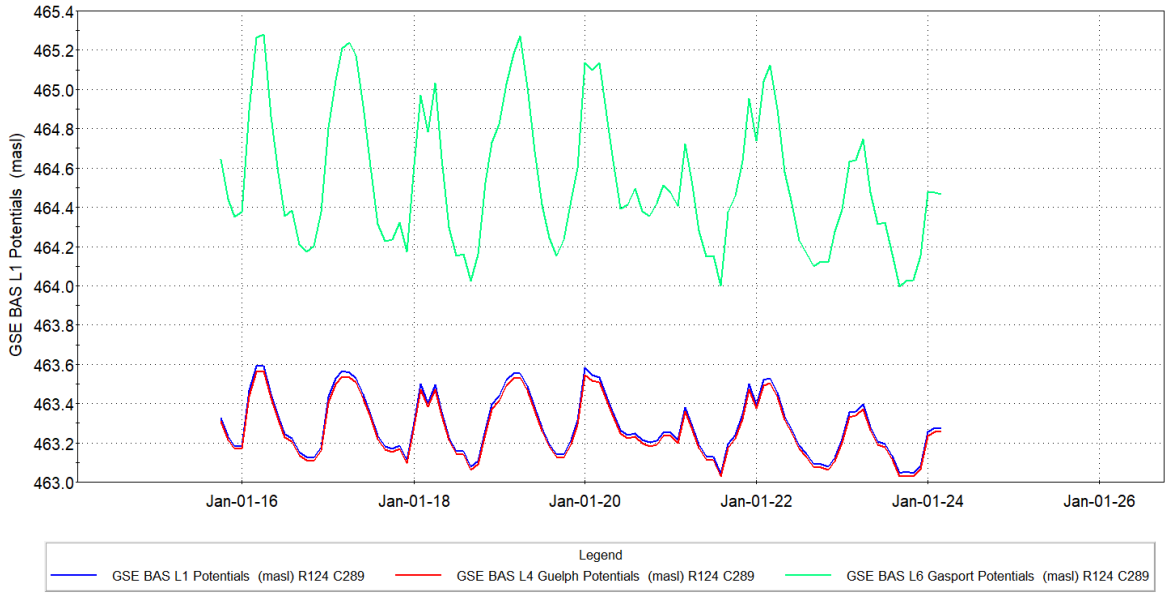


Figure 2.17: Baseline water levels at location GWP6 for Overburden (L1), Guelph (L4), and Gasport (L6) aquifer units.

2.5 *Surface Water Flows*

The numerical model provides total simulated streamflow for every stream reach. A set of common assessment points were selected for the Baseline and future conditions comparative analyses. These locations, shown on Figure 2.11, are located at a range of distances from the proposed quarry extraction area.

The average streamflow is shown spatially in Figure 2.3. The cell color intensity is proportional to the flow in the stream, and flows range from 0.0001 m^3/s to 5.0 m^3/s. Note that some stream reaches are not color visible where the stream enters a large wetland and the channel is not mapped or evident.

2.5.1 Streamflow South of Proposed Pit/Quarry

Figure 2.18 shows the simulated transient streamflow for the baseline period at 4 locations south of the proposed quarry. Location STR12 is upstream of STR15, and location STR13 is upstream of Location STR14. Note that summer flows are very low at all locations.

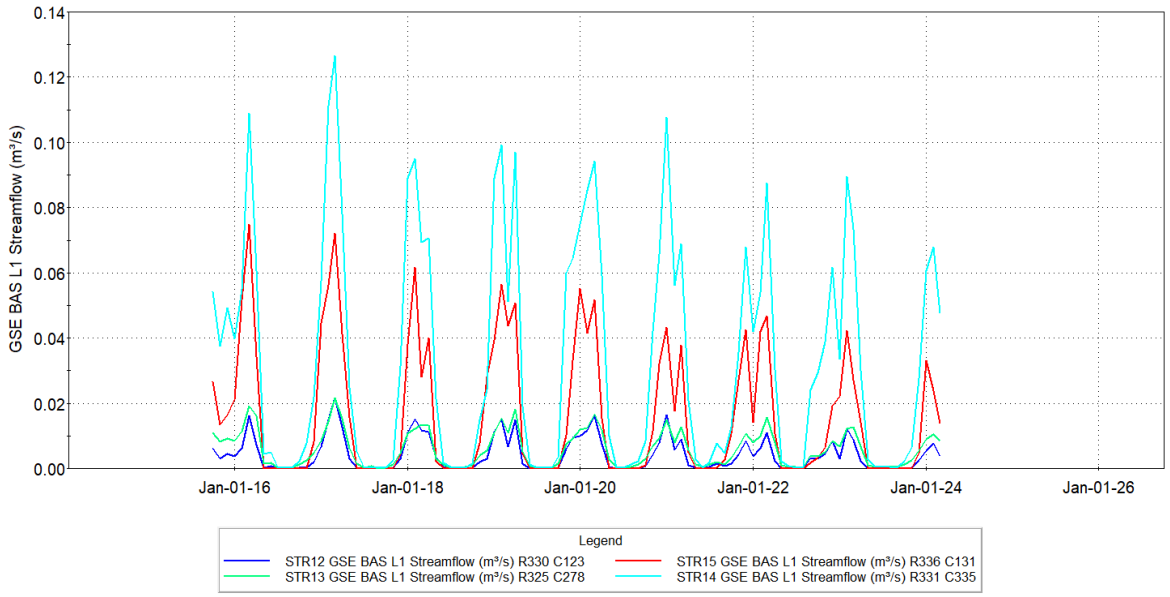


Figure 2.18: Baseline Surface Water flows at Stream locations south of the site

The relationship between streamflow and surface leakage into the large wetlands in this area is discussed in more detail in the next section.

2.5.2 Streamflow and Surface Discharge near Horning's Mills

The average streamflow near Horning's Mills is shown in Figure 2.19. Stream reaches STR9 and STR10 flow into a dammed pond (NAT-18) west of the town center (refer to the NRSI companion report for a discussion of the pond and dam). The streamflow hydrograph suggests that STR10 is intermittent and contributes little to the pond water budget (Figure 2.20), while STR9 contributes more flow.

The stream riparian areas and the pond permitter also receive surface discharge, as illustrated in Figure 2.21. The total flow out of the pond (including stream inflows and surface leakage) is shown at location STR8 (Figure 2.20). Flow at downstream STR7 (Figure 2.20) represents the cumulative flow from the pond and a northern tributary. Note that portions of the stream, below the pond dam, pass under the road and are difficult to evaluate.

Streamflow from the northern tributary passes through location STR3 and STR4 to STR7 (Figure 2.22). The contribution from surface discharge is illustrated in Figure 2.21. This reach and wetland area receives considerable surface discharge (Figure 2.21), and are further affected by ponds and a fisheries operation with a permitted surface water taking.

For comparison, seasonal groundwater level fluctuations in the area are illustrated in Figure 2.14, Figure 2.15, and Figure 2.17. The groundwater fluctuations drive the surface leakage process in the area, and changes in groundwater levels will be evaluated to better understand quarry development effects.

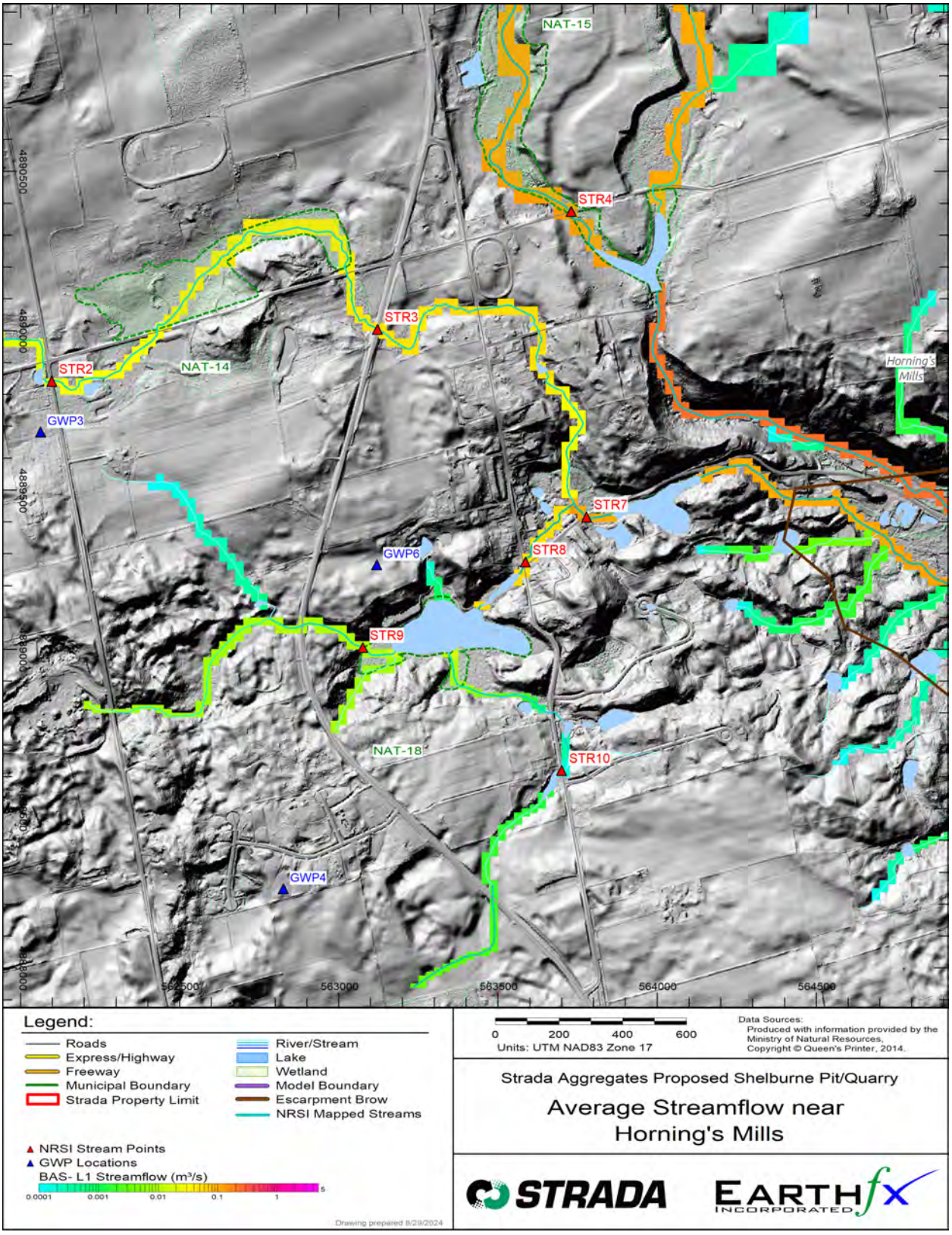


Figure 2.19: Average streamflow near Horning's Mills

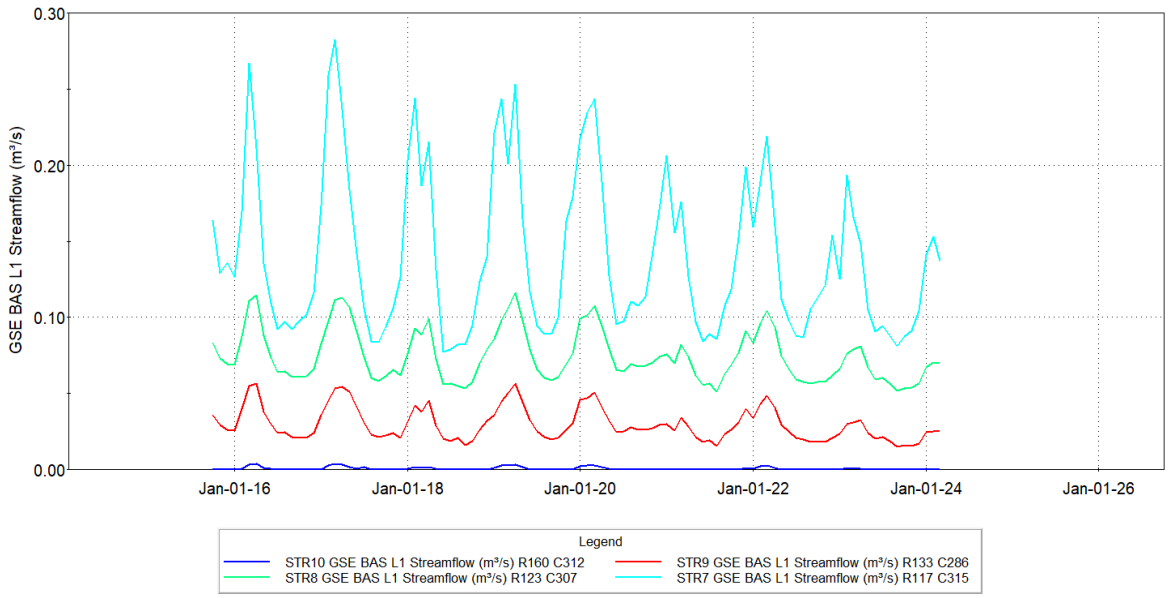


Figure 2.20: Baseline surface water flows at stream locations (STR) near Horning's Mills

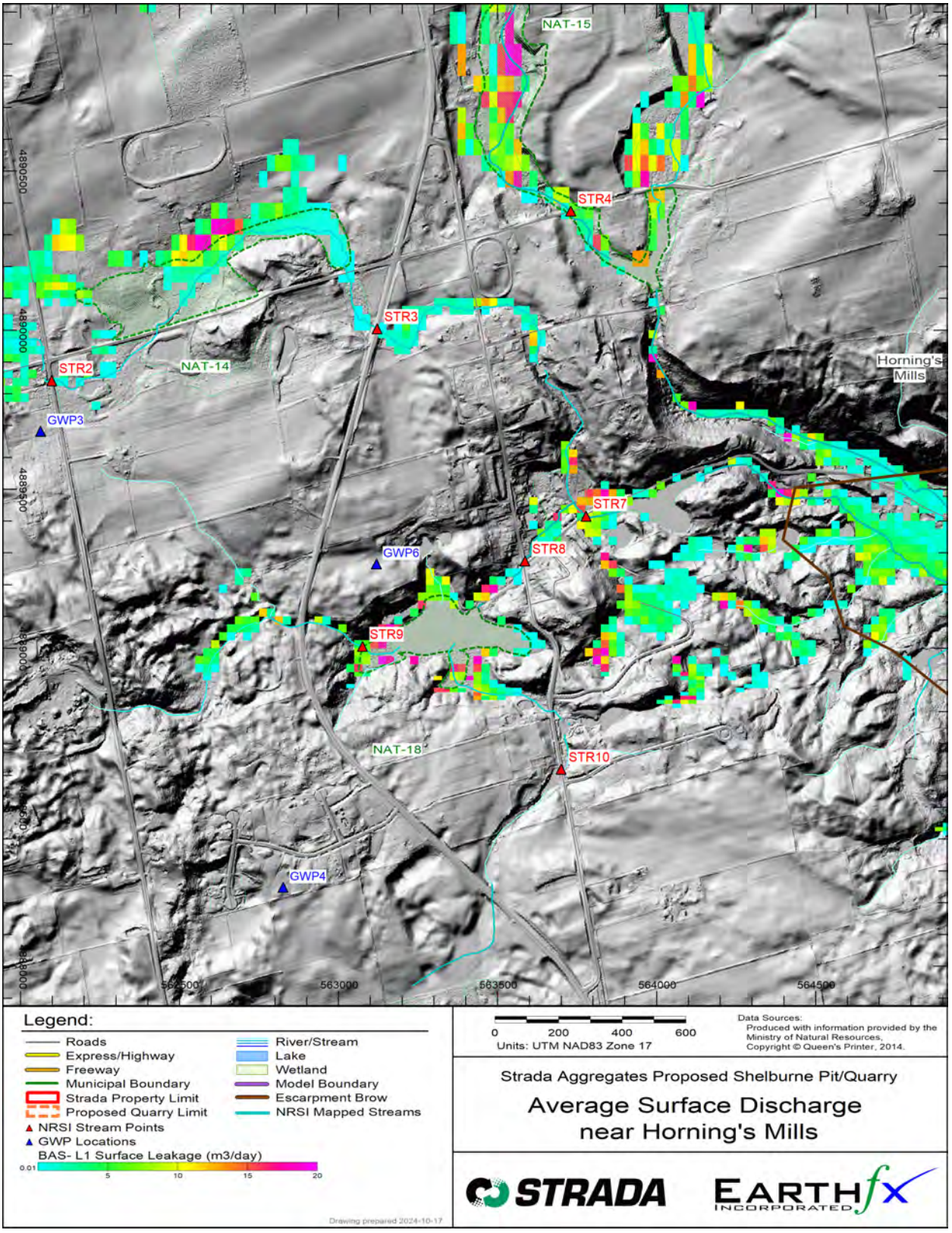


Figure 2.21: Average surface leakage near Horning's Mills

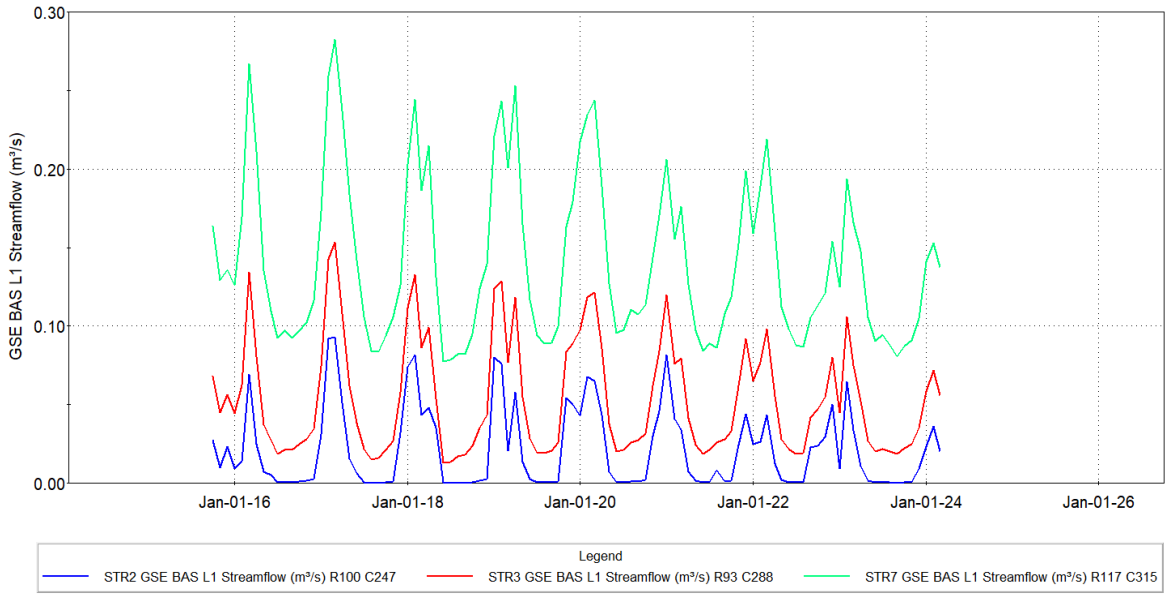


Figure 2.22: Baseline surface water flows at stream locations (STR) north-east of the site

2.6 *Wetlands*

A set of Priority Natural Features (hereafter referred to as NAT complexes, and labelled as NAT-XX) were identified by NRSI as part of their impact assessment (NRSI, 2024, Section 1.1). The location of these features is shown Figure 2.11 and they are described in detail in the NRSI report.

As noted above, the large wetlands south of the proposed pit/quarry interact with the groundwater system. The depth to water table map (Figure 2.9) provides some insight into the interaction, but seasonal fluctuations must also be considered. The distribution of the Tavistock Till beneath the wetlands is also highly variable and can significantly limit interaction. Extensive analysis of wetland conditions and impacts have been simulated, and key wetlands with groundwater interactions are discussed in this report.

The wetlands receive inflows from multiple surface and groundwater processes. Each of these flow components are evaluated in the detailed wetland water budgets (presented below), but surface discharge (groundwater seepage) is perhaps one of the most insightful parameters, particularly in headwater wetlands with little stream inflow.

The stream flow and surface discharge maps presented in Figure 2.19 and Figure 2.21 illustrate the average conditions in Wetland NAT14, NAT15 and NAT18. The streams and pond discussed in Section 2.5.2 includes a more balanced inflow of streamflow and surface discharge.

The average surface discharge to the large wetlands south of the property (NAT-02 and NAT-03) is shown in Figure 2.23. These are “headwater” wetlands so they have little stream inflow, and receive significant inflow from groundwater seepage. The surface discharge in a wet month such as April 2019 is shown in Figure 2.24 and illustrates extensive areas of seepage. At the other extreme of climate conditions, a period of low surface discharge in July 2018 is shown in Figure 2.25, with almost no surface discharge.

Average surface discharge to the streams and wetlands north of the property is shown in Figure 2.26. There is no discharge to any features to the north west, however there is groundwater discharge to the riparian area upstream of STR2, which is agreement with the surface water and groundwater permit downstream of STR2. Of interest to the fish farm near STR2, flow in the surface streams and inferred subsurface karst features is shown in Figure 2.27. The karst feature provides cold water discharge that likely supports the aquaculture. Flows under baseline, operations and rehab conditions at that location are discussed in Section 3.9.2.

A hydrograph comparing the total surface discharge into a number of NAT wetlands is shown in Figure 2.28. Most of the wetlands, with the exception of the NAT-18 dammed pond, exhibit large natural seasonal variation in total surface discharge. As discussed above in Section 2.5.2, the NAT-18 pond is located in an area of regional groundwater discharge which likely explains why the groundwater seepage is relatively more stable across the seasonal and inter-annual climate variation.

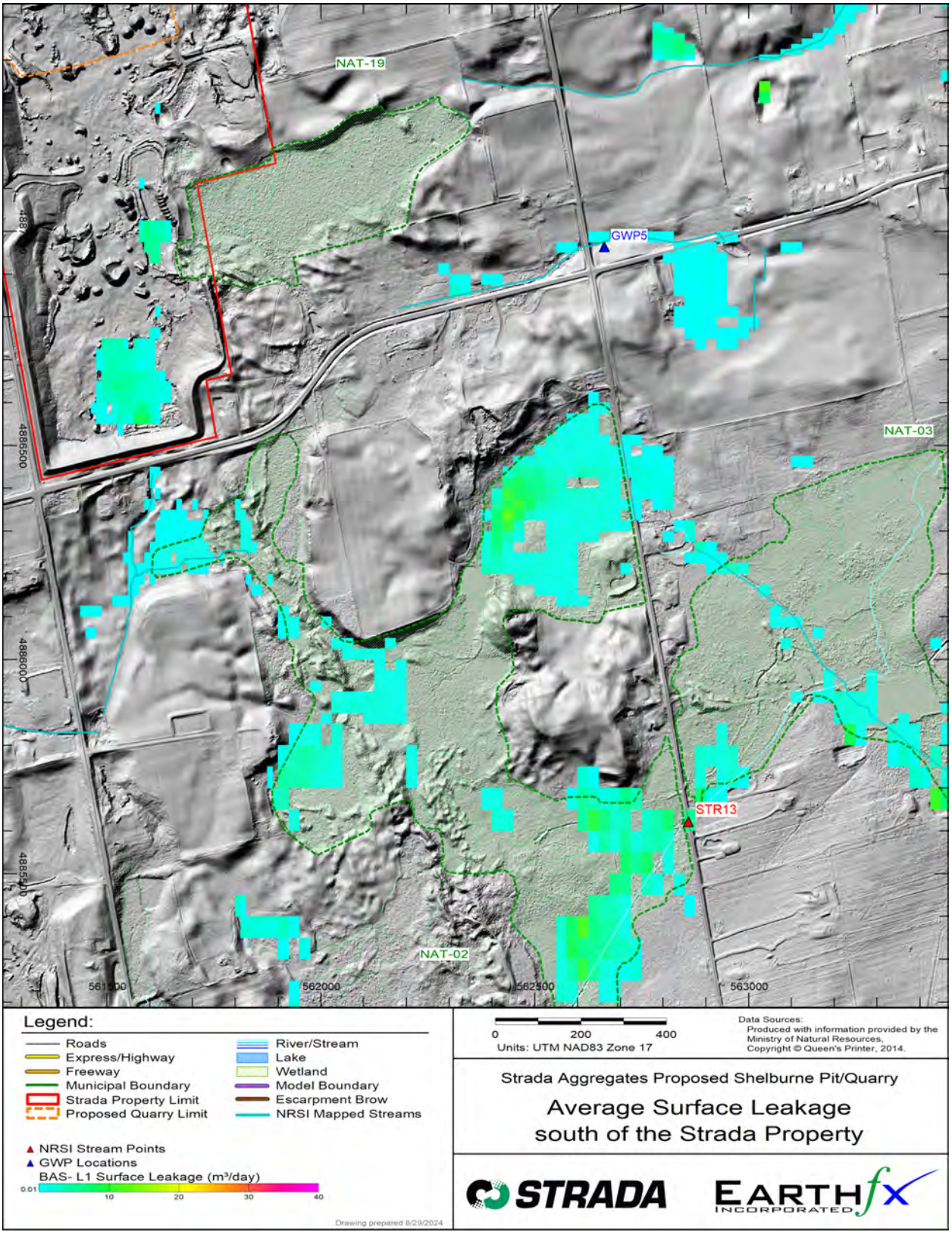


Figure 2.23: Average surface leakage south of the Strada property

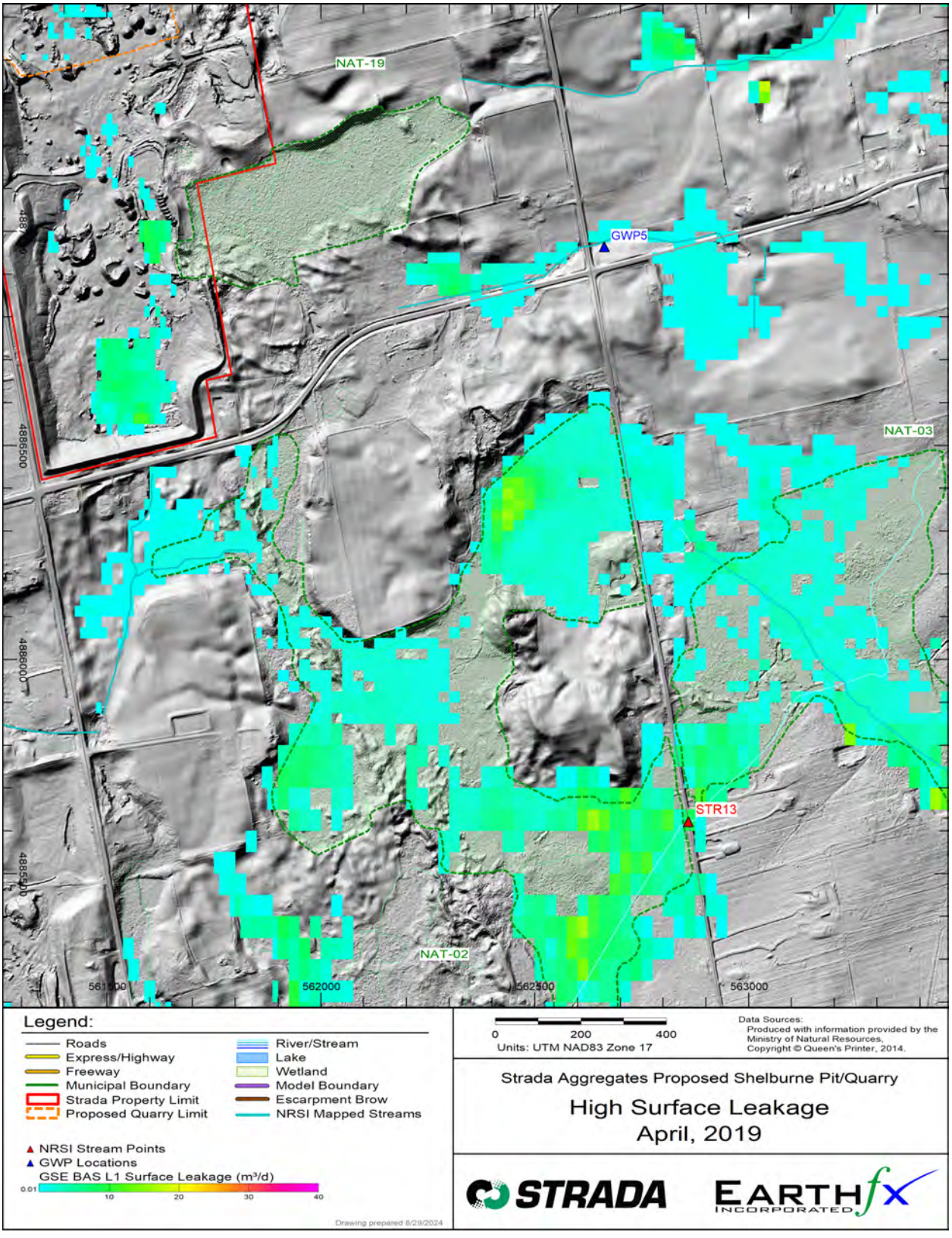


Figure 2.24: High surface leakage in April 2019 south of the Strada property

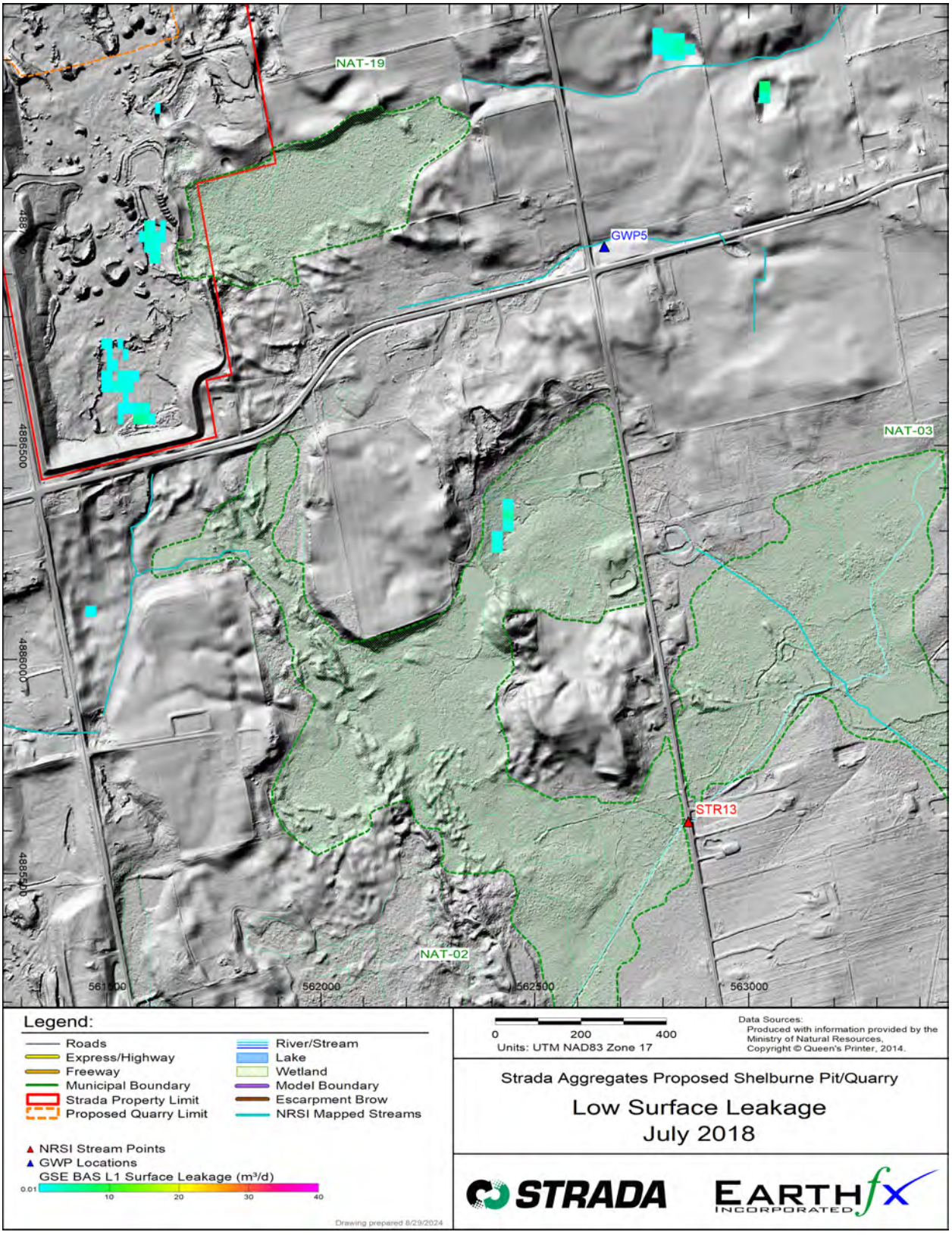


Figure 2.25: Low surface discharge in July 2018 south of the Strada property

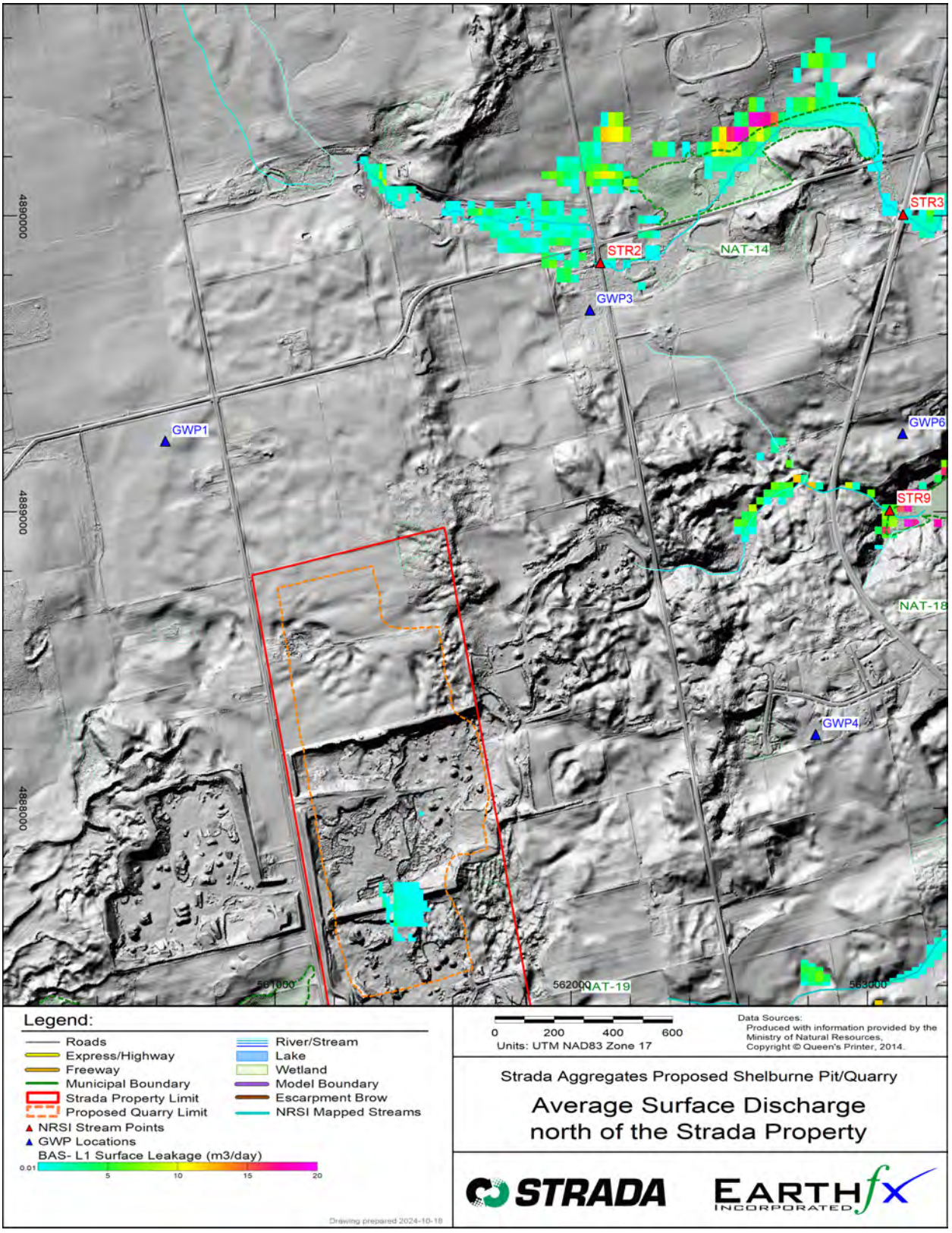


Figure 2.26: Average surface leakage north of the Strada property

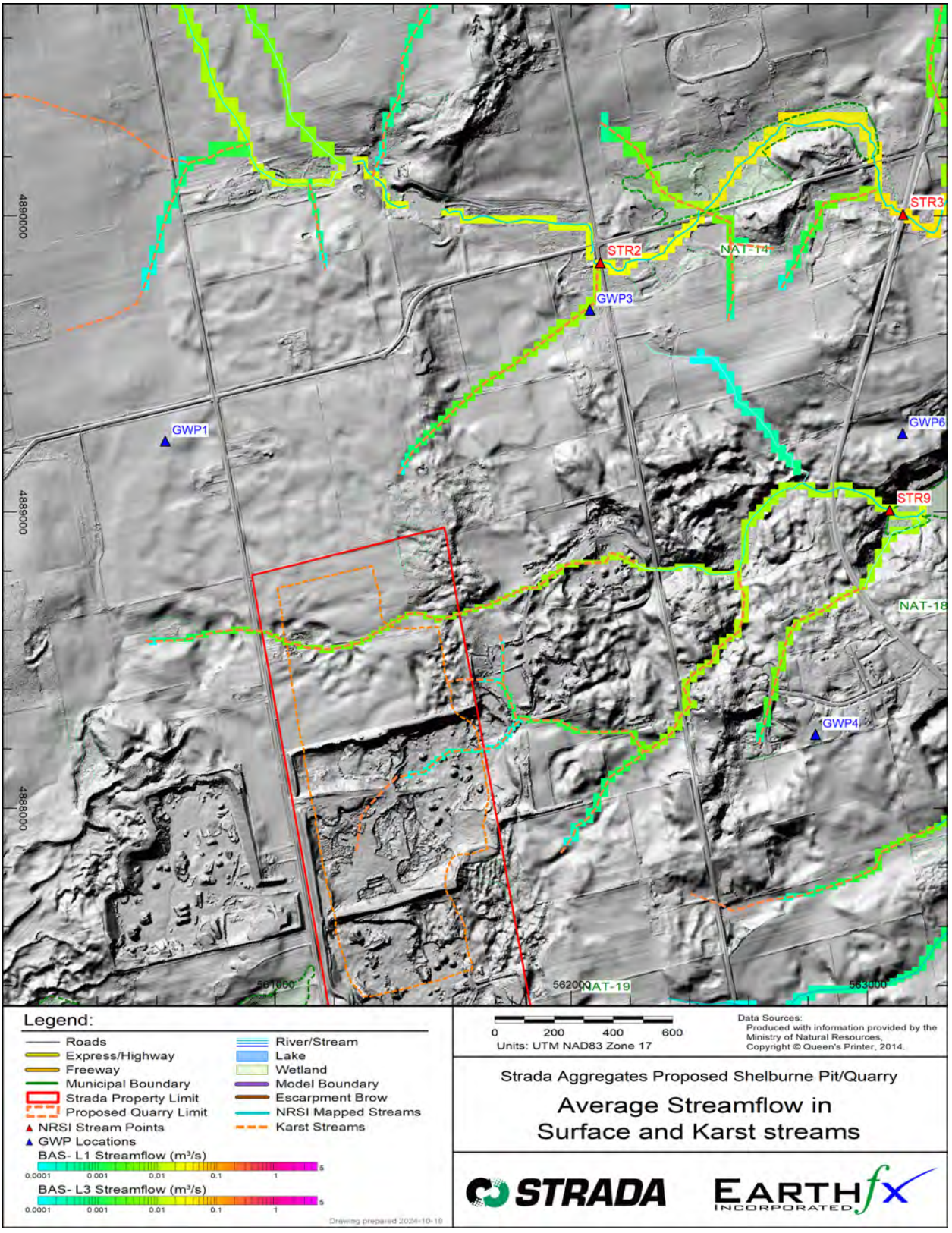


Figure 2.27: Average streamflow in surface streams and subsurface karst segments (dotted orange lines)

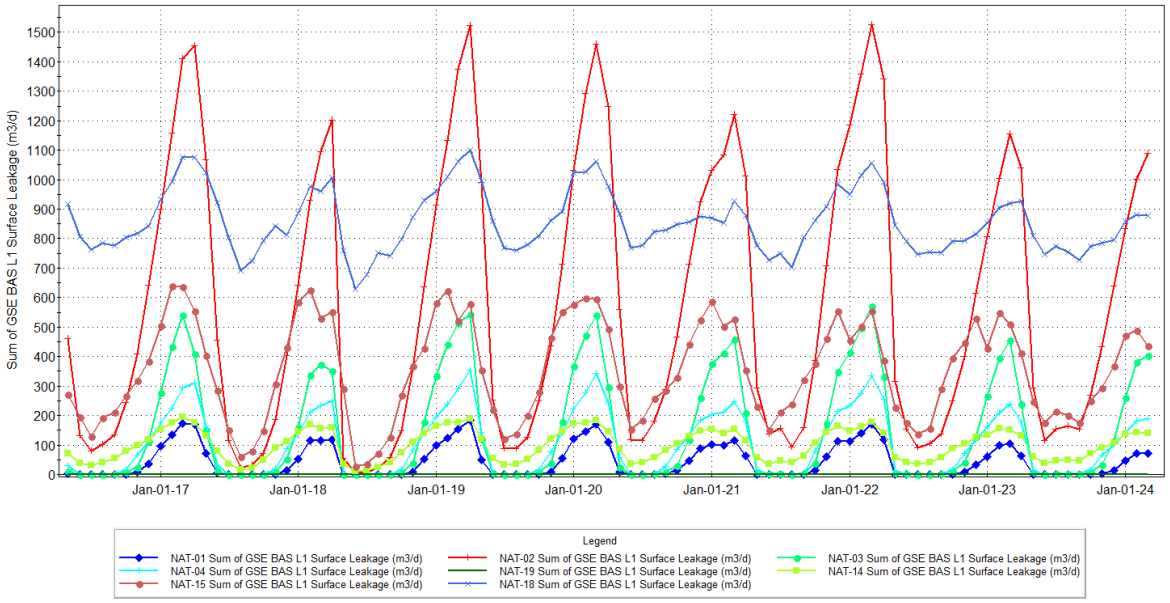


Figure 2.28: Hydrograph of total surface leakage into various NAT wetlands. GSE BAS: GSFLOW of Baseline conditions.

2.6.1 **Wetland Water Budgets**

There are eight NAT wetlands within the study area (locations are shown in Figure 2.29). Detailed feature-based water budgets were calculated to analyze the inflows and outflows to these local features.

The integrated water budgets presented here supplement and complement the natural heritage investigations and analysis provided under separate cover (NRSI, 2024)

The Earthfx GSFLOW post-processor was used to compute all flows within each area as well as lateral groundwater flow, streamflow, overland runoff, and interflow crossing the wetland boundaries. The water budgets presented here are in terms of monthly averages based on processing 10 years of daily values. The monthly averages help to capture the seasonal variability in the flow. The water budgets have been simplified in the sense that several of the 58 reported components have been combined for the summary tables presented here. The baseline water budgets are presented in separate monthly water budget bar charts and summary tables for surface water and groundwater.

Overall, the main components of the surface water budgets appear to be relatively similar. Rates of precipitation are nearly identical. Some of the precipitation is added to the snowpack during winter months. The snow pack serves as a mechanism to store water in one month and carry it over to succeeding months where it appears as snowmelt. Amounts of snow accumulation and melt are relatively similar but can differ slightly due to the density and type of vegetative cover in the area. Rates of groundwater recharge, soil evapotranspiration (ET), and interception/sublimation also are relatively similar due to the similarity in vegetation type, and soil properties assigned to wetland areas. Runoff to streams can differ based on topography within the wetland, the cascade flow network, and the stream network within the wetland. Rates of runoff into the wetland depend on topography and soil conditions upslope of each wetland. Runoff into the wetland is a significant component of the total flow to wetlands NAT-03 but a smaller component of the water budget in the other wetlands.

The groundwater budgets show much more variability between wetlands. Wetland NAT-19 shows limited groundwater ET under baseline conditions indicting a deeper water table (about 2 m below surface) than other wetlands. Wetland NAT-01 shows higher groundwater ET as well as surface leakage (i.e. groundwater discharge to the soil surface) indicating a water table above land surface during the winter months. Surface discharge is decreased in the other months as recharge decreases and groundwater ET increases. The remaining wetlands all show year-round surface discharge indicating a high-water table and a large degree of interaction with the groundwater system. Wetland NAT-18 is unusual in that there is no groundwater recharge occurring

The size of the wetland areas is not altered in any of the future-conditions scenarios, so most components of the surface water budget do not change as the pit/quarry is developed and then rehabilitated. Runoff generated within the contributing area to the wetlands does change in some scenarios, so there can be more or less runoff crossing the wetlands boundaries. Reduced runoff can lead to decreased infiltration, groundwater recharge, soil ET, and runoff to streams.

Groundwater budgets are expected to change to varying degree under future conditions. The changes are relatively small as the proposed on-site water management system is designed to mitigate the effects of development. The proposed water management system and detailed surface water and groundwater budgets are presented in Section 3. Additional tables are presented showing the change in the water budget components for each of the future-conditions scenarios.

Wetland NAT-18 and Wetland NAT-19, are presented in this section of the report due to their proximity to the site and Horning's Mills. Detailed water budgets for all of the wetlands under Baseline conditions are included in Section 9.

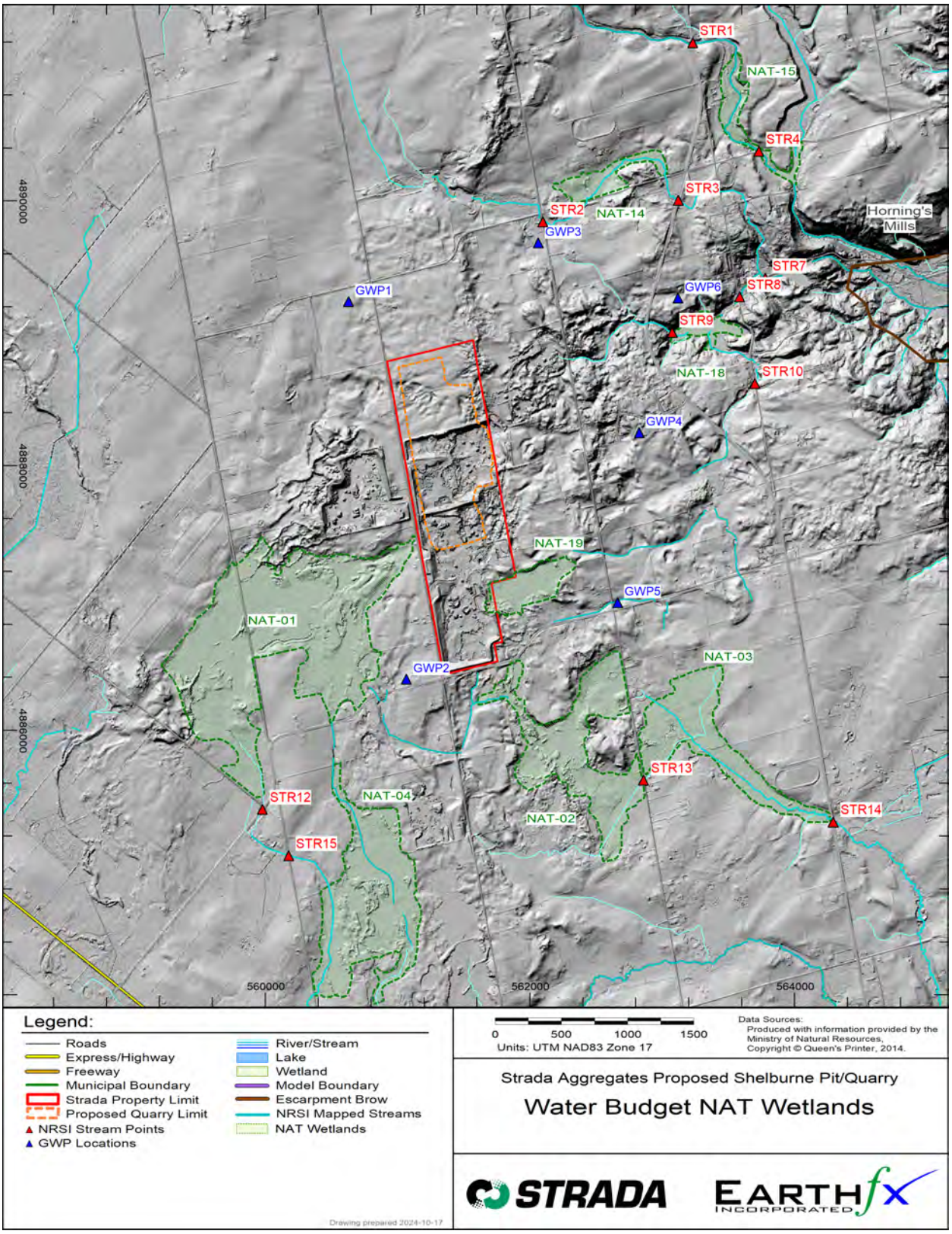


Figure 2.29: Water budget NAT wetland polygons

2.6.1.1 Wetland NAT-18

Wetland NAT-18 is the dammed pond near Horning's Mills as was discussed in Section 2.5.2. The surface water and groundwater components of the water balance are presented as bar charts and tables. Precipitation and snowmelt dominate the surface water inflows (Figure 2.30). High rates of soil zone ET, groundwater recharge, and runoff to streams are the largest outflows. The groundwater budget is dominated by interaction with the lake. The key inflow to the aquifer is the high net lateral inflow across the wetland area boundaries (net lateral inflow represents the difference between lateral inflow and lateral outflow). Groundwater recharge and Inflows from the lake are negligible. The net lake flux represents groundwater discharge to the lake (Figure 2.31). The high rates of surface discharge and groundwater ET indicate a high-water table year-round in the open areas surrounding the lake. Table 2.2 also presents the simulated monthly stream inflows and outflows and lake stage for the baseline conditions.

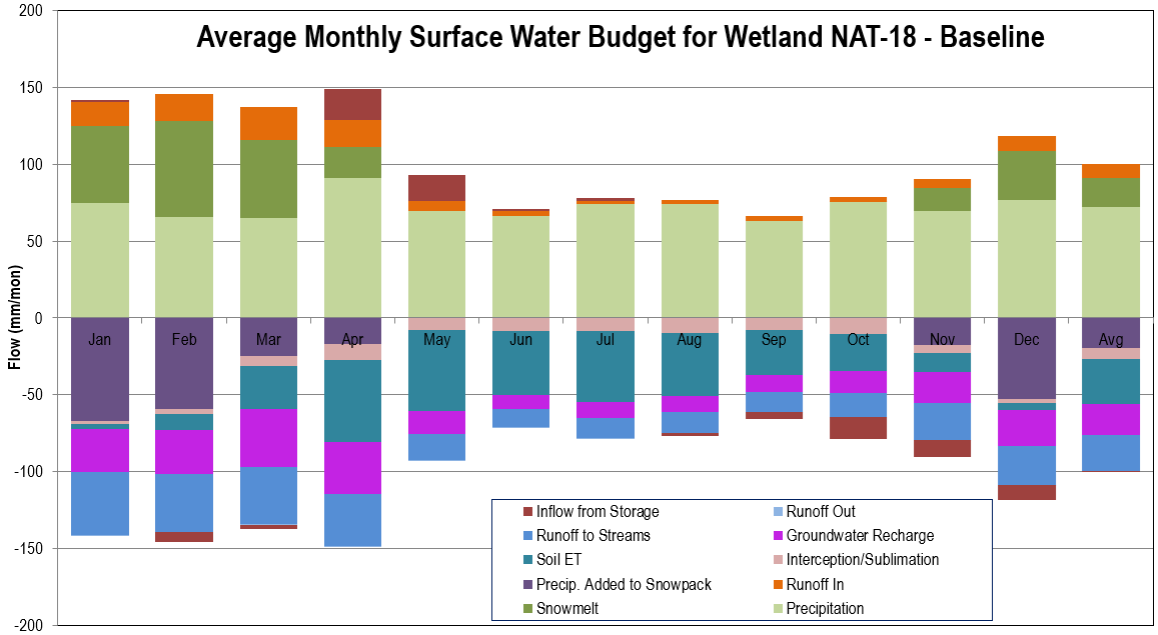


Figure 2.30: Surface water budget for NAT-18

Table 2.1: Monthly surface water budget under baseline conditions (in mm/month) Wetland NAT-18

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	74.83	65.72	65.06	90.70	69.46	66.21	73.84	73.95	63.10	75.60	69.24	76.44	72.01
Snowmelt	50.13	62.60	50.35	20.42	0.00	0.00	0.00	0.00	0.00	0.01	15.10	32.31	19.24
Runoff In	15.24	17.47	22.07	17.72	6.57	3.00	2.42	2.83	2.87	2.93	5.82	9.69	9.05
Precip. added to Snowpack	-67.29	-59.48	-24.71	-17.17	0.00	0.00	0.00	0.00	0.00	-0.01	-17.29	-52.53	-19.87
Interception/Sublimation	-1.49	-3.00	-6.58	-9.89	-8.10	-8.47	-8.74	-9.50	-7.72	-10.39	-5.60	-2.74	-6.85
Soil ET	-3.22	-10.35	-27.90	-53.86	-52.29	-41.89	-46.15	-41.01	-29.55	-24.01	-12.48	-4.84	-28.96
Groundwater Recharge	-28.49	-28.55	-37.47	-33.88	-15.38	-9.02	-10.33	-10.75	-10.61	-14.49	-20.22	-23.04	-20.19
Runoff to Streams	-40.72	-37.63	-37.40	-33.30	-16.69	-11.47	-12.87	-13.83	-13.18	-15.57	-23.52	-25.46	-23.47
Runoff Out	-0.39	-0.47	-0.69	-0.62	-0.21	-0.08	-0.05	-0.05	-0.06	-0.05	-0.12	-0.23	-0.25
Inflow from Storage	1.40	-6.30	-2.72	19.87	16.65	1.71	1.88	-1.64	-4.87	-14.00	-10.94	-9.59	-0.71

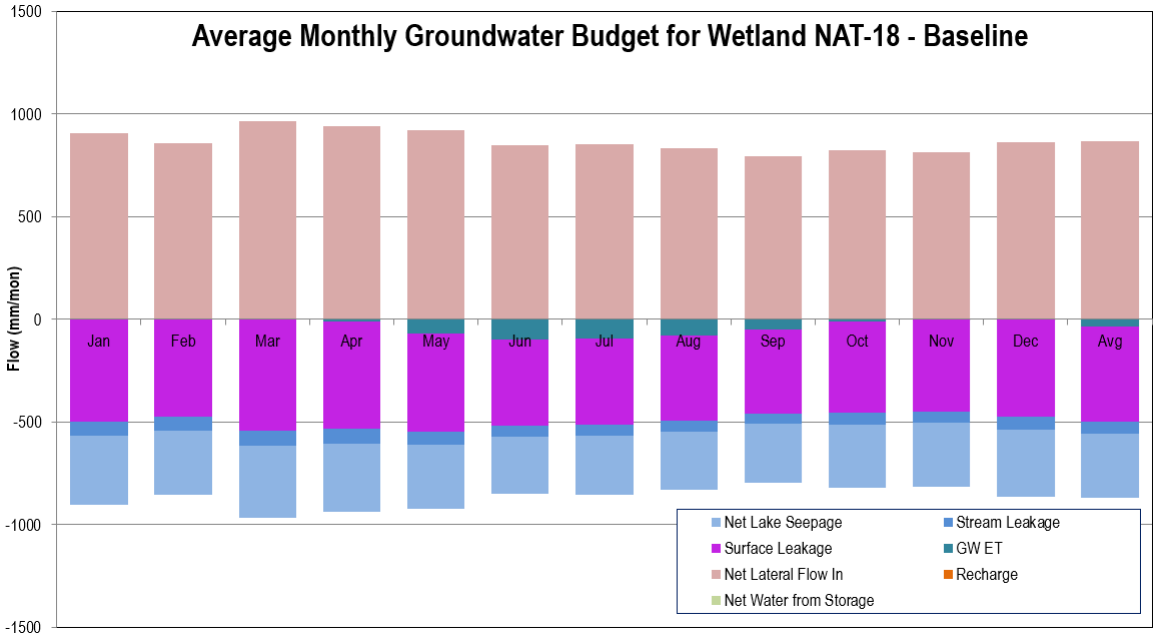


Figure 2.31: Groundwater budget for NAT-18

Table 2.2: Monthly groundwater budget under baseline conditions (in mm/month) Wetland NAT-18

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-0.30	-0.25	-0.18	0.07	0.77	0.71	0.19	0.10	-0.14	-0.35	-0.28	-0.20	0.01
Recharge	2.31	2.04	2.55	2.35	1.23	0.83	1.07	0.92	1.13	1.47	1.86	2.09	1.65
Net Lateral Flow In	904.3	854.6	963.9	936.4	917.6	848.3	851.8	830.8	793.3	821.2	812.6	861.2	866.3
GW ET	-0.38	-0.58	-1.79	-10.56	-67.18	-99.91	-92.78	-77.52	-48.06	-11.92	-1.88	-0.39	-34.41
Surface Leakage	-499.4	-474.4	-537.3	-519.7	-477.1	-417.6	-420.8	-416.0	-410.1	-444.0	-445.8	-474.7	-461.4
Stream Leakage	-67.35	-65.80	-76.44	-74.08	-63.57	-52.75	-52.10	-51.02	-50.44	-55.64	-57.04	-61.97	-60.68
Net Lake Seepage	-337.0	-315.0	-349.4	-334.5	-311.8	-279.6	-287.4	-286.7	-284.8	-308.7	-308.0	-325.7	-310.7
Streamflow In (L/s)	50.7	56.7	60.5	61.7	50.8	43.1	39.8	37.6	36.6	37.9	40.7	44.3	46.7
Streamflow Out (L/s)	79.0	86.1	91.3	93.0	79.8	69.2	64.4	61.9	61.2	63.3	67.0	71.4	74.0
Avg Lake Stage (masl)	450.8	450.8	450.8	450.8	450.8	450.7	450.7	450.7	450.7	450.7	450.7	450.7	450.8

2.6.1.2 Wetland NAT-19

Wetland NAT-19 is located immediately adjacent to the Strada property, and overlaps the southeastern property boundary. The water budget is considerably simpler than NAT-18, because it does not currently have streams or significant ponded areas. Runoff into and out of the wetland boundaries is small. The net precipitation in is balanced by soil ET and groundwater recharge. The groundwater budget is also relatively simple. Groundwater recharge to the aquifer is balanced by the increased lateral outflow (lateral outflow is about four times the lateral inflow), received stream or groundwater inflows, and net lateral groundwater flow in is negative (Figure 2.33). Groundwater ET occurs in the spring and summer months due to a seasonally high-water table. Water comes out of storage (considered to be an inflow to the aquifer) during the late spring and summer as groundwater levels recede and goes into storage during the fall and early spring when ET processes are shut down, recharge increases, and groundwater levels rise.

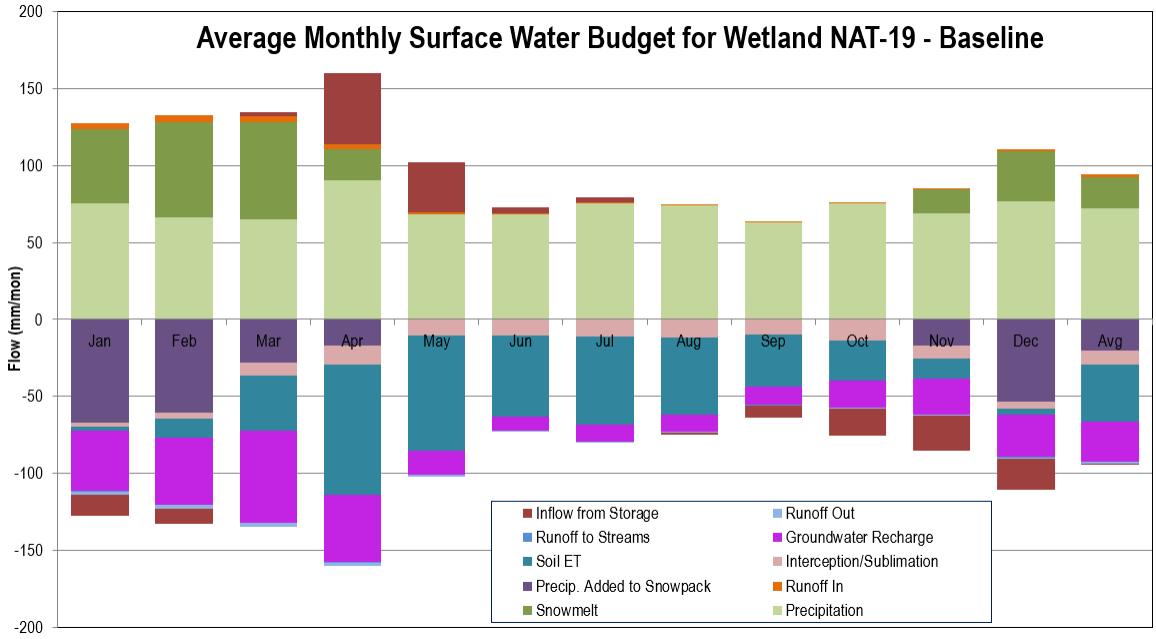


Figure 2.32: Surface water budget for NAT-19

Table 2.3: Monthly surface water budget under baseline conditions (in mm/month) Wetland NAT-19

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	75.51	66.41	65.25	90.65	68.47	68.53	75.62	74.12	63.06	75.28	69.12	76.54	72.38
Snowmelt	48.27	61.65	62.56	19.94	0.00	0.00	0.00	0.00	0.00	0.01	15.08	32.35	19.99
Runoff In	3.45	4.36	4.10	3.17	1.34	0.60	0.40	0.44	0.48	0.45	0.89	1.65	1.78
Precip. added to Snowpack	-67.00	-60.61	-28.07	-16.82	0.00	0.00	0.00	0.00	0.00	-0.01	-17.12	-53.09	-20.23
Interception/Sublimation	-2.58	-3.82	-8.25	-12.29	-10.21	-10.40	-11.02	-11.86	-9.78	-13.62	-8.19	-4.57	-8.88
Soil ET	-2.82	-12.09	-36.10	-84.80	-74.87	-52.72	-57.32	-49.88	-34.11	-26.32	-12.80	-3.89	-37.31
Groundwater Recharge	-38.95	-43.75	-59.58	-43.72	-15.86	-8.98	-10.73	-11.29	-11.70	-17.41	-23.60	-27.81	-26.12
Runoff to Streams	-0.26	-0.31	-0.27	-0.20	-0.08	-0.06	-0.06	-0.09	-0.10	-0.08	-0.12	-0.11	-0.15
Runoff Out	-1.95	-2.49	-2.42	-1.84	-0.79	-0.33	-0.20	-0.22	-0.25	-0.24	-0.48	-0.91	-1.01
Inflow from Storage	-13.66	-9.35	2.79	45.92	32.00	3.36	3.30	-1.22	-7.58	-18.05	-22.77	-20.15	-0.45

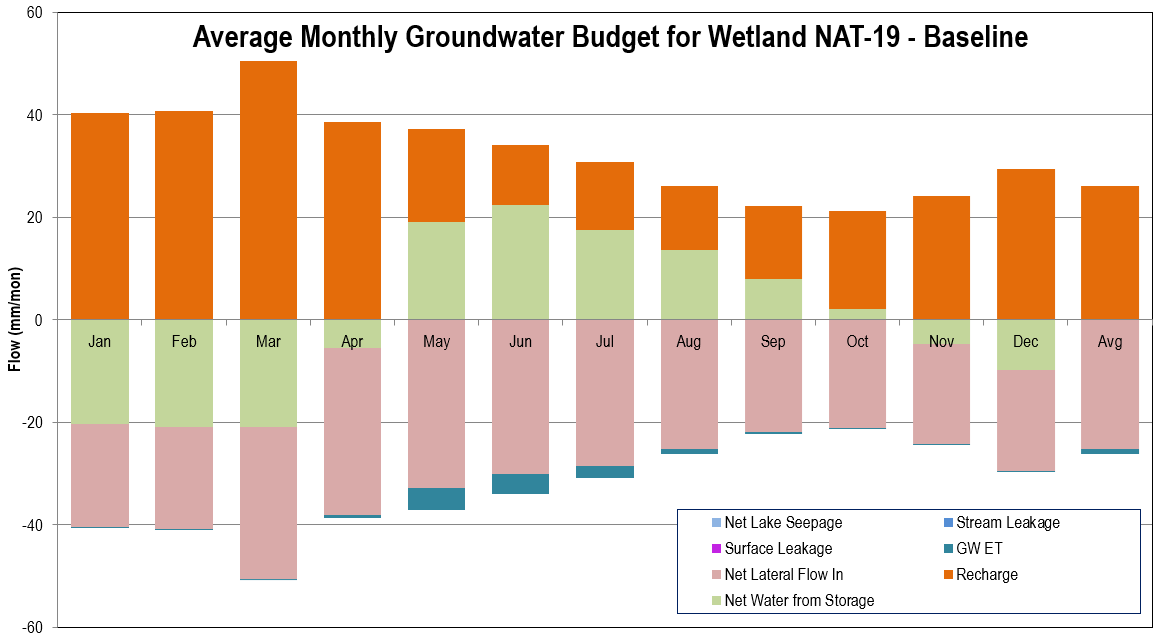


Figure 2.33: Groundwater budget for NAT-19

Table 2.4: Monthly groundwater budget under baseline conditions (in mm/month) Wetland NAT-19

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-20.23	-20.80	-20.83	-5.46	19.11	22.48	17.49	13.68	8.06	2.22	-4.60	-9.77	0.11
Recharge	40.38	40.78	50.50	38.61	18.06	11.56	13.35	12.45	14.19	19.00	24.19	29.47	26.04
Net Lateral Flow In	-20.14	-19.97	-29.68	-32.61	-32.74	-30.05	-28.57	-25.21	-21.94	-21.15	-19.57	-19.69	-25.11
GW ET	-0.01	-0.02	-0.05	-0.61	-4.43	-3.99	-2.27	-0.91	-0.30	-0.07	-0.01	0.00	-1.06
Surface Leakage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Stream Leakage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Lake Seepage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

2.7 *Baseline Conclusions*

The Baseline Conditions scenario provides a detailed and fully integrated transient numerical simulation of the study area. The average condition maps provide an overview, while the hydrographs from the assessment locations present insight regarding the dynamic and complex surface and groundwater processes. The water levels indicate that there are 10's of metres of available drawdown in the vicinity of the proposed pit/quarry.

The Baseline surface water analysis demonstrates that, while there are some interactions between the surface and groundwater systems, most of the wetlands are "headwater" features with strong seasonal variability in groundwater seepage. The dammed pond west of Horning's Mills (NAT-18) is located in a groundwater discharge area and thus receives relatively high groundwater inflows.

Groundwater level and streamflow hydrographs at select locations provide insight into the natural seasonal and inter-annual variability in the system. Wetland water budgets provide a more detailed breakdown in the function and effects on the natural heritage features.

3 Level 2 Future Conditions Evaluation

3.1 *Overview of Proposed Extraction Plan*

The site plans prepared by MHBC Planning outline the 4 phases of the proposed pit/quarry extraction plan. Mining will be conducted with groundwater capture and on-site re-infiltration, plus a network of groundwater control barriers constructed along the bench walls to limit groundwater inflow.

3.1.1 Benches

Three benches will be used to reach the full extraction depth of the proposed quarry extraction area. The first bench coincides with the Guelph formation; the second bench with the Ancaster/Niagara Falls formation, and the third bench with the Gasport formation. Gravel extraction in the remaining northern pit area will be extracted in conjunction with Phase 1 quarry development, along with simultaneous extraction of Bench 1 and 2.

3.1.2 Water Control Barriers

Groundwater inflow control barriers will be constructed along the overburden and bedrock benches as pit/quarry development progresses, thus restricting groundwater inflow to a limited active extraction face. Bench barriers will be constructed on Bench 1 (Guelph) and Bench 3 (Gasport), while no barriers are needed in the Ancaster/Niagara Falls bench because permeability and pump testing indicate it is a significant aquitard.

The design of the barriers will meet all standards for site closure, grading and rehabilitation. Geotechnical analysis indicates that the on-site Tavistock till may be suitable for water control barriers if confirmed to be sufficiently impermeable by a geotechnical consultant prior to construction of berms. (See Section 10: Geotechnical Assessment report). If the on-site Tavistock Till is not considered to be sufficiently impermeable off-site soil may need to be imported for berm construction.

A limited portion of the final deep Gasport bench face will be left open to allow long-term drainage of the quarry lake into the Gasport aquifer. The Closure scenario, presented below, demonstrates that this will ensure that the lake elevation never rises high enough to result in off-site overland discharge.

3.1.3 On-Site Infiltration System

Groundwater and surface water (including stormwater and precipitation) will be captured and infiltrated on-site. Three on-site infiltration systems will be constructed, including two infiltration ponds in the south portion of the site and a two-part infiltration trench along the north-east portion of the site. The location of the infiltration systems is shown in Figure 3.1. The infiltration systems will be constructed in peripheral areas of sand and gravel materials, thus locally recharging the overburden groundwater system with no off-site overland surface water flow.

A buried tile drain will be constructed along the western property boundary to collect groundwater and reduce groundwater mounding to the west of the property. The clean water from the drains will be injected directly into two Guelph and two Gasport injection wells along the eastern property boundary.

The combination of bench barriers (to restrict inflow), and on-site re-infiltration ensures that no off-site surface water discharge will occur, and that groundwater drawdowns will be minimal.

Water level control structures (weirs) will be put in place at each on-site infiltration location. The elevations of these overflow structures are kept the same for all evaluated scenarios. Table 3.1 lists the water control elevations used in all scenario models.

Detailed analysis of the fluxes and transient water level operations of the infiltration systems during all of the extraction and rehab scenarios is presented in Section 6.1.

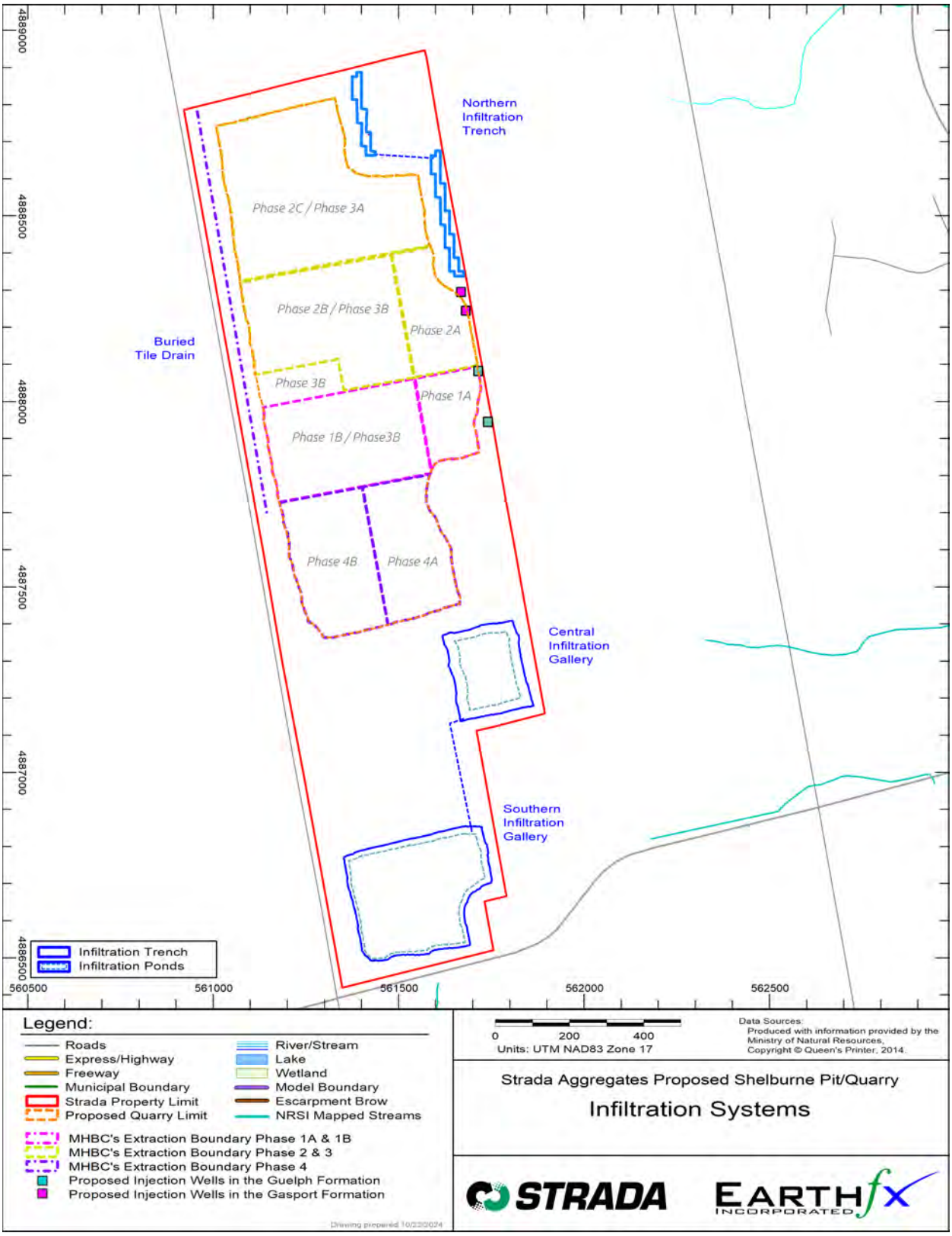


Figure 3.1: Infiltration systems

Table 3.1: Water control elevation for proposed on-site infiltration components

Infiltration Location	Water Control Elevation (masl, CGVD2013)	Function
Northern Infiltration Trench	509.0	Overflow to southern trench
Southern Infiltration Trench	506.0	Offsite discharge (never occurs as per results presented in Section 6.1)
Central Infiltration Gallery	494.0	Overflow to southern gallery
Southern Infiltration Gallery	494.0	Occasional excess discharge to Northern trench, as discussed in Section 6.1

Note: While a control elevation is defined, offsite discharge never occurs during any operating or closure phase.

Figure 3.2 and Figure 3.3 show the stage-area relationships of the proposed southern infiltration ponds and northeastern infiltration trenches. The base of the southern infiltration ponds is the top of bedrock. On the Central Infiltration site, a step-wise increment in area is due to the presence of more sand and gravel material.

The northeastern infiltration trenches are proposed to have a base at 503 masl. The southern portion of this system can provide a greater infiltration volume at lower stages, up to its capacity limit elevation at 506 masl. MODFLOW and GSFLOW use these relationships to estimate infiltration, lateral inflows/outflows, and routing through the elevation control structure. It assumes a fixed area beyond the water control elevation at the structure.

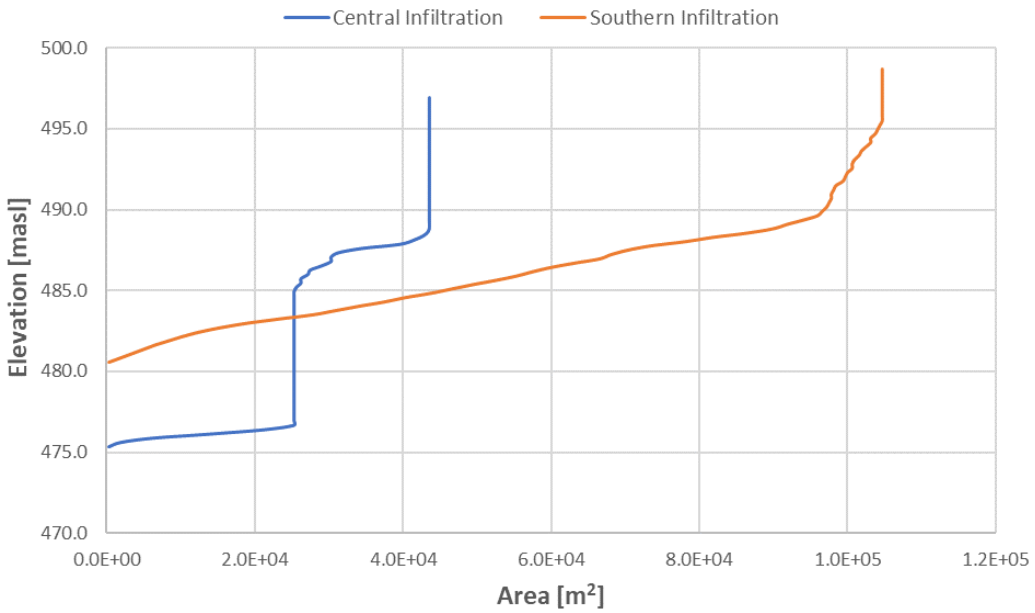


Figure 3.2: Stage-Area relationships of the proposed Central and Southern infiltration sites.

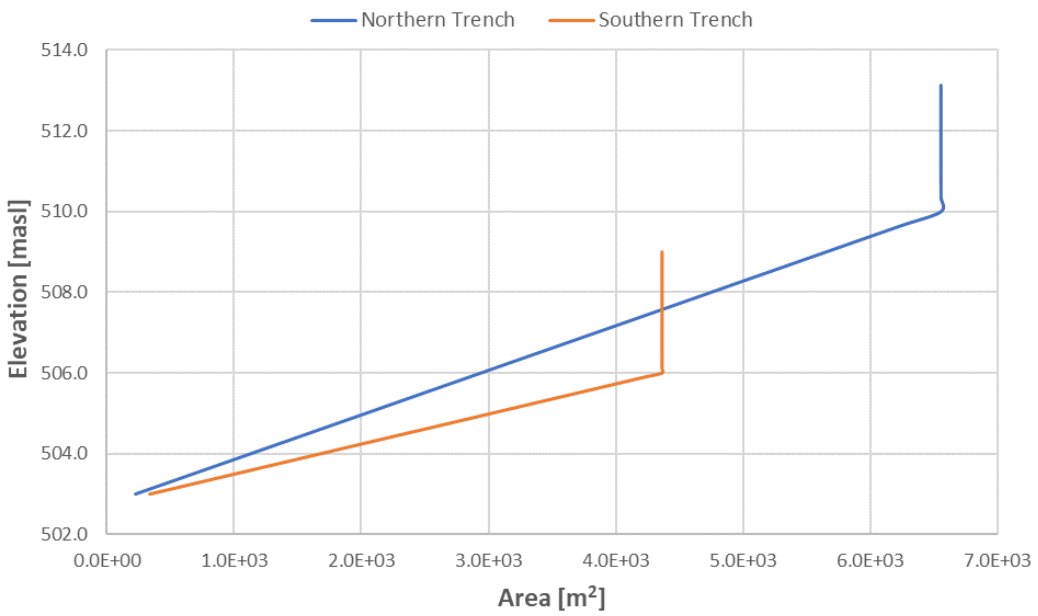


Figure 3.3: Stage-Area relationships of the proposed Northern and Southern infiltration trenches, located at the northeastern portion of the site.

3.2 *Level 2 Evaluation Requirements*

As per the Ministry of Natural Resources standards, a Level 1 and/or a Level 2 evaluation are needed for an aggregate license application.

Table 3.2 summarizes the requirements for a Level 1 and Level 2 assessment, with an overview of the issues particular to this application. Given the local presence of water wells, springs and wetlands, a Level 2 evaluation, as described by MNR, is needed.

3.3 *Level 2 Assessment Overview*

The surface and groundwater issues identified in the Level 2 Assessment are fully addressed through the integrated model. To facilitate the impact assessment, a number of groundwater and surface water assessment or evaluation points have been selected around the development area. These points, introduced in the preceding baseline analysis chapter, are shown in Figure 2.11.

The preceding appendices (A through D), indicate that, from a geologic and hydrogeological perspective, the proposed development is located in an area favorable to extraction. The site is located in an area with thick aquifer layers, and extensive available aquifer drawdown (see Figure 2.8). The distance of the proposed excavation from private well clusters and the Pine River Valley further minimizes the effects on those features. The Pine River Valley is a local groundwater discharge area, and as such it is less susceptible to seasonal and inter-annual water level fluctuations (See Section 2.4). These, and many more, aspects of the groundwater and surface water impact assessment are discussed below.

Table 3.2: Evaluation of need for Level 2 Hydrogeological Assessment

Category	Level 1 Assessment	Level 2 Assessment Needed?
Water Wells	Water wells located within 120 metres of the Site obtain water from sand and gravel aquifer.	Level 2 Assessment for water wells required.
Springs	Springs located downgradient of Site in the Pine River Valley, and headwater streams located in and around the escarpment area.	Level 2 assessment needed to assess potential impact on springs.
Groundwater Aquifers	Extraction will occur in the local Bedrock aquifer.	Level 2 assessment required to assess the potential reduction in water levels in the wells. Limited potential for water quality effects as groundwater dewatering will maintain flow directions into the quarry.
Discharge to Surface Water	The Site will be operating in geological materials that are contiguous with off-site surface water features. Field investigations indicate a portion of Wetland NAT-19 is located on the Strada property	Level 2 assessment required to evaluate the impact of changes to wetland water budget. Wetland NAT-19 is located adjacent to the proposed central infiltration gallery, ensuring the wetland will be protected
Water Diversion, Storage and Drainage Facilities On-Site	Water diverted into excavations	A Level 2 assessment is required to address alterations to water diversion, storage and drainage facilities. A detailed assessment of site water management is included in this report.
Water Balance	There will be an increase in evaporation from the Site.	Level 2 assessment is needed to evaluate changes in the water balance. Assessment of site water balance is included in each evaluation scenario in this report.
Source Water Protection	The Shelburne municipal wellfield, located more than 5 km to the south of the Strada property, includes the only wells in the area that fall under the provincial SWP assessment program. The wellfield capture zone and threats assessment were updated in 2022 and that analysis indicates that the wells capture groundwater from the west. This confirms that the proposed Strada development is lateral to, or downgradient of, the wellfield, and therefore will not be a water quality or quantity threat to the wellfield.	Level 2 assessment is not needed because of the detailed SWP analysis completed in 2022 (The Strada pit was not identified as a water quantity or quality threat). Water Quality: The proposed Strada quarry is lateral/ downgradient of the Shelburne wellfield so any possible water quality changes during rock extraction cannot impact the municipal wellfield. Water Quantity: The operational design of the proposed quarry, including the proposed southern infiltration system, ensures that drawdowns will not propagate towards the wellfield.

3.4 *Model Evaluation of Extraction Phases*

The baseline GSFLOW scenario was modified to create four additional scenarios representing the proposed extraction phases and rehab/closure conditions. The future scenarios were simulated through the same ten-year time period (October 1, 2015 to April 1, 2024) as the baseline scenario, with identical precipitation, temperature and solar radiation inputs, to facilitate direct comparative analysis of streamflow, groundwater levels, and other water budget components.

The proposed extension of the Strada Pit/Quarry is to occur in four phases of extraction, as discussed in detail in the MHBC site plan. The details and timing of the extraction, along with the proposed quarry rehabilitation plans have been submitted under separate cover. The baseline model was revised, as outlined in Section 2, to incorporate the specifics of the extraction and rehabilitation plans for each scenario.

In addition to the Baseline and Closure scenarios, three extraction scenarios have been developed to evaluate water management and off-site impacts. For a detailed description of the development phases, please refer to the MHBC Site Plan.

As noted above, the abbreviation “BAS” on model figures and hydrographs refers to “Baseline” simulation results. The following additional abbreviations are used to refer to model results from other scenarios described in detail below:

- P1 = Phase 1 Assessment scenario
- P2C = Phase 2C Assessment scenario
- P4A = Phase 4A Assessment scenario
- REHAB = Rehabilitation (closure) scenario

3.5 *Phase 1 Impact Assessment Scenario*

3.5.1 Introduction

Scenario P1 (Phase 1) represents the final extraction of sand and gravel from the north portion of the pit, (in the area labeled Phase 2C/Phase 3A in Figure 3.4, which refers to later phases of bedrock removal); and extraction of bedrock from Bench 1 and 2 in the central portion of the site, labeled as Phase 1A and Phase 1B. The open extraction faces are shown as dotted lines in Figure 3.4. A cross section showing the extraction conditions is shown in Figure 3.5.

The start of bedrock extraction will be a sinking cut located in the Phase 1A area. Groundwater levels in the Phase 1A area are near the lowest recorded on site, and extraction from this initial location will have the minimal impact on the overburden water table. This will allow confirmation of extraction design operations at an early stage of extraction.

Overburden water control barriers have been constructed on three sides of the overburden (green line). Progressive barriers have been constructed along the south and east face of Bench 1 (dark blue line), and an open face exists in Bench 1 and 2 along the west and northern faces (dashed red lines).

Quarry floor drains have been constructed to distribute inflow to both the infiltration trenches in the northeast portion of the site and the southern infiltration galleries. The numerical model was run with the modified inputs for Scenario P1 and model results were post-processed and compared to Baseline Conditions.

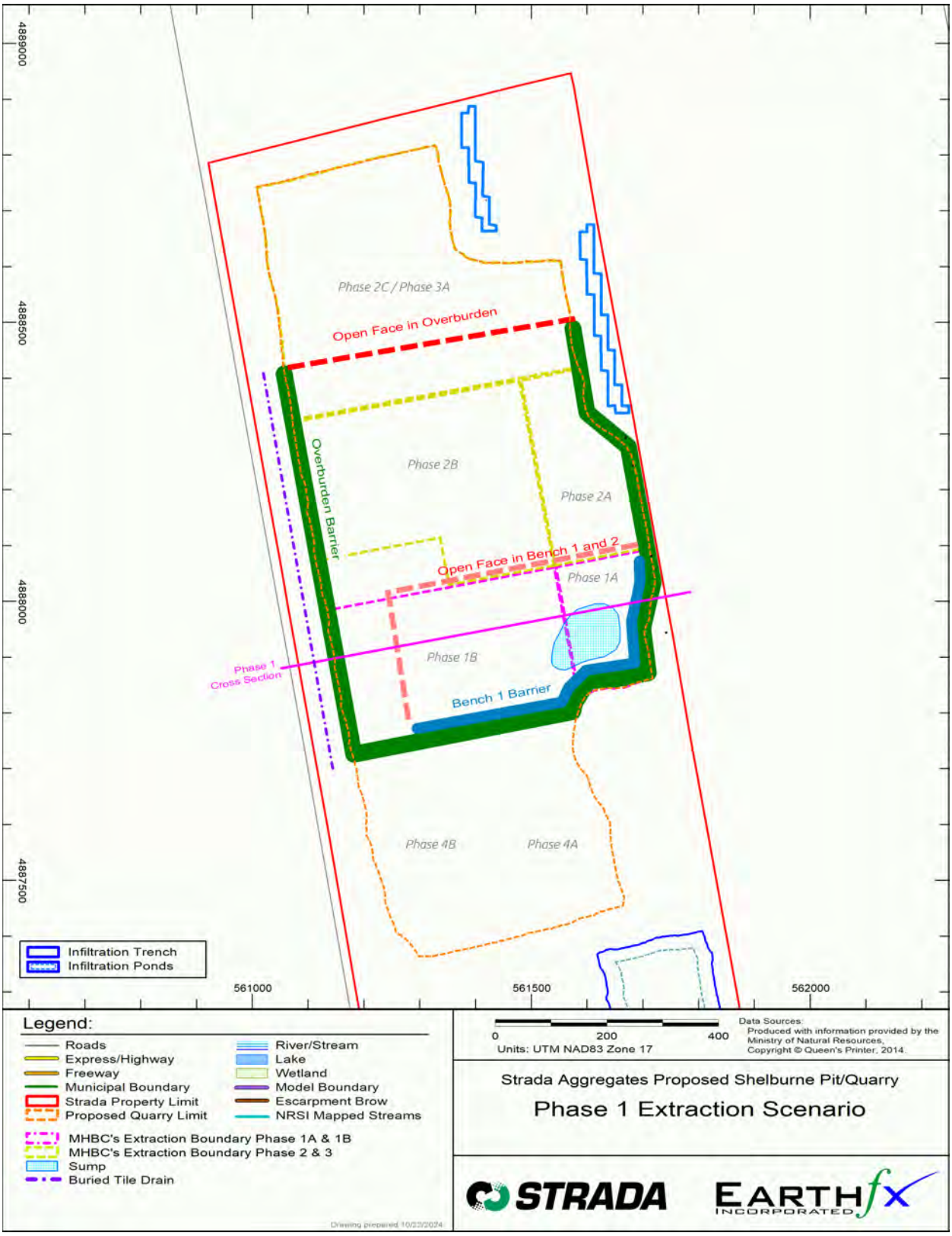


Figure 3.4: Phase 1 extraction scenario: barrier placement and open face location.

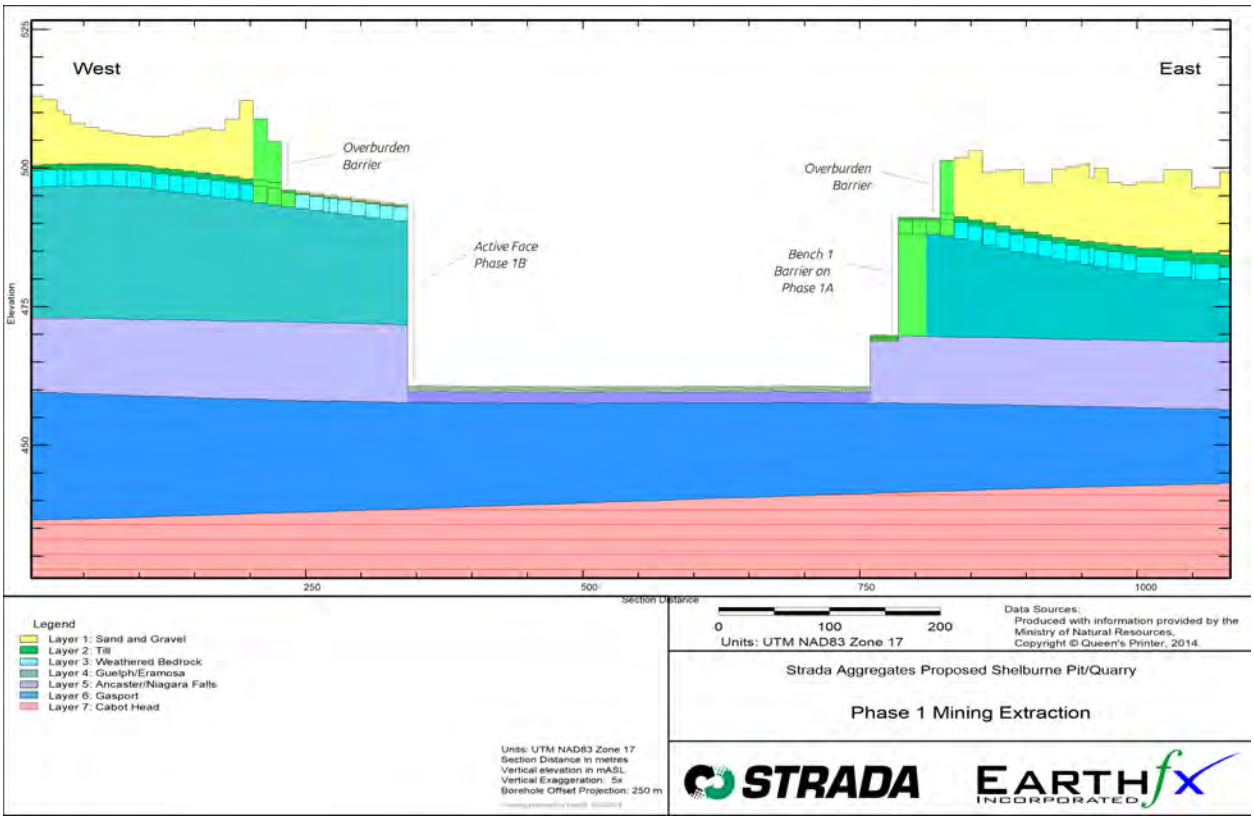


Figure 3.5: Cross section (elevations in CGVD13) showing Phase 1 extraction

3.5.2 Phase 1 Drawdowns and Change in Surface Water Flow

Figure 3.6 shows the average simulated drawdown between Baseline and P1 extraction in Model Layer 1. Both drawdown (in red) and mounding (in blue) occur in the vicinity of the site, as the infiltration systems leak water into the shallow aquifer system causing a rise in water levels above the till. The simulated drawdowns decrease rapidly with distance from the excavation, and fall to below 0.5 m at a distance of approximately 1000 m east of the excavation.

Figure 3.7 and Figure 3.8 show the drawdown in the Layer 4 (Guelph) and Layer 6 (Gasport) aquifers. Like Layer 1, mounding is also evident in the Guelph aquifer, and to a lesser extent in the confined Gasport aquifer. The 1 m drawdown in the Gasport extends approximately 740 m to the east of the site.

The drawdowns are, at every location, small relative to the available drawdown in the aquifer (Figure 2.8), indicating that any shallow private wells could be readily deepened if necessary. The higher drawdowns near the excavation occur in an area with very few private wells and very high available drawdown (40-60 m). The drawdown at location GWP-4 (near a new housing development west of Horning's Mills) is approximately 0.5 m (Figure 3.6), while the available drawdown at that location is approximately 25 m (Figure 2.8). In general, 5 m of available drawdown is considered adequate in limestone aquifers such as those encountered in the study area, so there remains plenty of available well capacity during operations.

The effects on adjacent extraction licenses, surface and groundwater permits, agricultural lands and private septic systems are discussed in Section 3.9.

Figure 3.9 and Figure 3.10 show the average simulated increase and decrease in streamflow. There is a modest increase in flows in streams north and south of the site due to the infiltration system. The decrease in streamflow is limited to the stream reaches which flow into the NAT-18 pond.

In summary, P1 has a very minor impact on local groundwater levels and streams. Despite open extraction faces in the north facing overburden and north and west facing Bench 1 and 2, the infiltration systems mitigate the effects of the drawdowns.

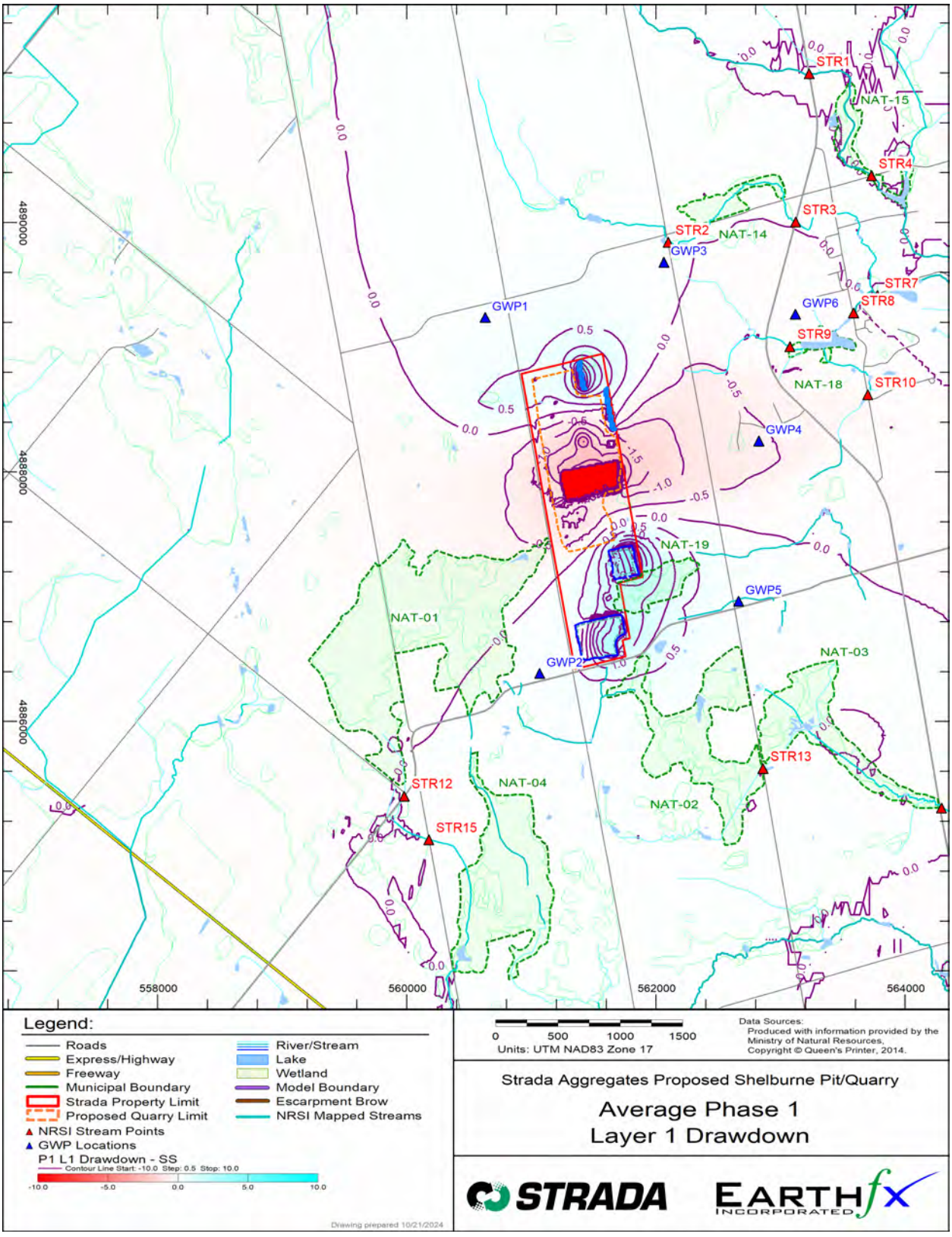


Figure 3.6: Average Phase 1 layer 1 drawdown

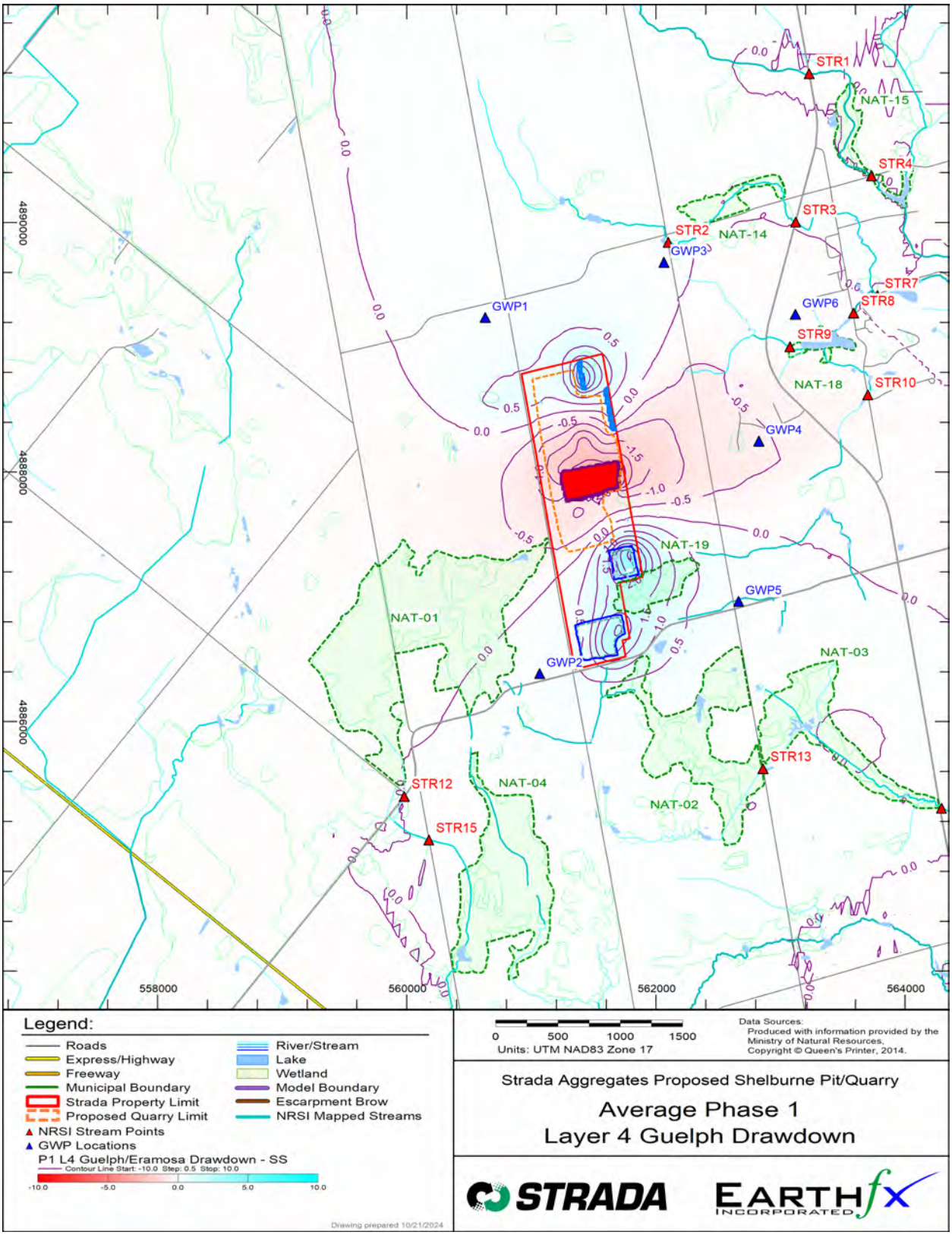


Figure 3.7: Average Phase 1 layer 4 Guelph drawdown

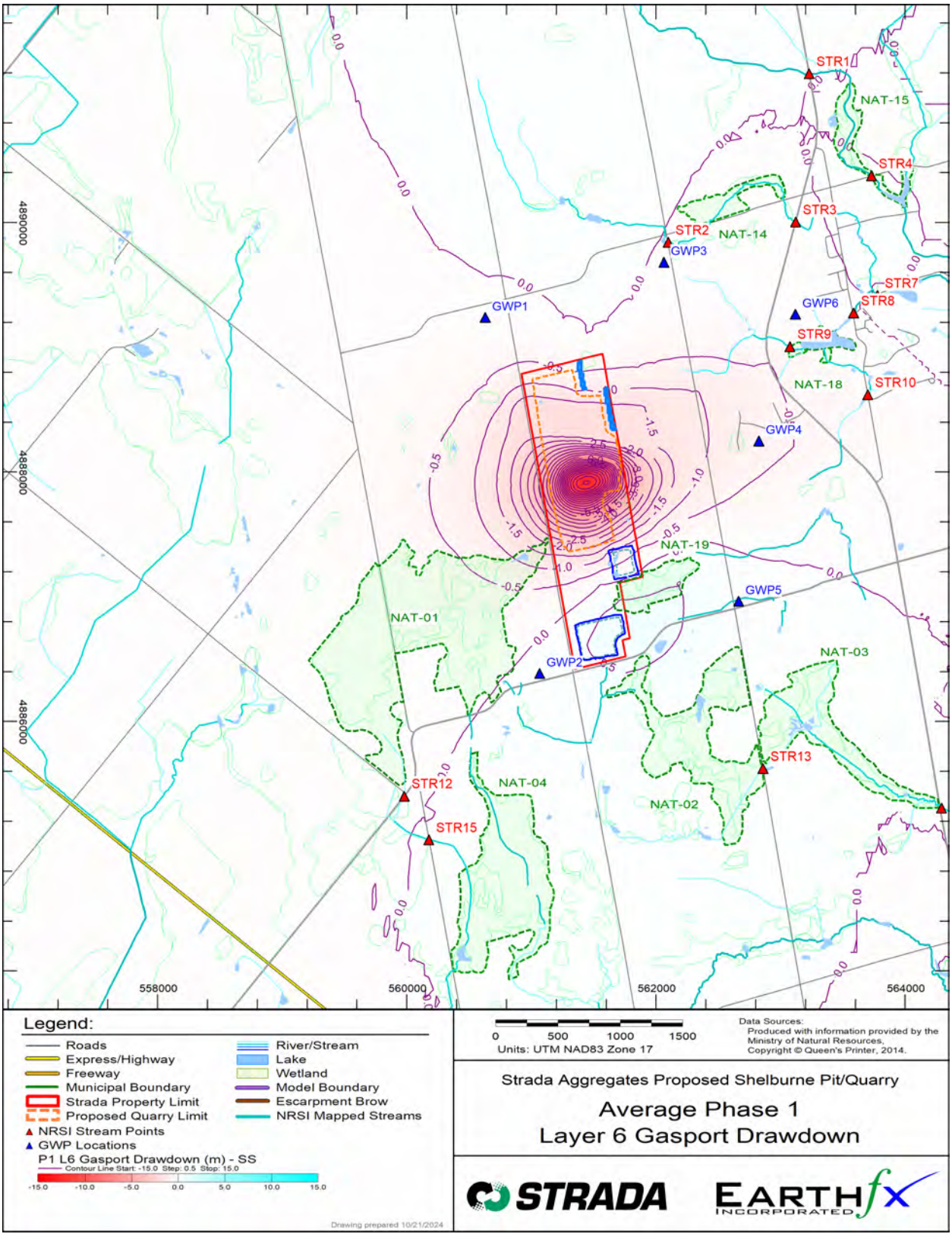


Figure 3.8: Average Phase 1 layer 6 Gasport drawdown

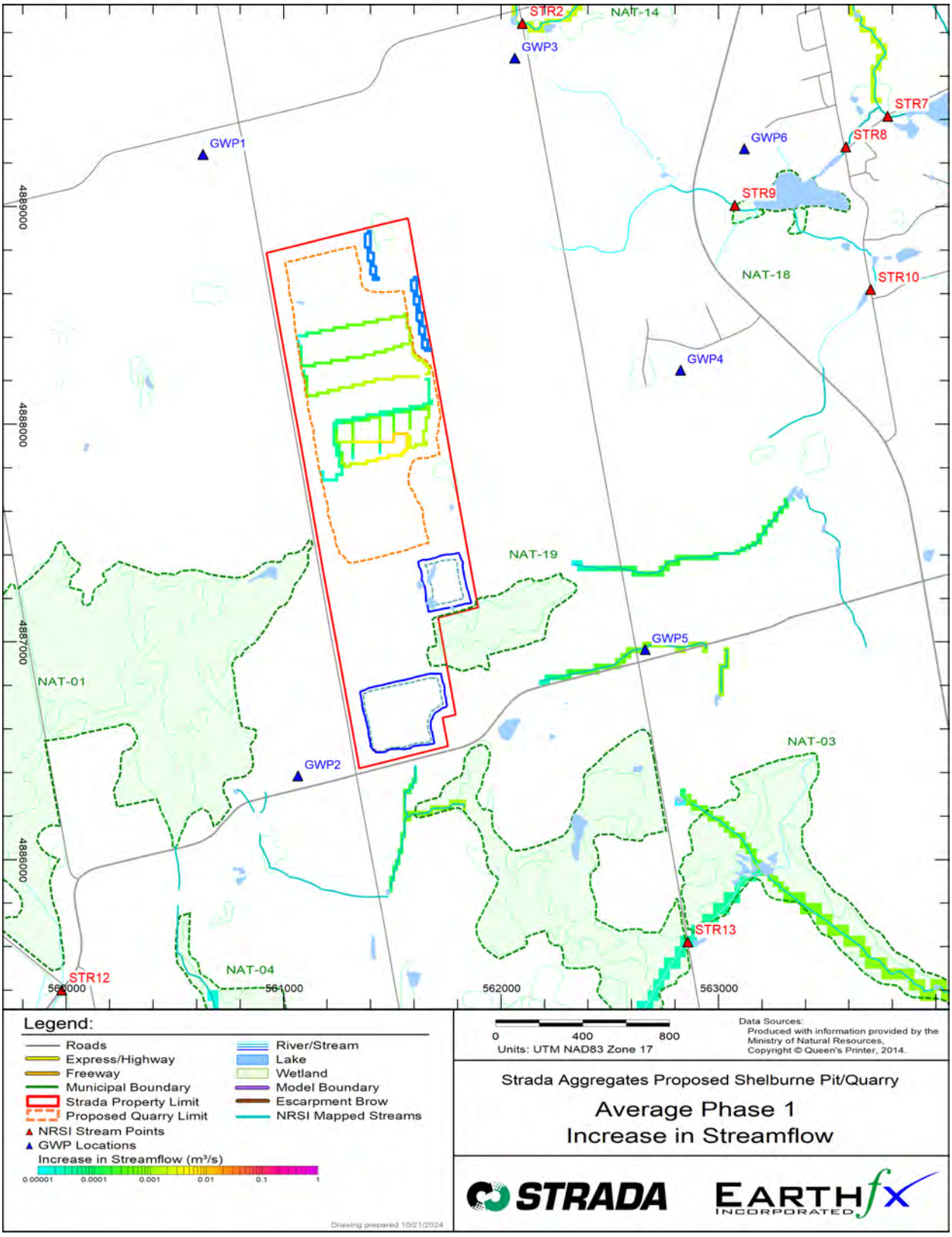


Figure 3.9: Average Phase 1 increase in streamflow

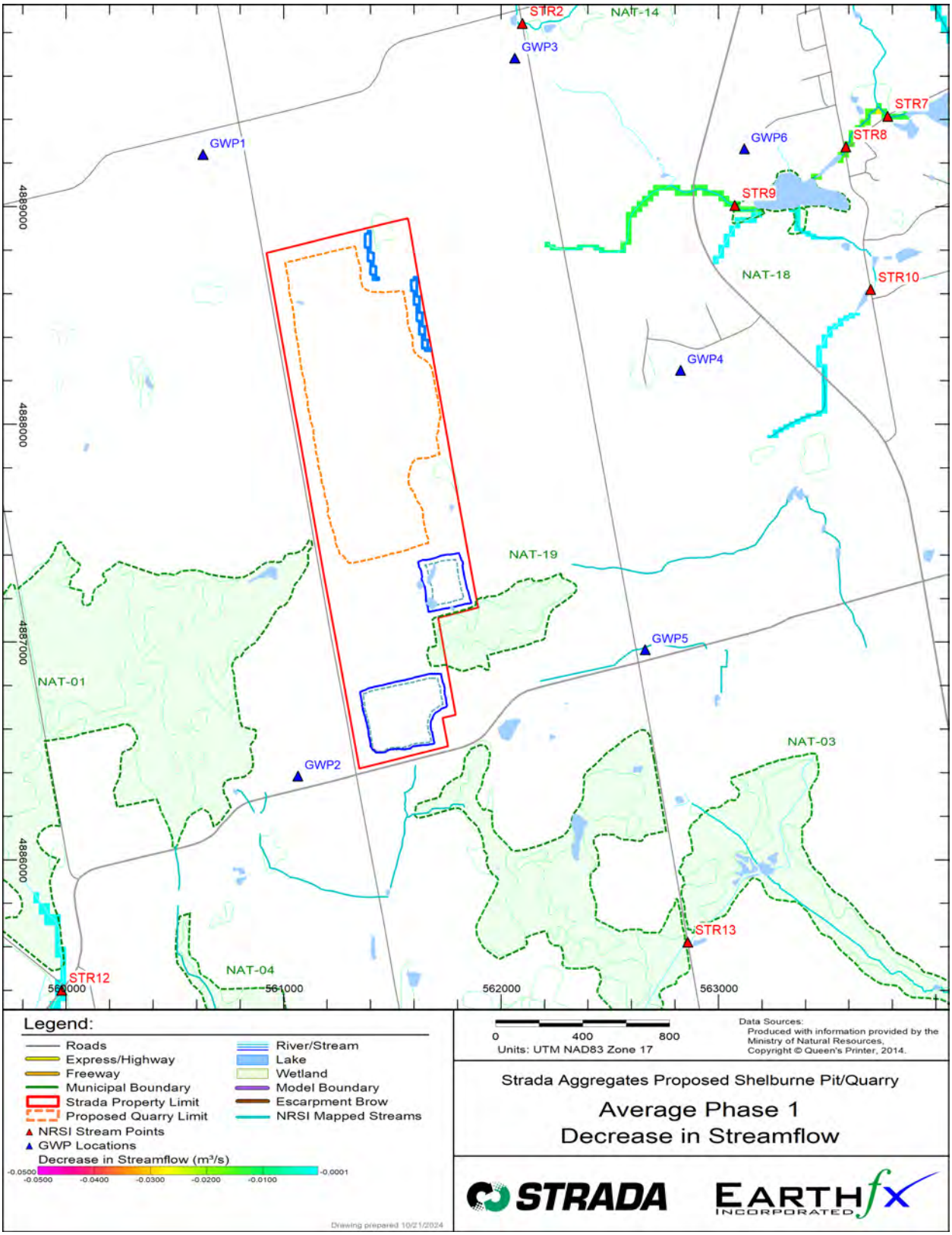


Figure 3.10: Average Phase 1 Decrease in Streamflow

3.5.3 Phase 1 Seasonal and Inter-Annual Change in Flows and Levels

The transient simulations through 2015—2024 provide insight into the effects of Phase 1 during seasonal and inter-annual variation.

The groundwater levels at two key locations, GWP4 and GWP6 (location shown in Figure 2.11), east of the property have been selected to illustrate the seasonal variation. Groundwater drawdowns at other locations are minimal, and mounding effects are discussed in the feature-based water budgets. Figure 3.11 shows that the change in groundwater levels between Baseline and Phase 1 in the Guelph and Gasport formations at location GWP4 are generally ranging between 0.6 to 0.8 m during the summer and 0.2 to 0.4 m during the wet season.

Figure 3.12 shows that the change in groundwater levels between Baseline and Phase 1 in the Guelph and Gasport formations at location GWP6 are very small, with slightly higher drawdowns during the summer in the Gasport formation. This is a location near the Escarpment where the water levels in deeper unit are higher than those in the Guelph formation. Drawdowns in the Guelph formation are almost non-existent, whereas in the Gasport Formation are only limited to 0.1 m during the summer.

Figure 3.13 shows the change in streamflow at STR9 between the Baseline and Phase 1 scenario (location shown in Figure 2.11). Peak flows in this small headwater tributary are more affected than summer low flows. This tributary is only one component of the water budget of Pond NAT-18, and the full water budget for that feature is discussed in the following section. However, at this particular location, a reduction of streamflow is predicted ranging from 40 to 45%.

Figure 3.14 shows the effect of Phase 1 on streamflow down stream of Pond NAT-18 at locations STR8 and STR7. The hydrograph indicates that at STR8 there is a reduction of 25% and 30% for the dry and wet seasons, respectively. Downstream at STR7 flow is reduced by approximately 10% during wet and dry seasons.

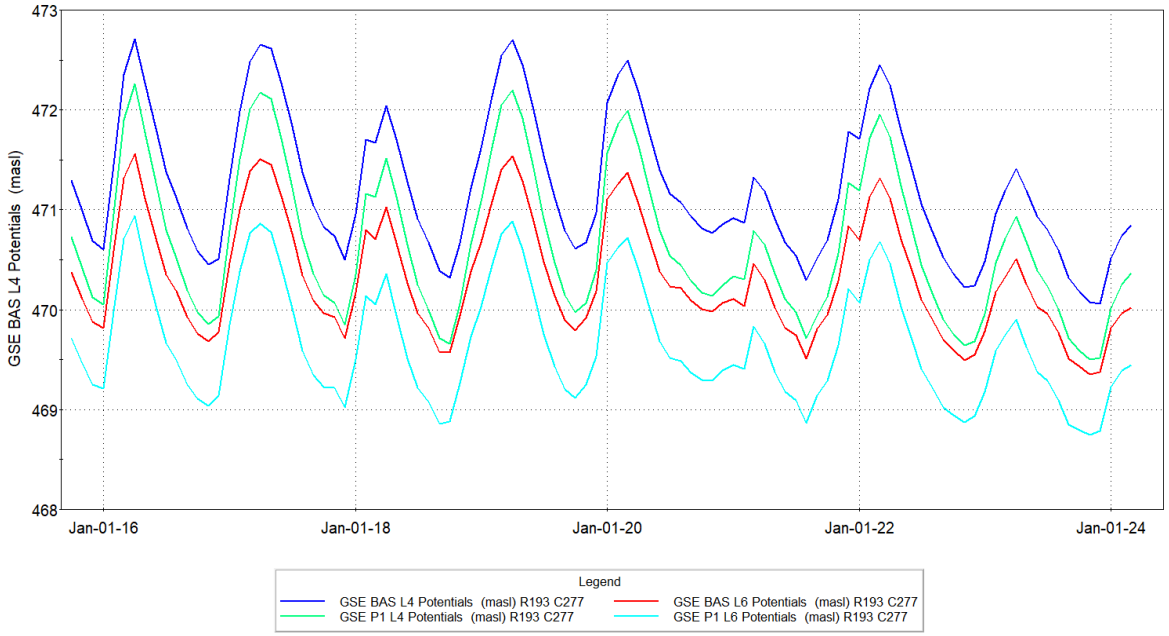


Figure 3.11: Comparison of Groundwater Levels under Phase 1 at location GWP4. GSE BAS: GSFLOW of Baseline conditions; GSE P1: GSFLOW of Phase 1 conditions.

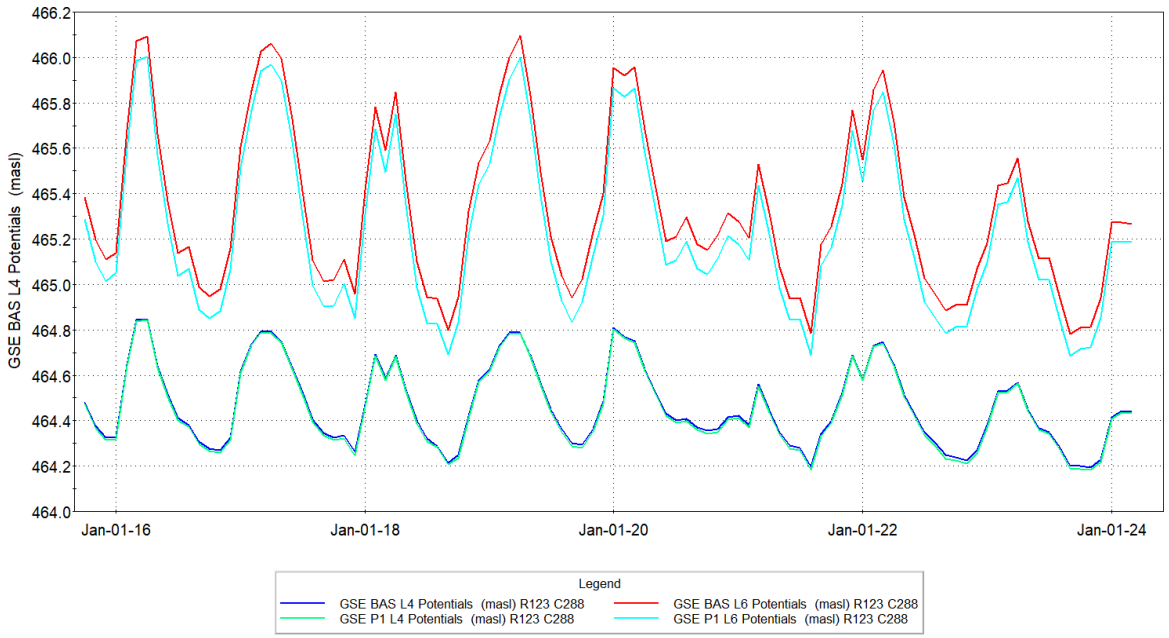


Figure 3.12: Comparison of Groundwater Levels under Phase 1 at location GWP6

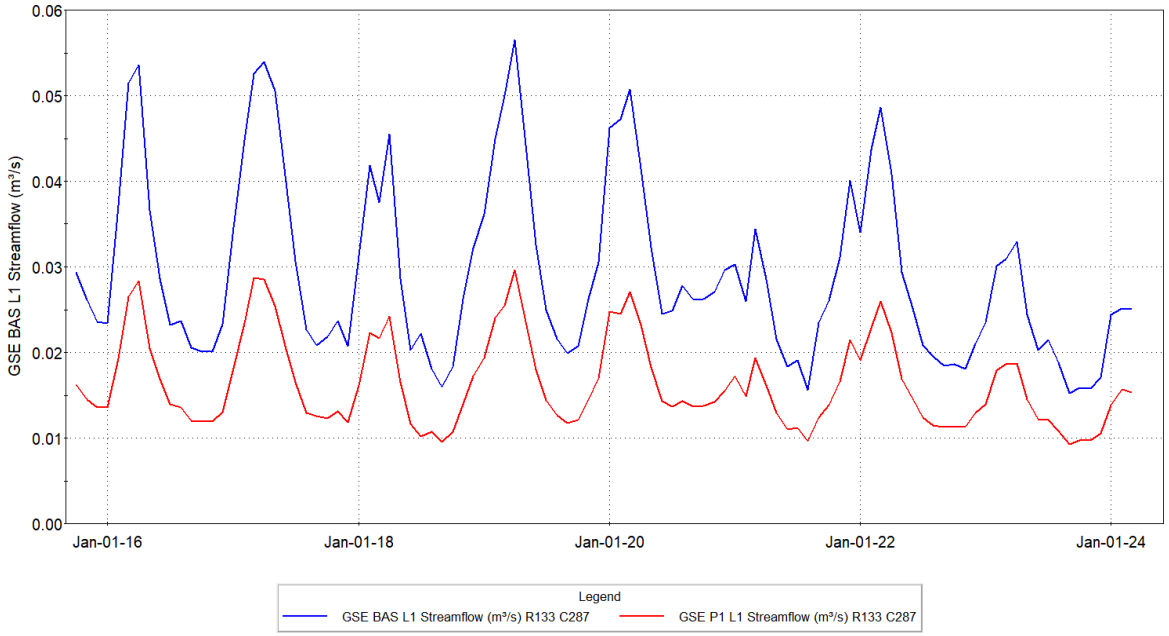


Figure 3.13: Comparison of Streamflow at STR9 under Baseline and Phase 1 scenarios

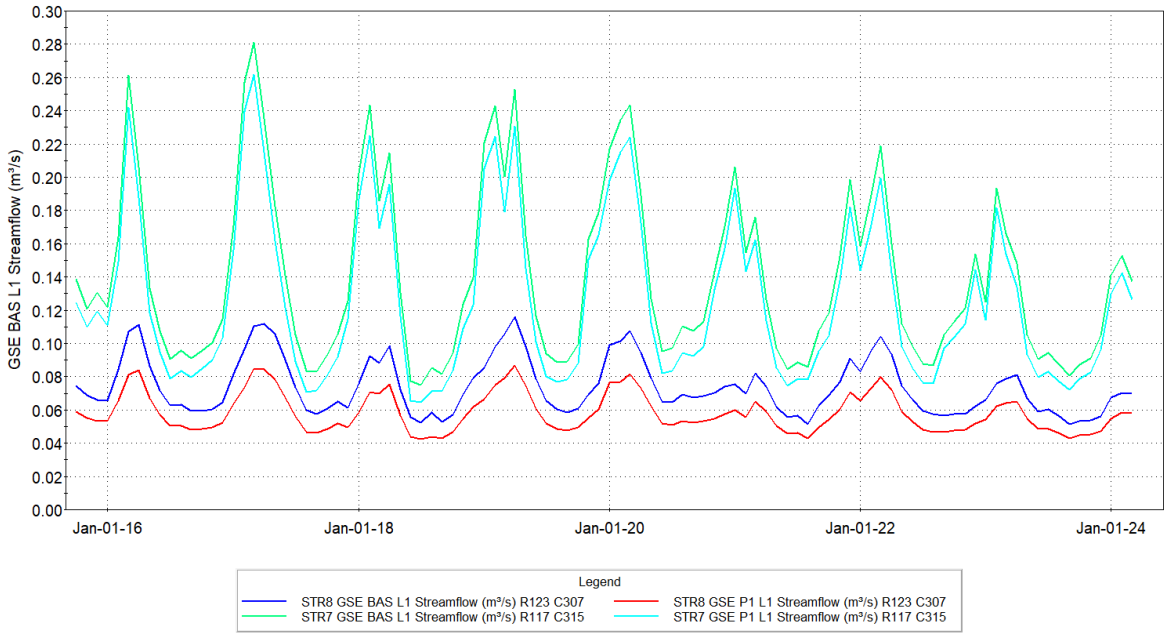


Figure 3.14: Comparison of streamflow under Baseline and Phase 1 at locations STR8 and STR7

3.5.4 **Phase 1 Surface Water/Groundwater Interaction**

The spatial change in average groundwater seepage to wetlands and ponds is shown in Figure 3.15 and Figure 3.16. The wetlands to the south and north east of the development are predicted to receive an increase in surface leakage from the infiltration systems. Wetland NAT-18 will see a modest reduction in surface leakage, as discussed below.

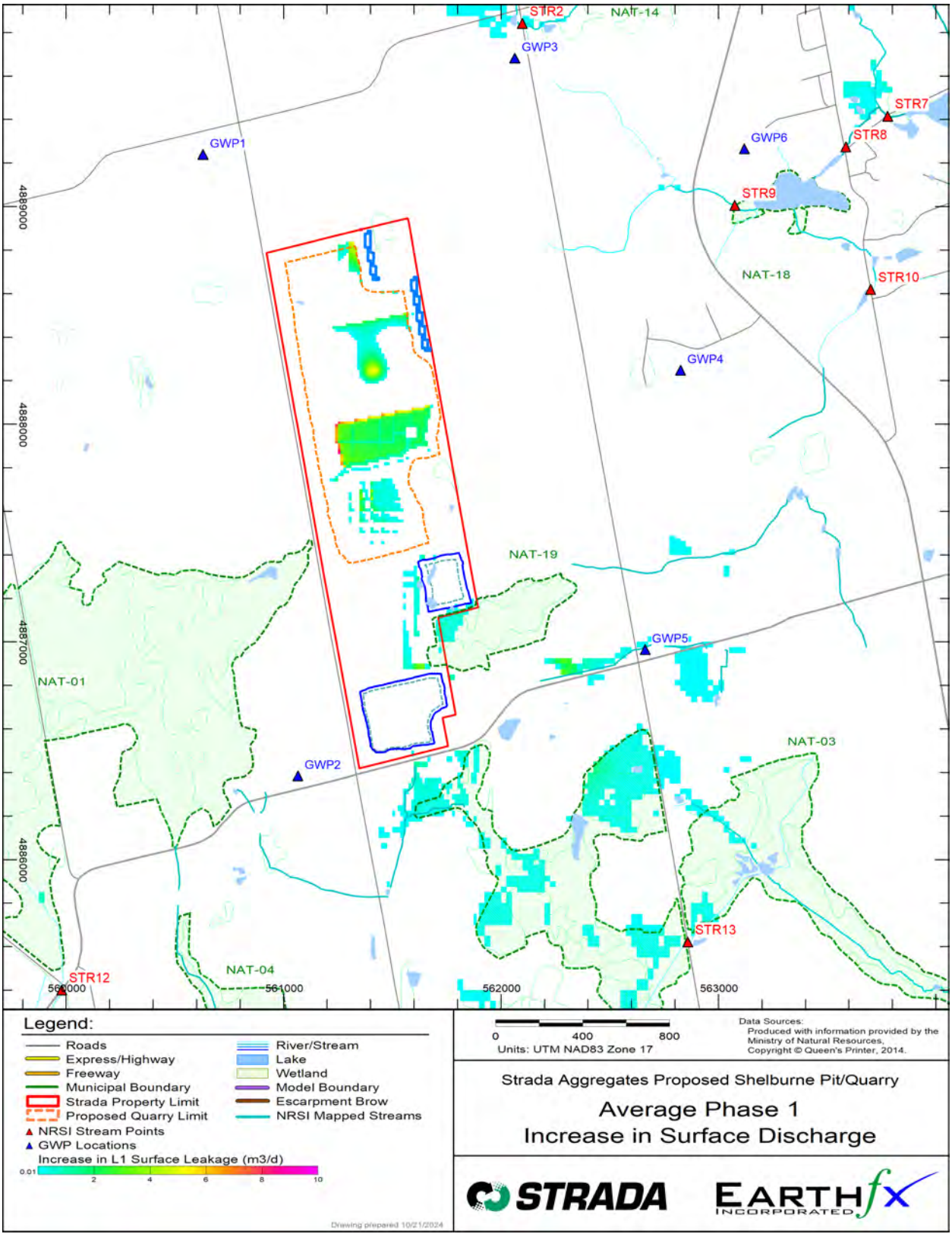


Figure 3.15: Average Phase 1 increase in surface leakage

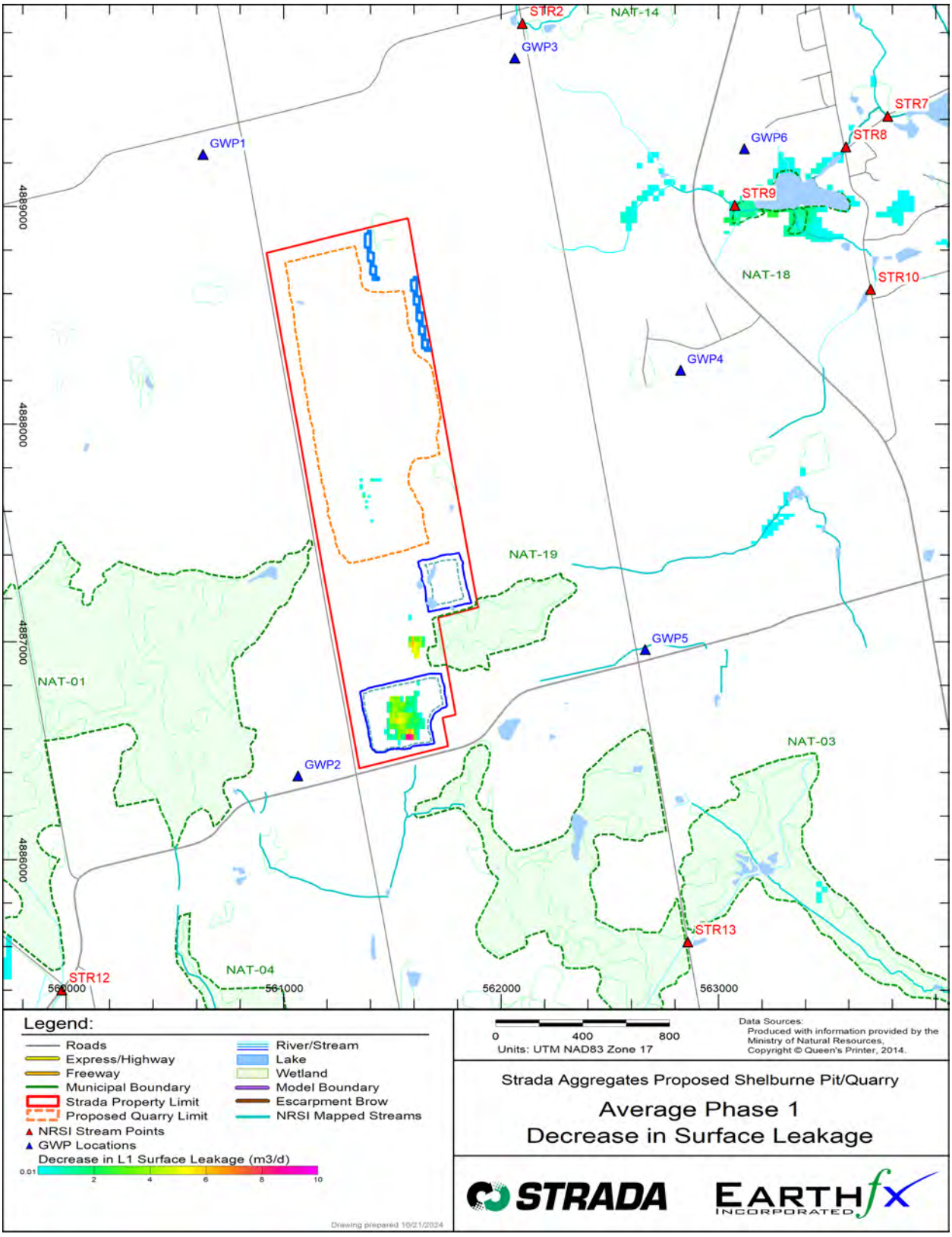


Figure 3.16: Average Phase 1 decrease in surface leakage

3.5.5 Wetland Water Budgets

A complete set of wetland water budgets under Phase 1 are included in Section 9.2. The two wetlands of interest are discussed below.

3.5.5.1 Wetland NAT-18

Wetland NAT-18 is the dammed pond near Horning's Mills as discussed in Section 2.5.2. The surface water and groundwater components of the water budget are presented as bar charts (Figure 3.17 and Figure 3.18) and tables(Table 3.3 and Table 3.5)

The change in the surface water budget is tabulated in Table 3.4 and shows that there is no significant change in surface water flows (all changes less than 0.5 mm/month).

The change in the groundwater budget is documented in Table 3.6. Differences are determined by subtracting the simulated flows under Phase 1 from the simulated flows under Baseline conditions. For example, there is a reduction of 33.3 mm/month in January net lateral inflow from the baseline conditions flow of 904.3 mm/month to the Phase 1 flow of 870.7 mm/month. This represents a reduction in the net lateral flow in by approximately 3.7%. The reduction in net lateral inflow ranges from 3.21 mm/month (February) to 42.0 mm/month (July/August). The reduction is accompanied by a similar scale decrease in the magnitude of surface leakage and stream leakage (note that surface leakage (groundwater discharge to land surface) into the wetland is considered negative and a decrease from the baseline flux will also be negative). Overall, the changes are small.

Simulated stream inflow decreases by 11.3 to 19.8 L/s from baseline conditions due to changes occurring outside the wetland. Inflow into the wetland decreases by about 0.8 to 1.9 L/s. Simulated stage (water level in the pond) also drops slightly (0.05 to 0.08 m) due to changes in lake inflows.

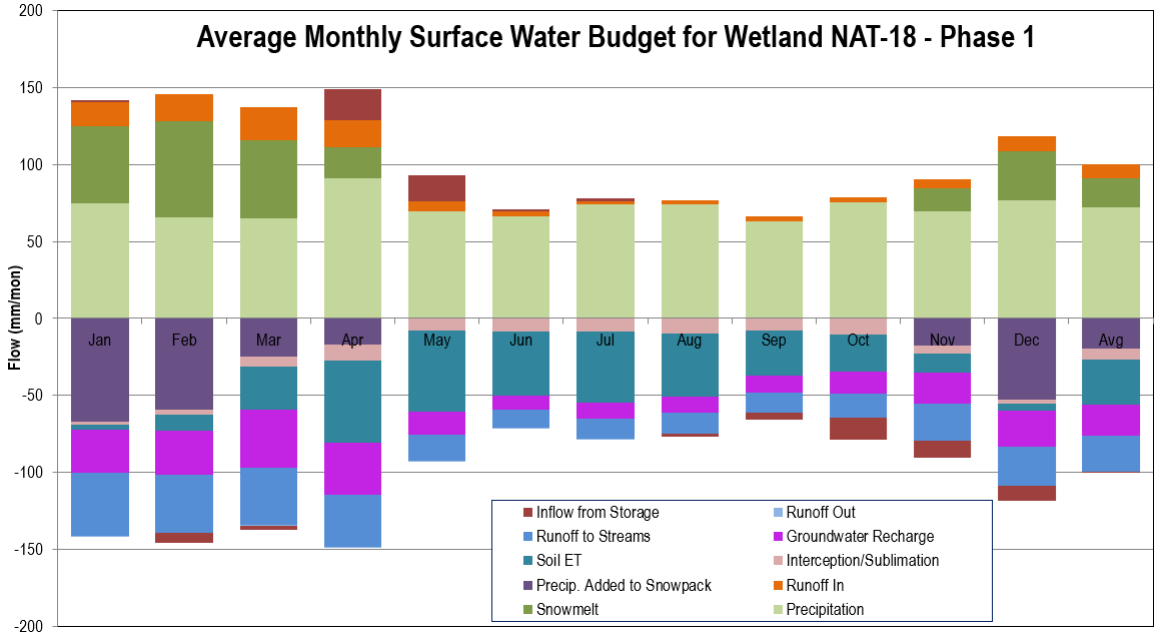


Figure 3.17: Phase 1 surface water budget for NAT-18

Table 3.3: Monthly surface water budget under Phase 1 conditions (in mm/month) Wetland NAT-18

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	74.83	65.72	65.06	90.70	69.46	66.21	73.84	73.95	63.10	75.60	69.24	76.44	72.01
Snowmelt	50.13	62.60	50.35	20.42	0.00	0.00	0.00	0.00	0.00	0.01	15.10	32.31	19.24
Runoff In	15.24	17.47	22.07	17.72	6.57	3.00	2.42	2.83	2.87	2.93	5.82	9.69	9.05
Precip. added to Snowpack	-67.29	-59.48	-24.71	-17.17	0.00	0.00	0.00	0.00	0.00	-0.01	-17.29	-52.53	-19.87
Interception/Sublimation	-1.49	-3.00	-6.58	-9.89	-8.10	-8.47	-8.74	-9.50	-7.72	-10.39	-5.60	-2.74	-6.85
Soil ET	-3.22	-10.35	-27.90	-53.86	-52.29	-41.89	-46.15	-41.01	-29.55	-24.01	-12.48	-4.84	-28.96
Groundwater Recharge	-28.49	-28.55	-37.47	-33.88	-15.38	-9.02	-10.33	-10.75	-10.61	-14.49	-20.22	-23.04	-20.19
Runoff to Streams	-40.72	-37.63	-37.40	-33.30	-16.69	-11.47	-12.87	-13.83	-13.18	-15.57	-23.52	-25.46	-23.47
Runoff Out	-0.39	-0.47	-0.69	-0.62	-0.21	-0.08	-0.05	-0.05	-0.06	-0.05	-0.12	-0.23	-0.25
Inflow from Storage	1.40	-6.30	-2.72	19.87	16.65	1.71	1.88	-1.64	-4.87	-14.00	-10.94	-9.59	-0.71

Table 3.4: Difference in monthly surface water budget (Baseline - Phase 1) in mm/month Wetland NAT-18

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precip. added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater Recharge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff to Streams	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

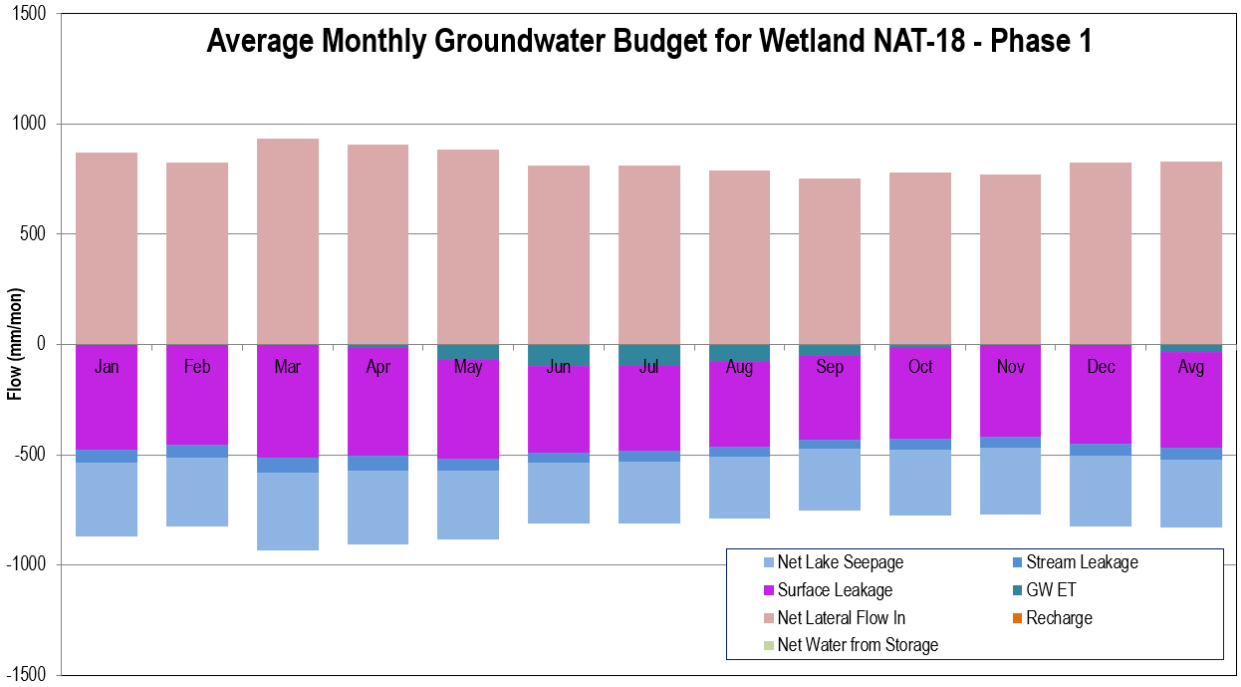


Figure 3.18: Groundwater budget for NAT-18

Table 3.5: Monthly groundwater budget under Phase 1 conditions (in mm/month) Wetland NAT-18

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-0.31	-0.27	-0.21	0.09	0.85	0.73	0.21	0.10	-0.14	-0.36	-0.29	-0.23	0.01
Recharge	2.38	2.07	2.86	2.56	1.25	0.86	1.08	0.99	1.14	1.51	1.94	2.18	1.74
Net Lateral Flow In	870.7	824.2	930.5	903.6	880.2	809.5	809.5	787.9	751.4	776.8	771.1	822.4	828.1
GW ET	-0.38	-0.58	-1.79	-10.54	-66.56	-98.92	-91.81	-76.73	-47.56	-11.82	-1.87	-0.39	-34.08
Surface Leakage	-474.6	-451.6	-512.7	-494.4	-449.5	-390.3	-392.0	-386.5	-382.5	-415.7	-417.6	-447.9	-434.6
Stream Leakage	-60.58	-59.01	-68.73	-66.30	-56.43	-46.65	-45.79	-44.68	-44.33	-48.98	-50.28	-55.11	-53.90
Net Lake Seepage	-334.1	-313.9	-349.8	-334.8	-309.8	-275.3	-280.9	-279.8	-277.5	-300.9	-301.3	-320.4	-306.5
Streamflow In (L/s)	35.2	37.8	40.5	40.7	34.0	29.3	27.1	25.7	25.2	25.9	27.6	30.0	31.6
Streamflow Ou (L/s)t	62.6	66.3	70.4	71.0	61.4	53.8	50.4	48.5	48.3	49.9	52.6	56.0	57.6
Avg. Lake Stage (masl)	450.7	450.7	450.8	450.8	450.7	450.7	450.7	450.7	450.7	450.7	450.7	450.7	450.7

Table 3.6: Difference in monthly groundwater budget (Baseline - Phase 1) in mm/month Wetland NAT-18

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	0.01	0.02	0.02	-0.02	-0.08	-0.02	-0.02	-0.02	0.02	0.00	0.01	0.03
Recharge	-0.08	-0.03	-0.30	-0.21	-0.02	-0.03	-0.01	-0.07	-0.02	-0.04	-0.06	-0.09
Net Lateral Flow In	33.34	30.21	33.23	32.67	37.21	38.66	42.02	42.03	41.51	43.87	40.99	38.55
GW ET	0.00	0.00	0.00	-0.02	-0.61	-0.98	-0.96	-0.81	-0.49	-0.10	-0.01	0.00
Surface Leakage	-24.56	-22.65	-24.42	-25.21	-27.43	-27.11	-28.65	-29.51	-27.31	-27.98	-27.78	-26.50
Stream Leakage	-6.71	-6.74	-7.65	-7.71	-7.08	-6.14	-6.28	-6.28	-6.06	-6.57	-6.67	-6.77
Net Lake Seepage	-2.97	-1.18	0.33	0.26	-1.99	-4.39	-6.40	-6.28	-7.30	-7.79	-6.60	-5.20
Streamflow In (L/s)	15.4	18.7	19.8	20.8	16.7	13.7	13.0	11.5	11.3	11.8	12.9	14.1
Streamflow Ou (L/s)	16.2	19.6	20.7	21.8	18.2	15.3	14.0	13.4	12.8	13.1	14.1	15.2
Avg. Lake Stage (masl)	0.07	0.08	0.08	0.08	0.07	0.06	0.07	0.06	0.05	0.05	0.06	0.06

3.5.5.2 Wetland NAT-19

The average monthly surface water budget for wetland NAT-19 is presented in Figure 3.19; and in table format in Table 3.7. The difference with respect to the Baseline condition is shown in Table 3.8. Similarly, results for the average monthly groundwater budget for wetland NAT-19 are presented in Figure 3.20, Table 3.9 and Table 3.10.

Wetland NAT-19 is located immediately adjacent to the Strada property. Relative to Baseline, under Phase 1 there are very small changes (about 0.03 to 0.11 mm/month) in the overland runoff into wetland accompanied by a similar reduction in groundwater recharge (Table 3.8). The groundwater water budget shows more significant change in response with increased surface leakage and groundwater ET, indicative of a higher water table (Table 3.10). Net lateral groundwater flow out of the wetland decreases compared to baseline conditions and, in the summer and fall, there is net lateral inflow into the wetland. At the same time, groundwater recharge is predicted to decrease as a portion of the wetland has changed to a groundwater discharge zone and the recharge provided by the surface water model is rejected. The effect of changing from a fully perched wetland to groundwater-fed wetland is discussed under separate cover (NRSI, 2024).

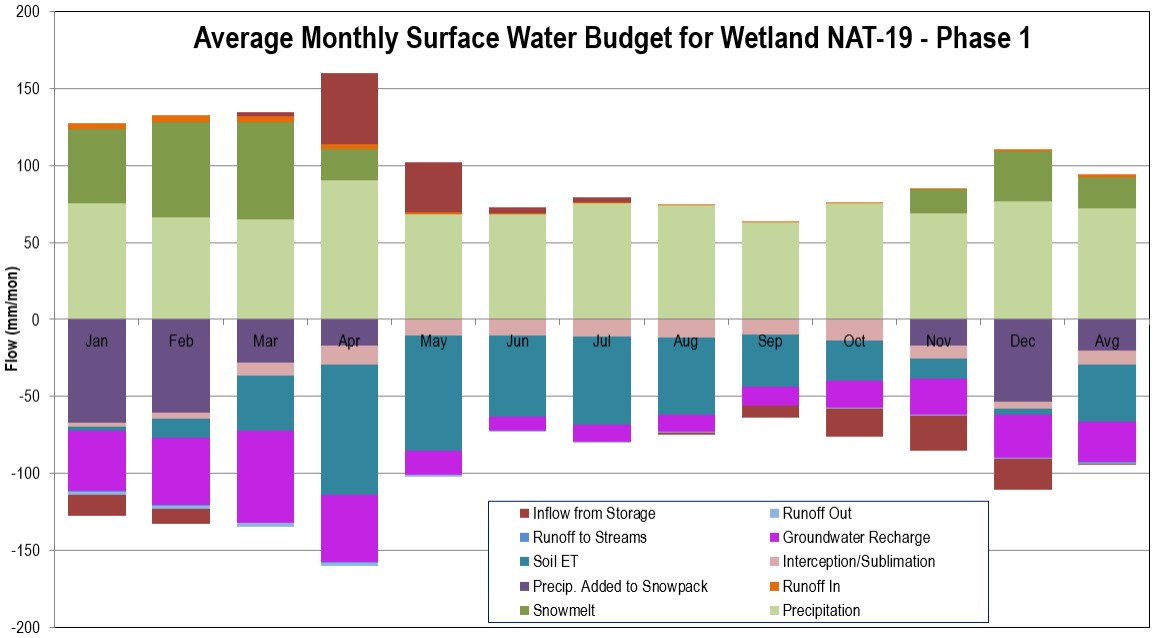


Figure 3.19: Surface water budget for NAT-19

Table 3.7: Monthly surface water budget under Phase 1 conditions (in mm/month) Wetland NAT-19

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	75.51	66.41	65.25	90.65	68.47	68.53	75.62	74.12	63.06	75.28	69.12	76.54	72.38
Snowmelt	48.27	61.65	62.56	19.94	0.00	0.00	0.00	0.00	0.00	0.01	15.08	32.35	19.99
Runoff In	3.55	4.43	4.15	3.20	1.38	0.64	0.46	0.51	0.54	0.52	0.99	1.76	1.84
Precip. added to Snowpack	-67.00	-60.61	-28.07	-16.82	0.00	0.00	0.00	0.00	0.00	-0.01	-17.12	-53.09	-20.23
Interception/Sublimation	-2.58	-3.82	-8.25	-12.29	-10.21	-10.40	-11.02	-11.86	-9.78	-13.62	-8.19	-4.57	-8.88
Soil ET	-2.82	-12.09	-36.10	-84.80	-74.89	-52.75	-57.37	-49.93	-34.14	-26.34	-12.81	-3.89	-37.33
Groundwater Recharge	-39.07	-43.87	-59.66	-43.76	-15.88	-8.98	-10.74	-11.30	-11.72	-17.43	-23.66	-27.90	-26.16
Runoff to Streams	-0.26	-0.31	-0.27	-0.20	-0.08	-0.06	-0.06	-0.09	-0.10	-0.08	-0.12	-0.11	-0.15
Runoff Out	-1.95	-2.49	-2.42	-1.84	-0.79	-0.33	-0.20	-0.22	-0.25	-0.24	-0.48	-0.91	-1.01
Inflow from Storage	-13.65	-9.29	2.81	45.93	32.00	3.35	3.30	-1.22	-7.60	-18.08	-22.82	-20.18	-0.45

Table 3.8: Difference in Monthly Surface Water Budget (Baseline - Phase 1) in mm/month Wetland NAT-19

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	-0.11	-0.06	-0.05	-0.03	-0.04	-0.04	-0.06	-0.07	-0.06	-0.07	-0.11	-0.11
Precip. added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.00	0.00	0.02	0.03	0.05	0.05	0.03	0.02	0.00	0.00
Groundwater Recharge	0.12	0.12	0.08	0.04	0.02	0.01	0.01	0.01	0.02	0.03	0.06	0.12
Runoff to Streams	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

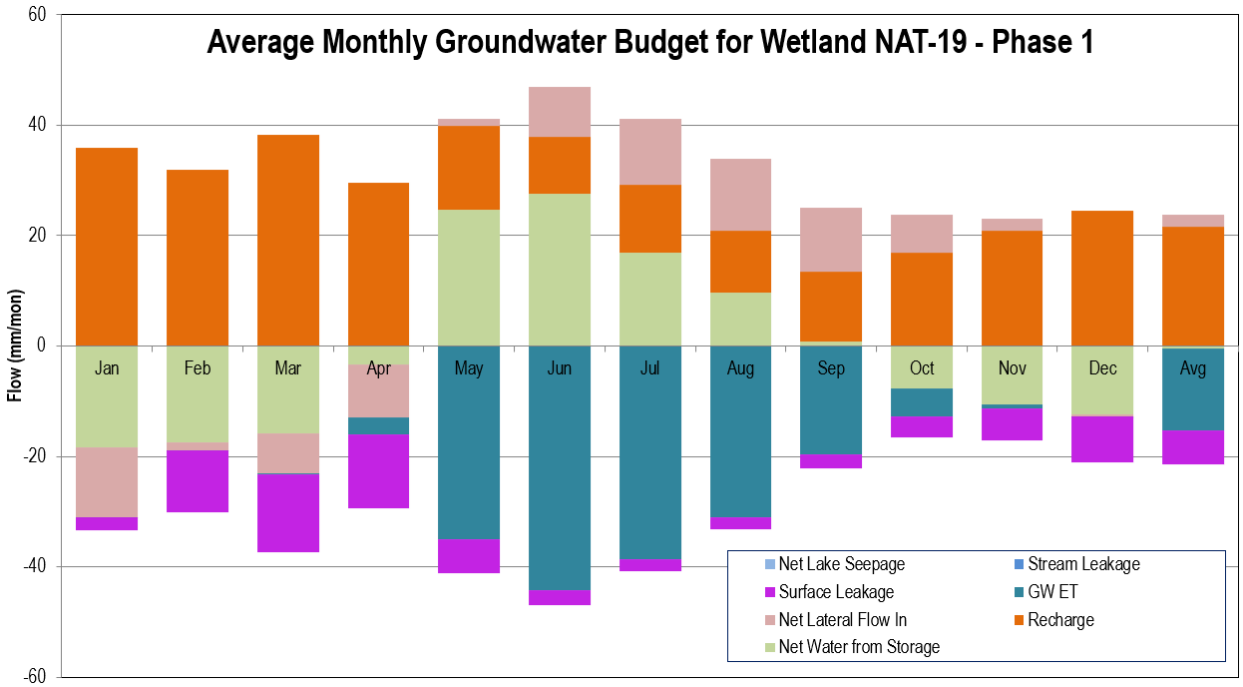


Figure 3.20: Groundwater budget for NAT-19

Table 3.9: Monthly groundwater budget under Phase 1 conditions (in mm/month) Wetland NAT-19

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-18.39	-17.50	-15.77	-3.31	24.76	27.58	16.92	9.65	0.77	-7.71	-10.59	-12.40	-0.50
Recharge	35.90	31.90	38.26	29.64	15.05	10.36	12.27	11.32	12.75	16.88	20.86	24.45	21.64
Net Lateral Flow In	-12.70	-1.33	-7.36	-9.67	1.32	9.04	12.04	13.02	11.60	6.92	2.27	-0.27	2.07
GW ET	-0.01	-0.04	-0.11	-3.07	-35.06	-44.30	-38.62	-30.95	-19.70	-5.10	-0.69	-0.02	-14.81
Surface Leakage	-2.24	-11.33	-14.05	-13.35	-6.16	-2.67	-2.10	-2.17	-2.54	-3.73	-5.80	-8.40	-6.21
Stream Leakage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Lake Seepage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 3.10: Difference in monthly groundwater budget (Baseline - Phase 1) in mm/month - Wetland NAT-19

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	-1.89	-3.31	-5.09	-2.21	-5.75	-5.18	0.49	3.97	7.27	9.87	5.96	2.60
Recharge	4.48	8.88	12.30	9.00	3.01	1.20	1.08	1.12	1.44	2.12	3.33	5.02
Net Lateral Flow In	-7.39	-18.63	-22.30	-22.90	-34.02	-39.06	-40.57	-38.21	-33.53	-28.01	-21.82	-19.39
GW ET	0.00	0.02	0.06	2.47	30.69	40.37	36.39	30.06	19.41	5.03	0.68	0.02
Surface Leakage	2.24	11.33	14.05	13.35	6.16	2.67	2.10	2.17	2.54	3.73	5.80	8.40
Stream Leakage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Lake Seepage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

3.5.6 Phase 1 Conclusions

The development of Phase 1 will create groundwater drawdown in the central portion of the site, but this will be offset by groundwater mounding related to the infiltration systems. The net change is small, and the 1 m drawdown in the deepest layer extends less than 800 m from the proposed excavation.

The drawdowns are, at every location, small relative to the available drawdown in the aquifer (Figure 2.8), indicating that any shallow private wells could be readily deepened if necessary. The drawdown at location GWP-4 (near a new housing development west of Horning's Mills) is approximately 0.5 m (Figure 3.6), while the available drawdown at that location is approximately 25 m (Figure 2.8), so there remains plenty of available well capacity during Phase 1 operations.

The drawdown reduces streamflow and surface leakage into Pond NAT-18. Hydrographs indicate that the difference between Baseline and Phase 1 streamflows at location STR8 are moderate while at STR7 they are low. Impact varies with the season at STR7, being less impactful during spring time. Of note is that the measured impact on streamflows tends to penalize both headwater streams with low flows throughout the year and higher order streams during the summer. At NAT-19, however, the water table is expected to rise, leading to increased groundwater ET, groundwater discharge to land surface, and decreased groundwater recharge (i.e. seepage out the bottom of the wetland).

3.6 *Phase 2 Impact Assessment Scenario*

3.6.1 Introduction

Scenario P2 (Phase 2) represents the complete extraction of aggregate from Bench 1 and 2 under Phases 1 and 2 and the ongoing extraction of Phase 2C. The open extraction face is shown as dotted lines in Figure 3.21. A cross section showing the extraction conditions is shown in Figure 3.22.

Overburden water control barriers have been constructed on four sides of the overburden (green line). Progressive barriers have been constructed along three sides of Bench 1 (dark blue line), and an open face exists in Bench 1 and 2 along the northern face (dashed red line).

Quarry floor drains will be constructed to distribute inflow to both the infiltration trenches in the northeast portion of the site and the southern infiltration galleries.

During this phase a buried drain constructed along the north western property boundary will collect groundwater so as to reduce groundwater mounding to the west of the property. The drain design is shown on the MHBC site plans. This water is collected and directly injected into the Guelph and Gasport injection wells along the eastern property boundary. Any excess is added to the eastern infiltration system trenches. The combined injection capacity of these wells is of 12 L/s, and a minimum length of 570 m of drain is estimated to generate this flow.

The numerical model was run with the modified inputs for Scenario P2 and model results were post processed and compared to Baseline Conditions.

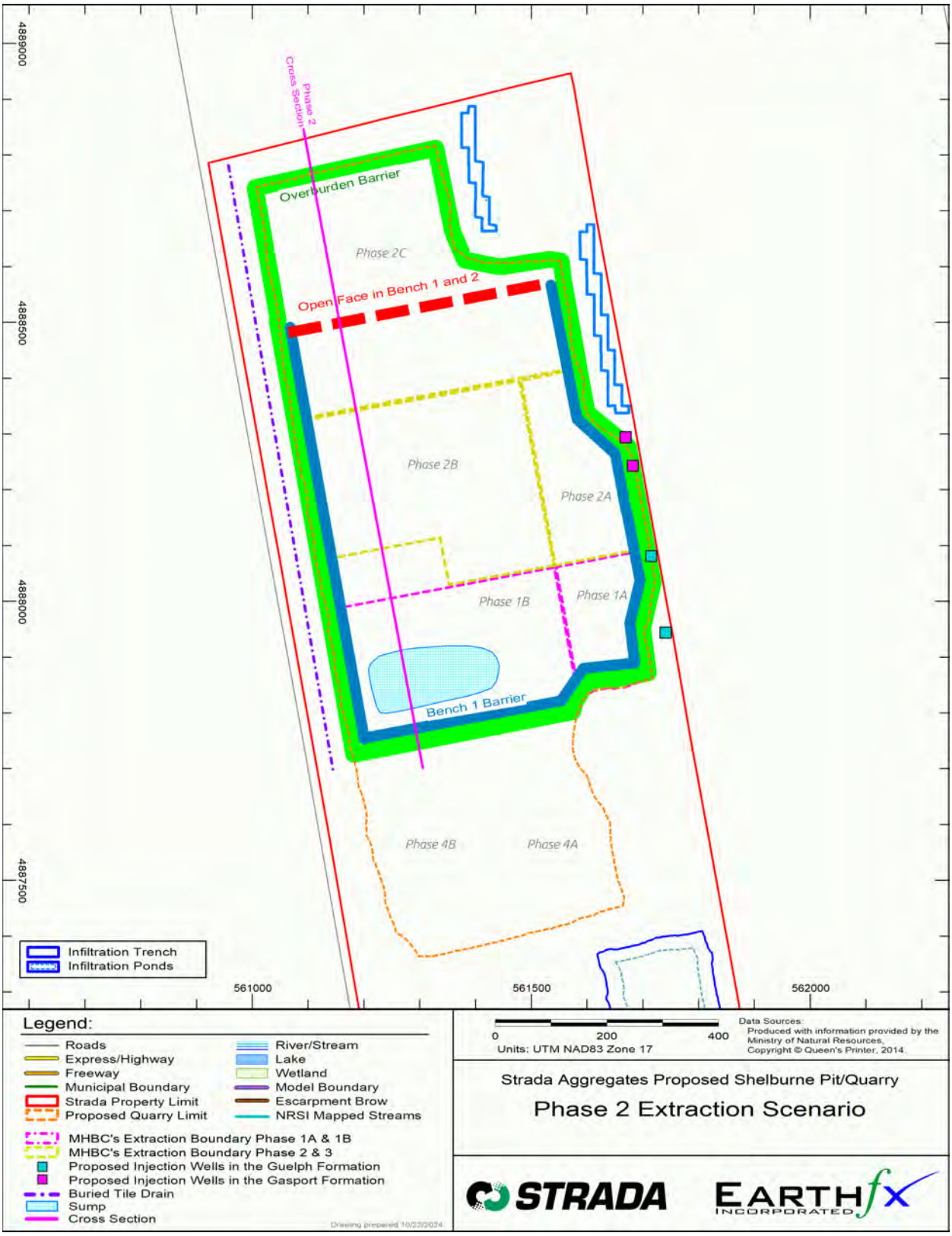


Figure 3.21: Phase 2 extraction scenario: barrier placement and open face location

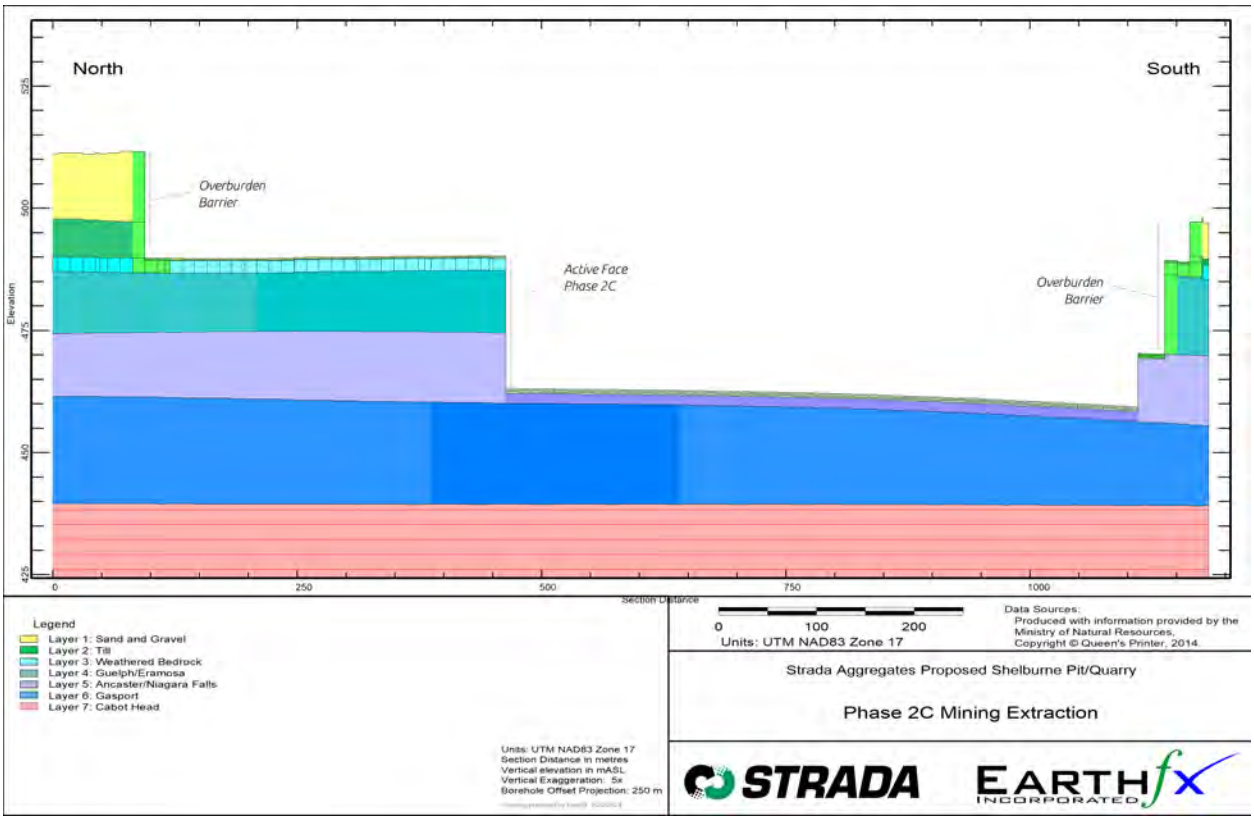


Figure 3.22: Cross section showing Phase 2 extraction

3.6.2 Phase 2 Drawdowns and Change in Surface Water Flow

Figure 3.23 shows the average simulated drawdown between Baseline and P2 extraction in Model Layer 1. Both drawdown (in red) and mounding (in blue) occur in the vicinity of the site, as the infiltration systems leak water into the shallow aquifer system causing a rise in water levels. The zone of impact extends farther east and west than the drawdowns simulated in P1 extraction, as the area of excavation to Bench 2 within the site has doubled, and a wide active face of excavation is maintained. The simulated drawdowns decrease with distance from the excavation, and fall to below 0.5 m at a distance of approximately 2000 m east and 1800 m west of the excavation.

In order to reduce the inflow from Gasport aquifer upwelling through the quarry floor, a 2 m thick layer of Niagara Falls formation is left unexcavated at the base of Bench 2.

Figure 3.24 and Figure 3.25 show the drawdown in the Layer 4 (Guelph) and Layer 6 (Gasport) aquifers. Like Layer 1, both the mounding and drawdown zones extend in a similar manner in the Guelph aquifer. In the confined Gasport aquifer, mounding is not evident, and the half metre drawdown extends to a distance of 2050 m west and 2300 m east.

The drawdowns are, at every location, small relative to the available drawdown in the aquifer (Figure 2.8), indicating that any shallow private wells could be readily deepened if necessary. The higher drawdowns near the excavation occur in an area with very few private wells and very high available drawdown (40-60 m). The drawdown at location GWP-4 (near a new housing development west of Horning's Mills) is approximately 1.1 m (Figure 3.23), while the available drawdown at that location is

approximately 25 m (Figure 2.8). In general, 5 m of available drawdown is considered adequate in limestone aquifers such as those encountered in the study area, so there remains plenty of available well capacity during operations. Water wells within the area of predicted drawdown will be visited and the available drawdowns will be confirmed, provided permission is granted by homeowners.

The effects on adjacent extraction licenses, surface and groundwater permits, agricultural lands and private septic systems are discussed in Section 3.9.

Figure 3.26 and Figure 3.27 show the average simulated increase and decrease in streamflow. There is a modest increase in flows in streams north, south, and west of the site due to both the infiltration system and overburden and Bench 1 barriers. The decrease in streamflow is limited to the stream reaches that flow into the NAT-18 pond, and very small decreases occur in a stream to the south.

In summary, P2 has a low impact on local groundwater levels and stream flows. Despite open extraction faces in the north facing Bench 1 and 2, the infiltration systems mitigate the effects of the drawdowns. The drawdowns are small relative to the available drawdown in the aquifer (Figure 2.8) and higher drawdowns near the site occur in areas with very high available drawdown.

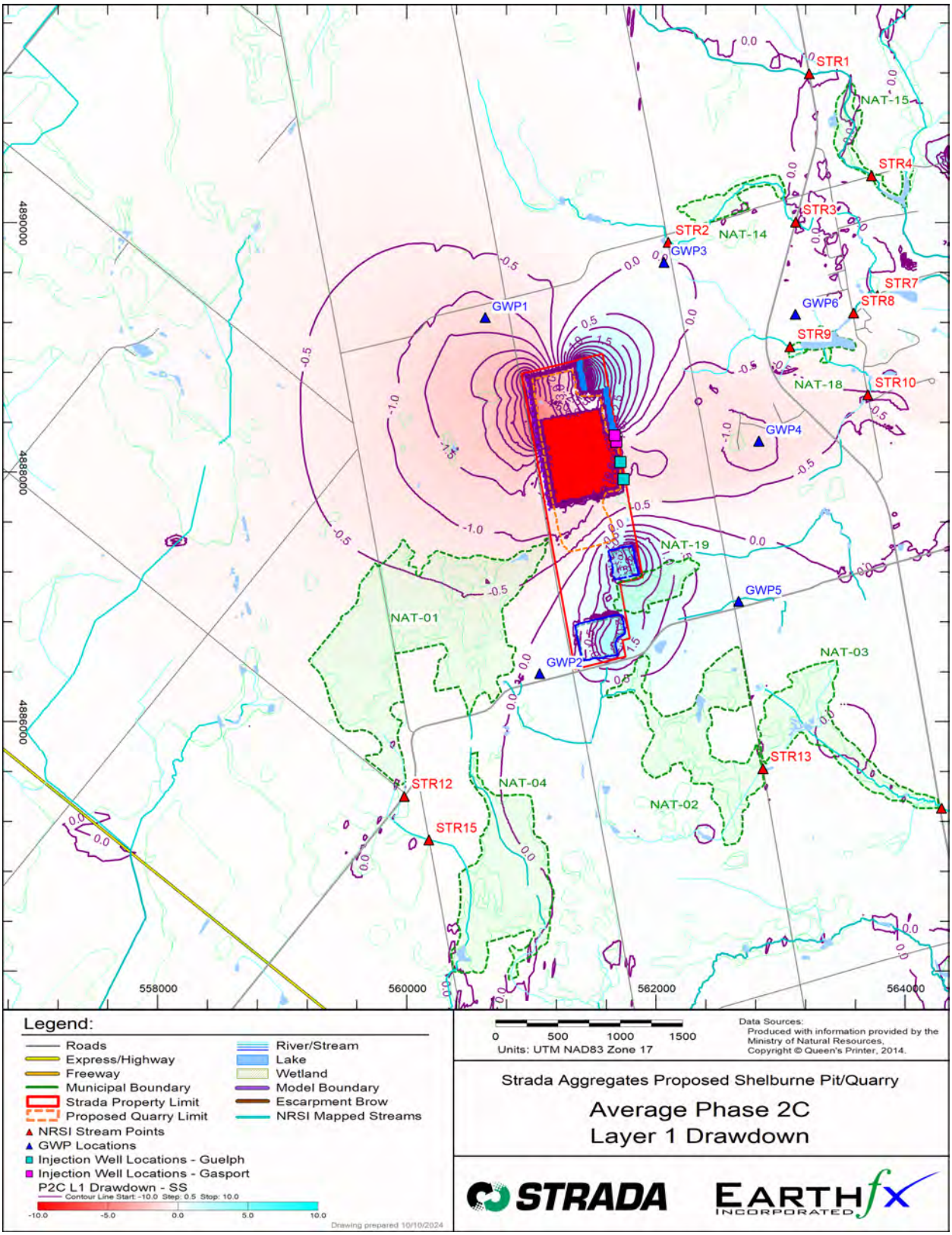


Figure 3.23: Average Phase 2 Layer 1 drawdown

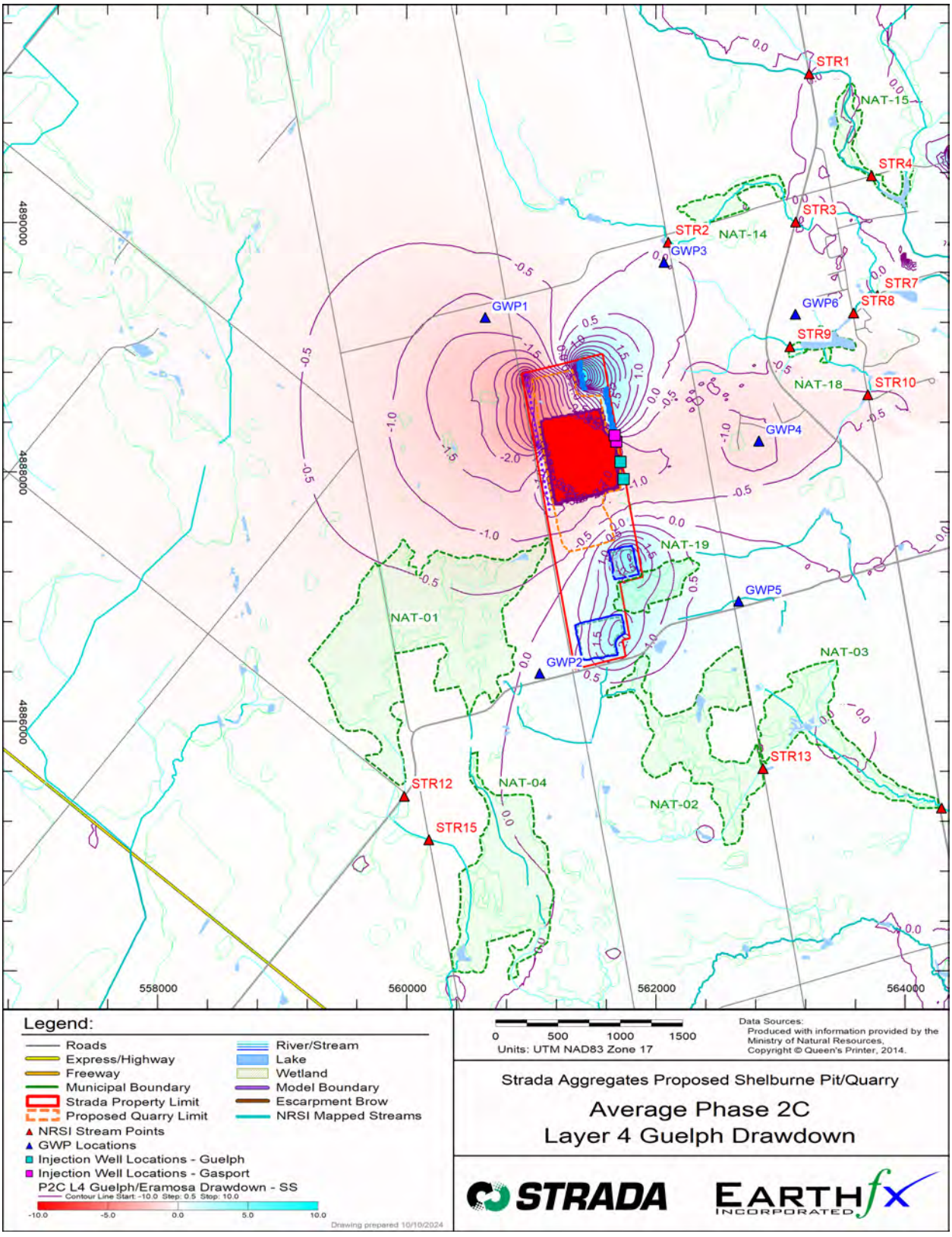


Figure 3.24: Average Phase 2 Layer 4 Guelph drawdown

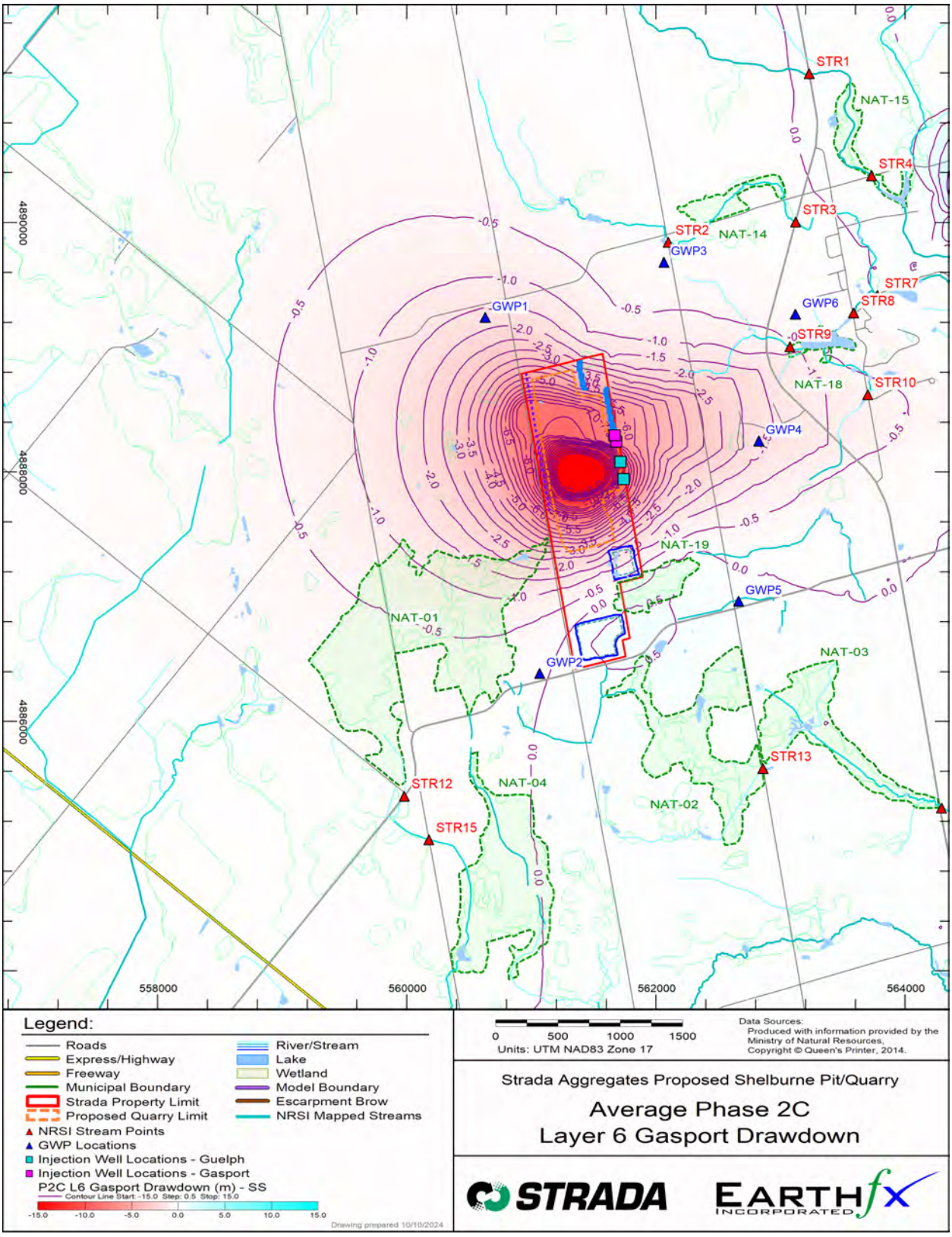


Figure 3.25: Average Phase 2 Layer 6 Gasport drawdown

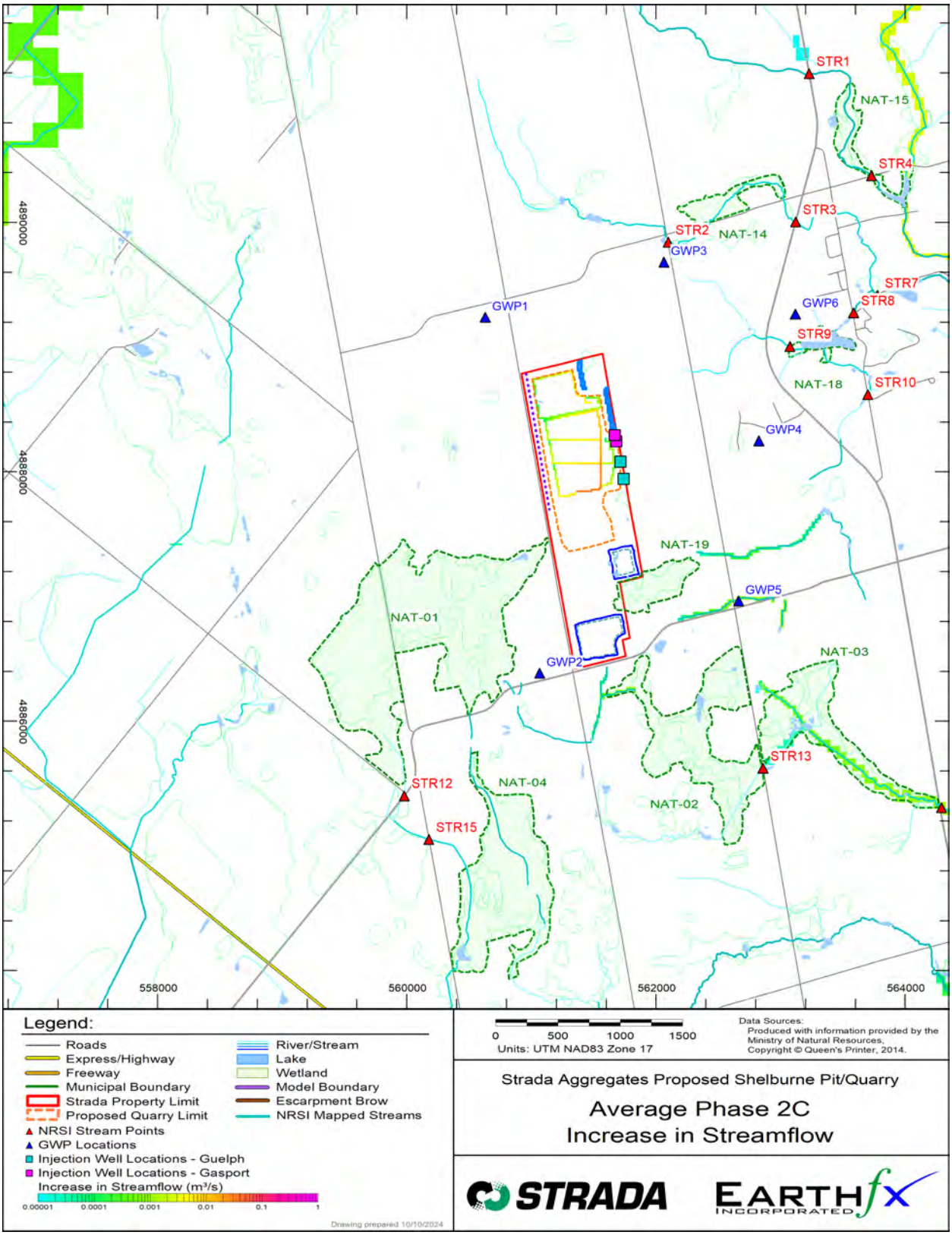


Figure 3.26: Average Phase 2 increase in streamflow

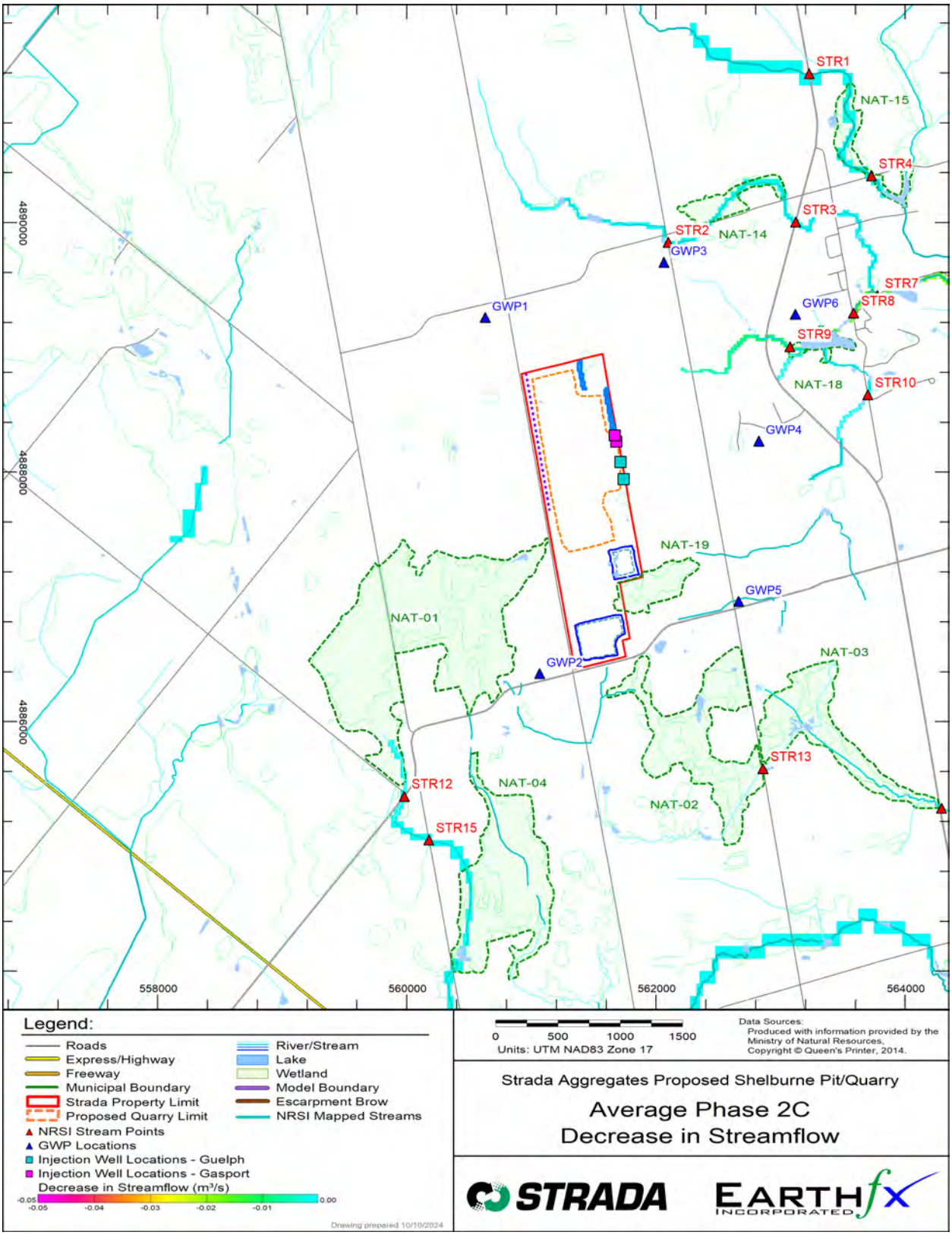


Figure 3.27: Average Phase 2 decrease in streamflow

3.6.3 Phase 2 Seasonal and Inter-Annual Change in Flows and Levels

The transient simulations through 2015-2024 provide insight into the effects of Phase 2 during seasonal and inter-annual variation.

The groundwater levels at two key locations, GWP4 and GWP6 (location shown in Figure 2.11), have been selected to illustrate the seasonal variation. Groundwater drawdowns at other locations are minimal, and mounding effects are discussed in the feature-based water budgets. Figure 3.28 shows that the change in groundwater levels between Baseline and Phase 2 in the Guelph and Gasport formations at location GWP4 are generally varying with slightly higher drawdowns during periods of lower water levels. Specifically, water levels during the summer are predicted to be reduced by 1.0 (in Guelph) to 1.8 m (in Gasport), whereas the reduction during the winter will be limited to a range of 1.5 to 2.0 m.

Figure 3.29 shows that the change in groundwater variability between Baseline and Phase 2 in the Guelph and Gasport formations at location GWP6 are minimal. However, in the Gasport formation, slightly greater drawdowns of approximately 0.2 m are predicted during both the summer and the wet seasons.

Figure 3.30 shows the change in streamflow at STR9 between the Baseline and Phase 2 scenario (location shown in Figure 2.11). Peak flows in this small headwater tributary are slightly more affected than summer low flows. This tributary is only one small component of the water budget of Pond NAT-18, and the full water budget for that feature is discussed in the following section. However, similarly as in Phase 1, the very low flows in this stream are significantly affected with percent reductions of 40% to 50% during the dry and wet seasons, respectively.

Figure 3.31 shows the effect of Phase 2 on flows down stream of Pond NAT-18 at locations STR8 and STR7. The hydrograph indicates a reduction between Baseline and Phase 2 streamflows at location STR8 of approximately 30%. At location STR7 streamflow reductions are expected to be between 10% and 20%.

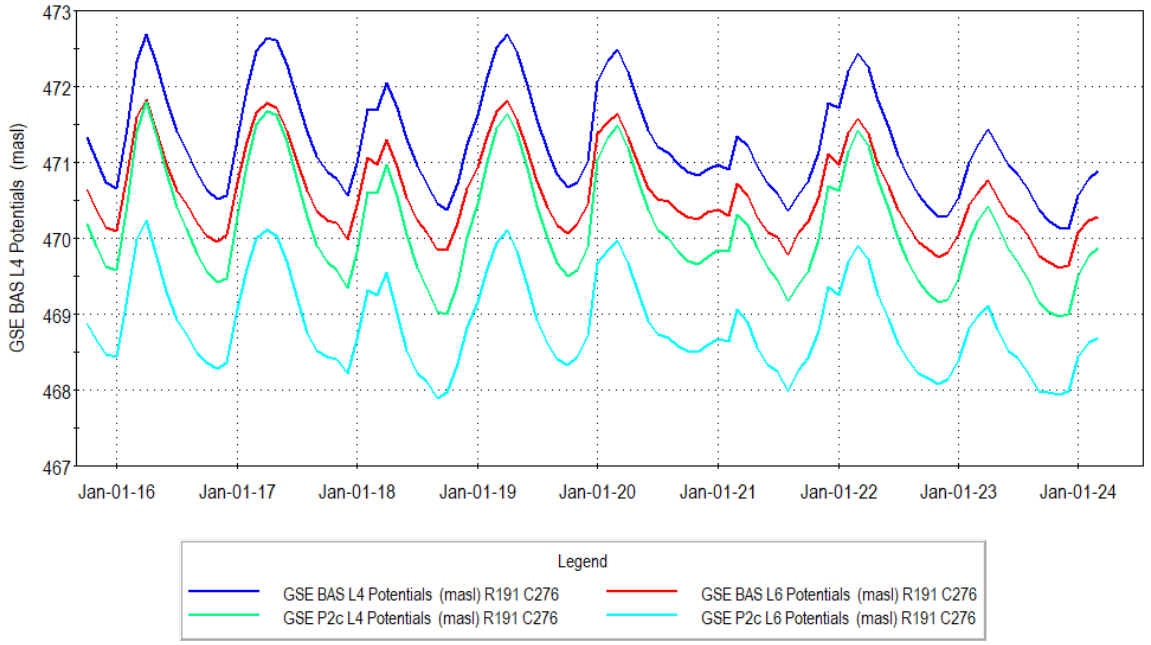


Figure 3.28: Comparison of groundwater levels under Phase 2 at location GWP4.

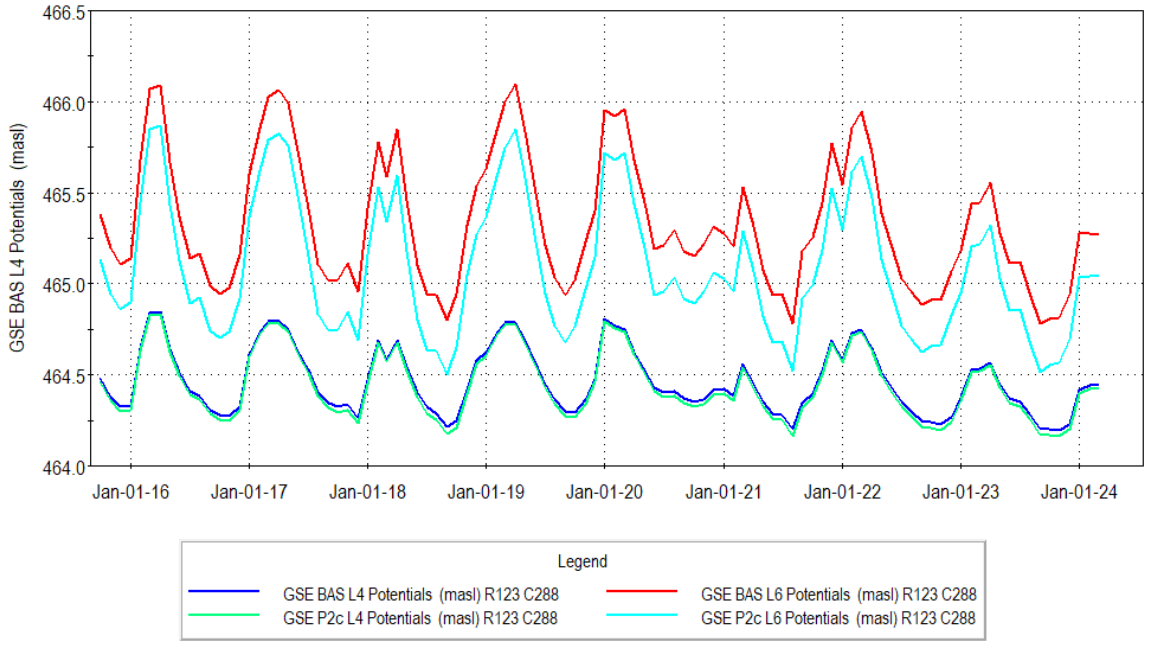


Figure 3.29: Comparison of groundwater levels under Phase 2 at location GWP6

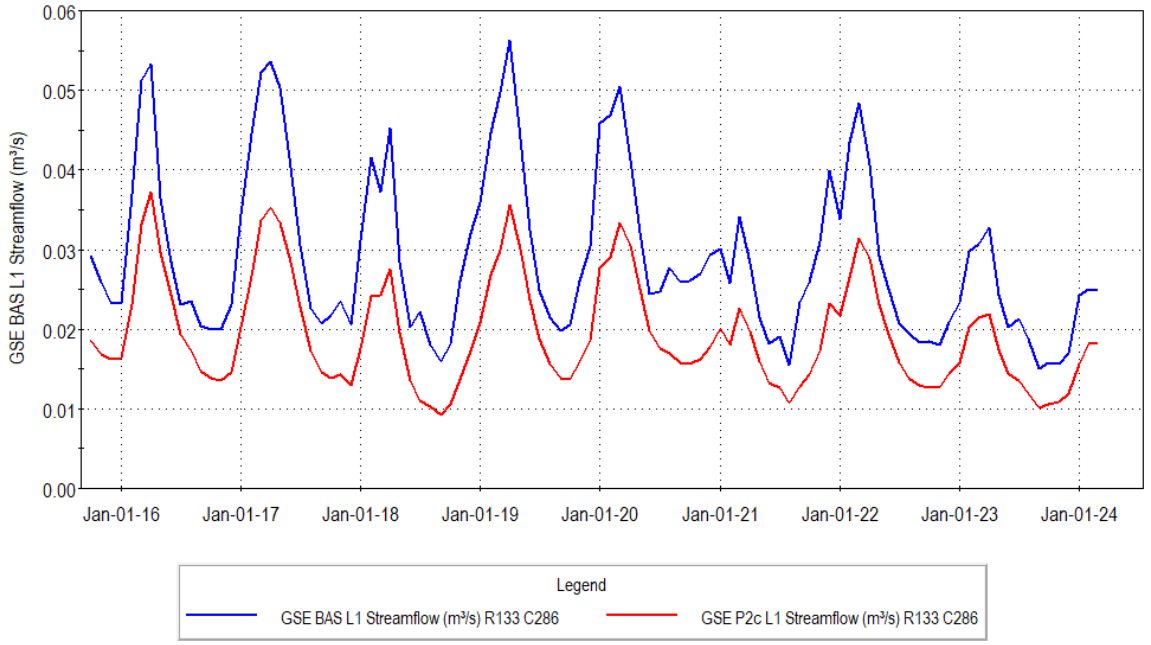


Figure 3.30: Comparison of streamflow at STR9 under baseline and Phase 2 scenarios

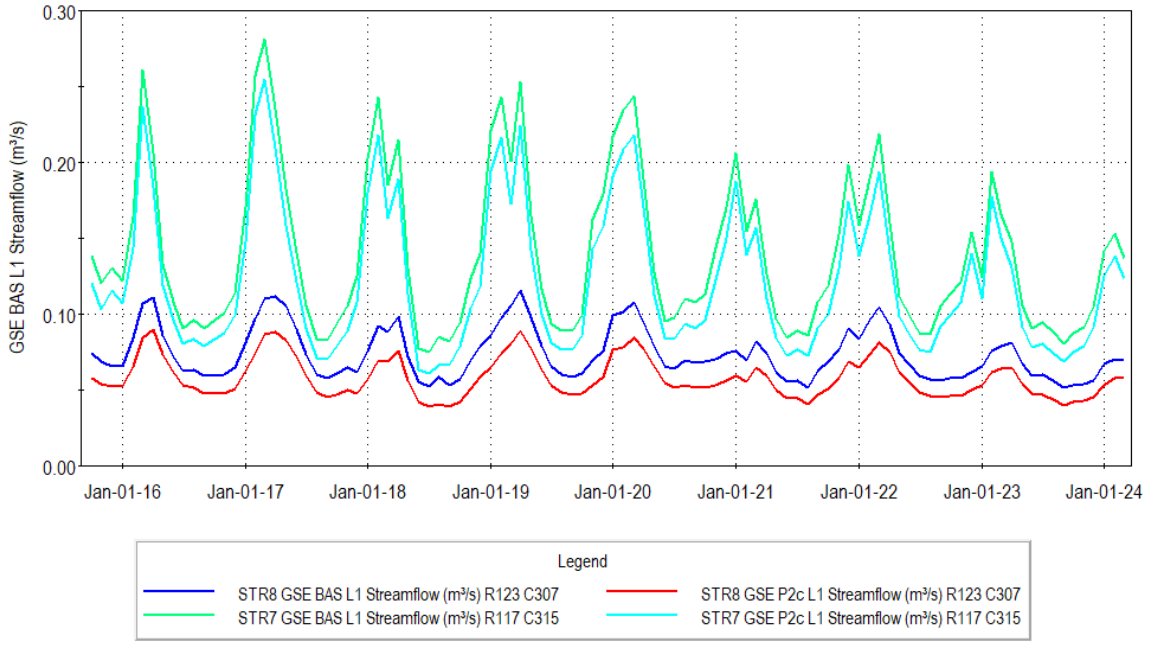


Figure 3.31: Comparison of streamflow under Baseline and Phase 2 at locations STR8 and STR7

3.6.4 **Phase 2 Surface Water/Groundwater Interaction**

The spatial change in average groundwater seepage to wetlands and ponds is shown in Figure 3.32 and Figure 3.33. The wetlands to the south and north east of the site are predicted to receive an increase in surface leakage from the infiltration systems. Wetland NAT-18 will see a modest reduction in surface leakage, as discussed below. NAT-14 also shows a loss of surface leakage of less 0.5% of the average surface leakage into the wetland (See Section 9.3).

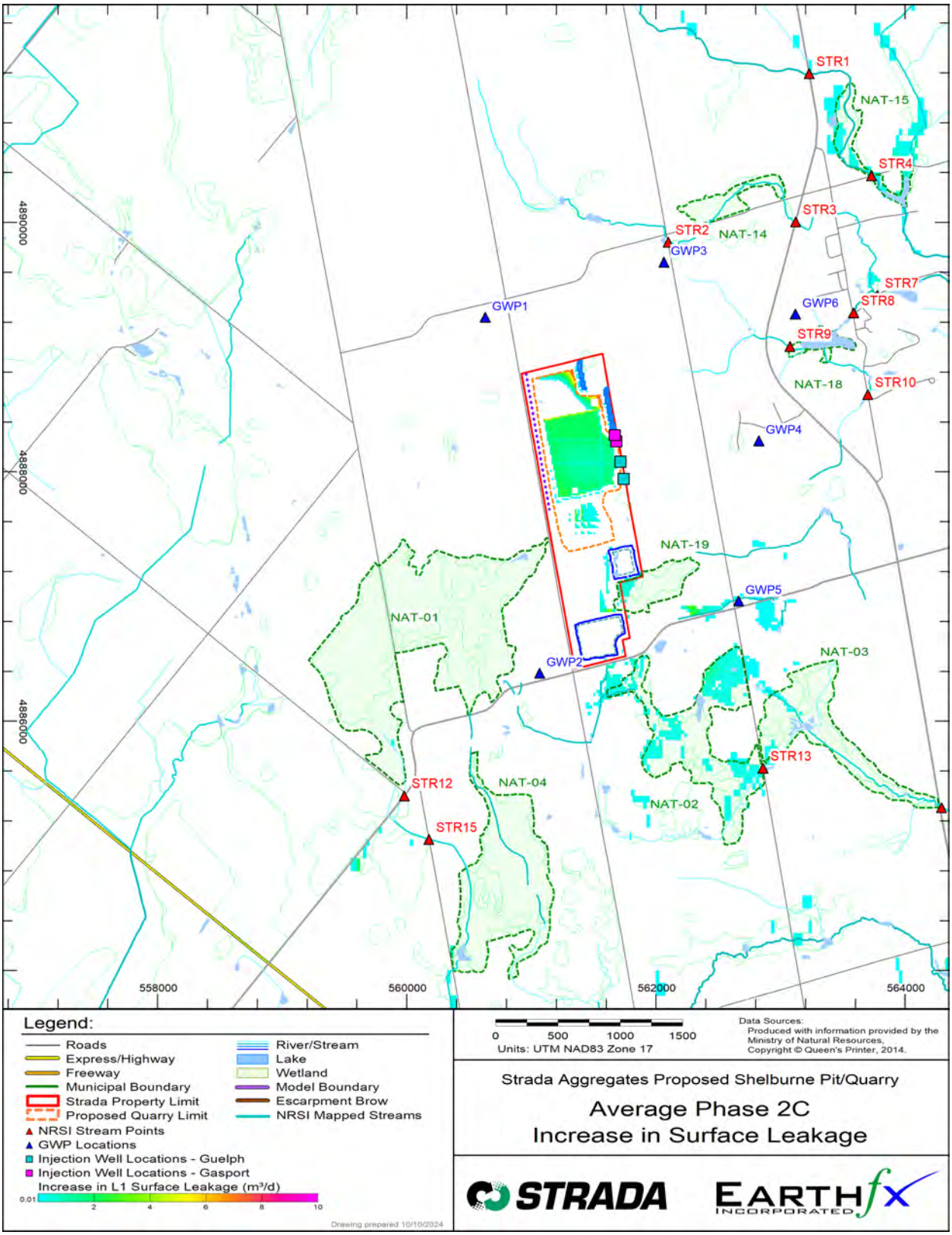


Figure 3.32: Average Phase 2 increase in surface leakage

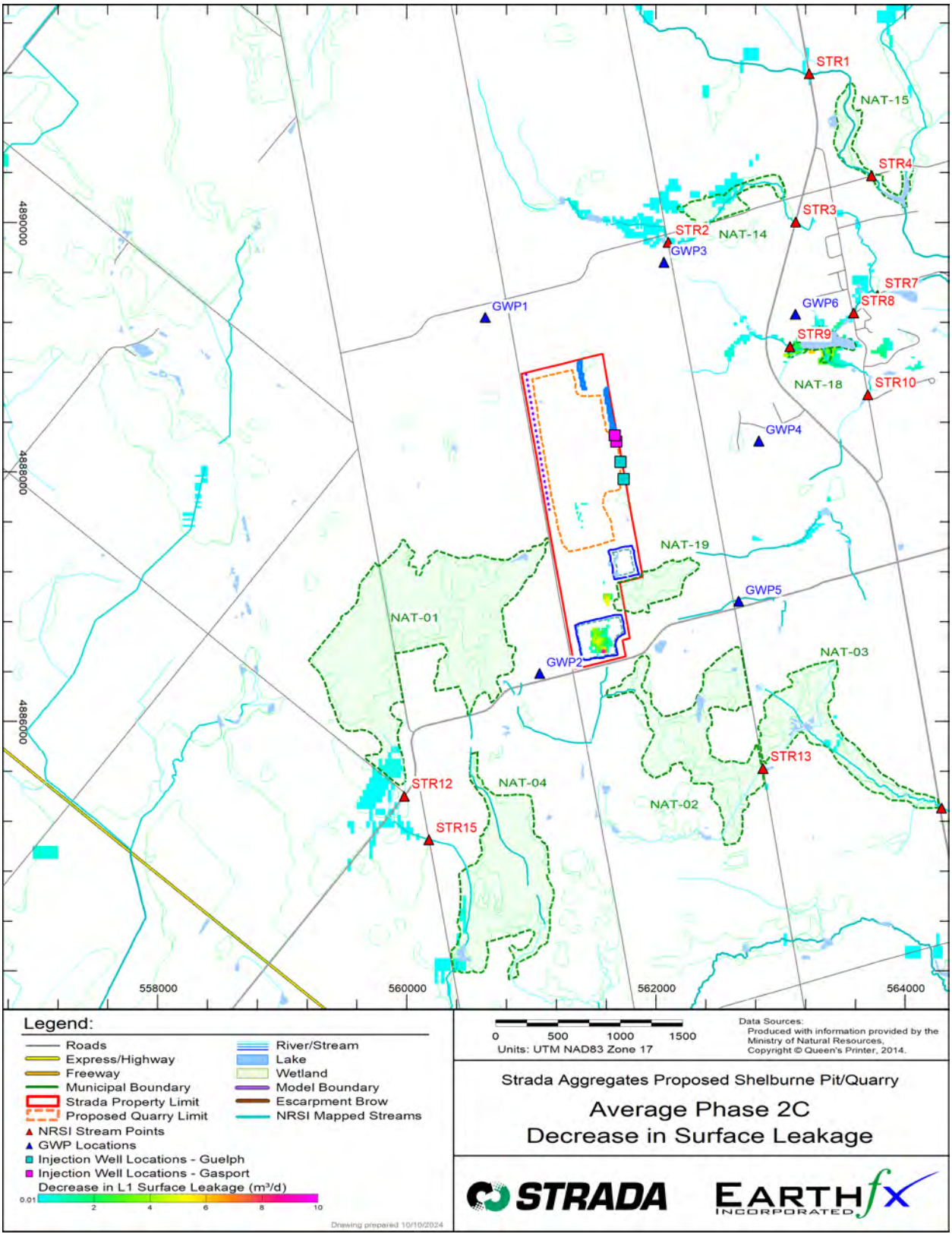


Figure 3.33: Average Phase 2 decrease in surface leakage

3.6.5 Wetland Water Budgets

A complete set of wetland water budgets under Phase 2 are included in Section 9.3. The two wetlands of particular interest are discussed below.

3.6.5.1 Wetland NAT-18

Wetland NAT-18 is the dammed pond near Horning's Mills that is discussed in Section 2.5.2. The surface water and groundwater components of the water budget are presented as bar charts (Figure 3.34 and Figure 3.35) and underlying tables Table 3.11 through Table 3.14 show both the raw values in these figures and their relative differences with respect to the Baseline Condition.

The change in the surface water budget is tabulated in Table 3.12 and shows that there is no change in surface water flows.

The change in the groundwater budget is documented in Table 3.14. There is a reduction in the net lateral flow in by 75.8 to 96.7 mm/month or approximately 11.6%. The reduction is accompanied by a similar scale decrease in the magnitude of surface leakage and stream leakage. Overall, the changes are moderate.

Simulated stream inflow decreases by 9.2 to 15.7 L/s from baseline conditions due to changes occurring outside the wetland. Inflow into the wetland decreases by about 2.7 to 3.5 L/s. Simulated stage also drops slightly (0.06 to 0.08 m) due to changes in lake inflows.

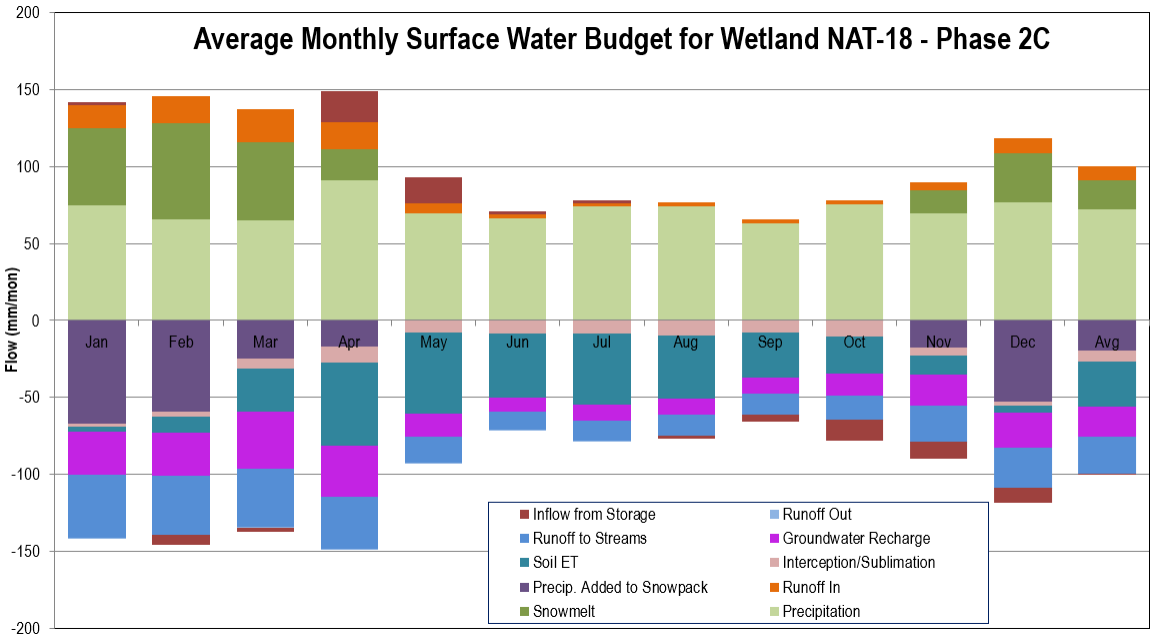


Figure 3.34: Phase 2 surface water budget for NAT-18

Table 3.11: Monthly surface water budget under Phase 2 Conditions (in mm/month) Wetland NAT-18

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	74.83	65.72	65.06	90.70	69.46	66.21	73.84	73.95	63.10	75.60	69.24	76.44	72.01
Snowmelt	50.13	62.60	50.35	20.42	0.00	0.00	0.00	0.00	0.00	0.01	15.10	32.31	19.24
Runoff In	15.24	17.47	22.07	17.72	6.57	3.00	2.42	2.83	2.87	2.93	5.82	9.69	9.05
Precip. added to Snowpack	-67.29	-59.48	-24.71	-17.17	0.00	0.00	0.00	0.00	0.00	-0.01	-17.29	-52.53	-19.87
Interception/Sublimation	-1.49	-3.00	-6.58	-9.89	-8.10	-8.47	-8.74	-9.50	-7.72	-10.39	-5.60	-2.74	-6.85
Soil ET	-3.22	-10.35	-27.90	-53.86	-52.29	-41.89	-46.15	-41.01	-29.55	-24.01	-12.48	-4.84	-28.96
Groundwater Recharge	-28.49	-28.55	-37.47	-33.88	-15.38	-9.02	-10.33	-10.75	-10.61	-14.49	-20.22	-23.04	-20.19
Runoff to Streams	-40.72	-37.63	-37.40	-33.30	-16.69	-11.47	-12.87	-13.83	-13.18	-15.57	-23.52	-25.46	-23.47
Runoff Out	-0.39	-0.47	-0.69	-0.62	-0.21	-0.08	-0.05	-0.05	-0.06	-0.05	-0.12	-0.23	-0.25
Inflow from Storage	1.40	-6.30	-2.72	19.87	16.65	1.71	1.88	-1.64	-4.87	-14.00	-10.94	-9.59	-0.71

Table 3.12: Difference in monthly surface water budget (Baseline - Phase 2) in mm/month Wetland NAT-18

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precip. added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater Recharge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff to Streams	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

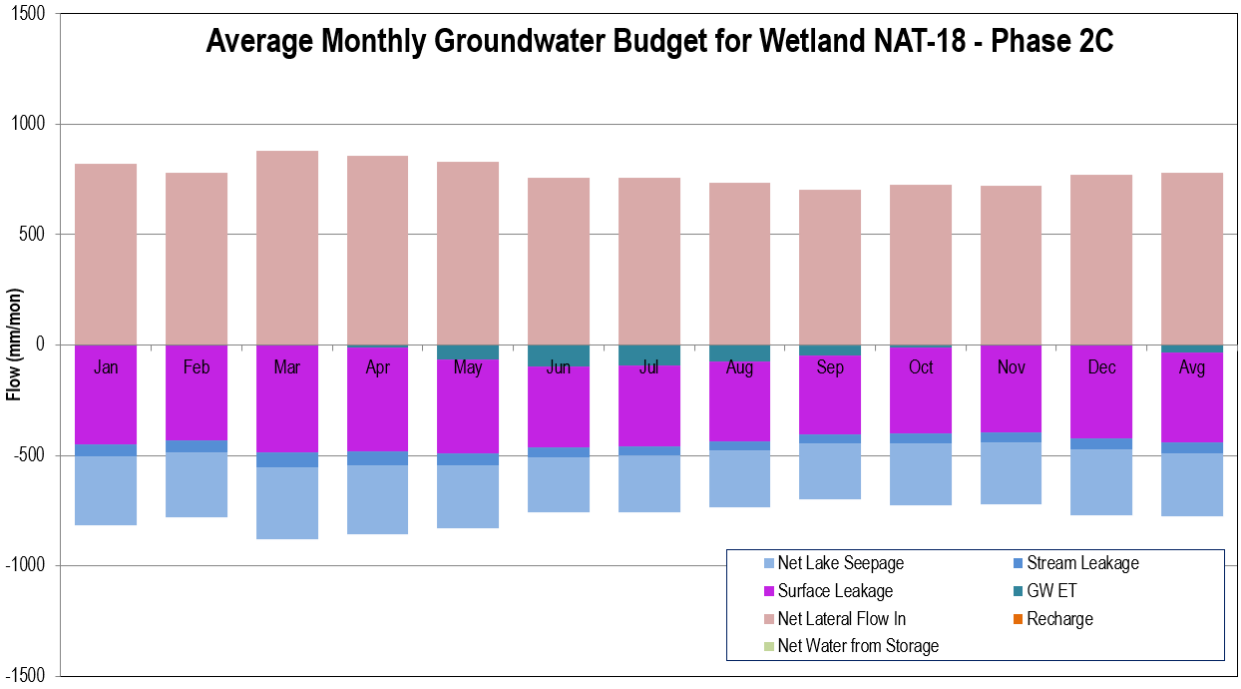


Figure 3.35: Groundwater budget for NAT-18

Table 3.13: Monthly groundwater budget under Phase 2 Conditions (in mm/month) Wetland NAT-18

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-0.35	-0.30	-0.20	0.06	0.88	0.77	0.20	0.10	-0.12	-0.35	-0.31	-0.25	0.01
Recharge	2.45	2.15	2.92	2.66	1.27	0.86	1.09	1.00	1.18	1.54	1.99	2.24	1.78
Net Lateral Flow In	817.4	778.6	877.0	853.0	826.7	756.9	755.7	733.3	700.1	725.4	721.7	771.1	776.4
GW ET	-0.38	-0.58	-1.79	-10.52	-66.18	-98.25	-91.20	-76.27	-47.25	-11.73	-1.87	-0.39	-33.87
Surface Leakage	-447.4	-429.2	-486.5	-470.2	-424.5	-365.7	-366.6	-360.4	-356.2	-388.7	-392.6	-422.2	-409.2
Stream Leakage	-56.11	-55.43	-64.44	-62.50	-52.79	-43.04	-42.07	-40.87	-40.45	-44.88	-46.39	-51.08	-50.00
Net Lake Seepage	-312.1	-293.8	-326.6	-312.0	-285.4	-251.6	-257.1	-256.1	-254.8	-278.3	-280.1	-298.5	-283.9
Streamflow In (L/s)	36.3	40.9	44.6	45.9	39.2	33.6	30.4	27.9	26.9	27.4	29.1	31.7	34.5
Streamflow Out (L/s)	61.8	67.6	72.5	74.2	64.8	56.4	52.0	49.1	48.3	49.7	52.3	55.9	58.7
Avg Lake Stage (masl)	450.7	450.7	450.8	450.8	450.7	450.7	450.7	450.7	450.6	450.7	450.7	450.7	450.7

Table 3.14: Difference in Monthly Groundwater Budget (Baseline - Phase 2) in mm/month - Wetland NAT-18

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	0.05	0.05	0.01	0.02	-0.11	-0.06	-0.01	-0.02	-0.01	0.00	0.03	0.05
Recharge	-0.14	-0.11	-0.37	-0.32	-0.04	-0.03	-0.03	-0.08	-0.05	-0.07	-0.11	-0.14
Net Lateral Flow In	86.58	75.81	86.77	83.26	90.68	91.18	95.90	96.65	92.84	95.31	90.34	89.87
GW ET	0.00	0.00	0.00	-0.04	-0.99	-1.66	-1.57	-1.28	-0.80	-0.18	-0.02	0.00
Surface Leakage	-51.79	-45.10	-50.61	-49.41	-52.43	-51.75	-54.11	-55.56	-53.65	-54.91	-52.85	-52.16
Stream Leakage	-11.18	-10.33	-11.94	-11.52	-10.73	-9.67	-10.01	-10.08	-9.93	-10.67	-10.57	-10.79
Net Lake Seepage	-25.01	-21.24	-22.80	-22.52	-26.38	-28.01	-30.22	-29.90	-29.94	-30.37	-27.85	-27.11
Streamflow In (L/s)	14.2	15.6	15.7	15.6	11.4	9.3	9.7	9.2	9.6	10.2	11.4	12.4
Streamflow Out (L/s)	17.0	18.3	18.6	18.6	14.8	12.6	12.4	12.7	12.8	13.3	14.4	15.3
Avg. Lake Stage (masl)	0.07	0.08	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07

3.6.5.2 Wetland NAT-19

Wetland NAT-19 is located immediately adjacent to the Strada property. The surface water and groundwater components of the water budget are presented as bar charts (Figure 3.36 and Figure 3.37) and underlying tables Table 3.13 through Table 3.16 show both the raw values in these figures and their relative differences with respect to the Baseline condition.

Under Phase 2, there are very small changes (all less than 0.3 mm/month) in groundwater recharge and runoff into the wetland, likely due to rejected recharge due to a higher water table near the infiltration pond (Table 3.16). Changes to the surface water budget are negligible, and due to small changes in the discharge from the infiltration ponds. The groundwater water budget shows more significant change in the pattern of the response with increased surface leakage and groundwater ET, indicative of a higher water table. Net lateral groundwater flow out of the wetland decreases compared to baseline conditions and, in the summer, there is net lateral inflow into the wetland. At the same time, groundwater recharge is predicted to decrease as a portion of the area has changed to a groundwater discharge zone and the recharge provided by the surface water model is rejected. The effect of changing from a perched wetland to groundwater-fed wetland (similar to the other wetlands analyzed) on wetland habitat is discussed under separate cover (NRSI, 2024).

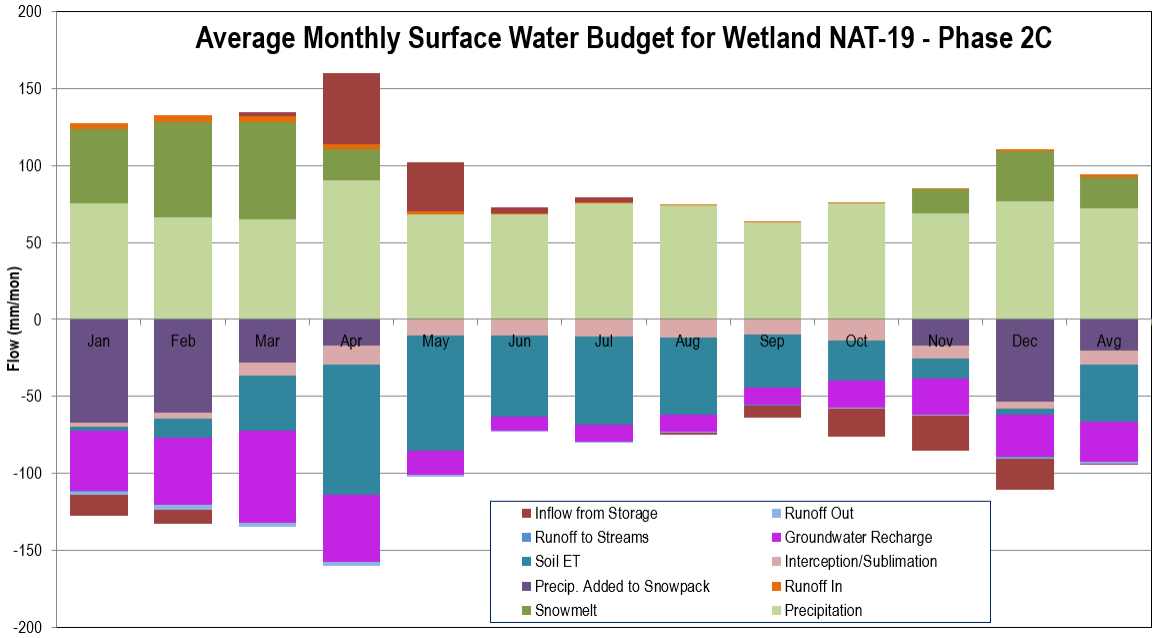


Figure 3.36: Surface water budget for NAT-19.

Table 3.15: Monthly surface water budget under Phase 2 Conditions (in mm/month) Wetland NAT-19.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	75.51	66.41	65.25	90.65	68.47	68.53	75.62	74.12	63.06	75.28	69.12	76.54	72.38
Snowmelt	48.27	61.65	62.56	19.94	0.00	0.00	0.00	0.00	0.00	0.01	15.08	32.35	19.99
Runoff In	3.69	4.50	4.17	3.23	1.40	0.64	0.47	0.54	0.56	0.54	1.10	1.88	1.89
Precip. added to Snowpack	-67.00	-60.61	-28.07	-16.82	0.00	0.00	0.00	0.00	0.00	-0.01	-17.12	-53.09	-20.23
Interception/Sublimation	-2.58	-3.82	-8.25	-12.29	-10.21	-10.40	-11.02	-11.86	-9.78	-13.62	-8.19	-4.57	-8.88
Soil ET	-2.82	-12.09	-36.11	-84.79	-74.91	-52.75	-57.39	-49.96	-34.17	-26.34	-12.81	-3.89	-37.34
Groundwater Recharge	-39.13	-43.87	-59.63	-43.67	-15.83	-8.92	-10.67	-11.24	-11.67	-17.39	-23.62	-27.88	-26.12
Runoff to Streams	-0.17	-0.20	-0.20	-0.13	-0.05	-0.03	-0.03	-0.06	-0.06	-0.05	-0.07	-0.07	-0.09
Runoff Out	-2.16	-2.71	-2.59	-2.01	-0.88	-0.40	-0.28	-0.31	-0.34	-0.33	-0.61	-1.05	-1.14
Inflow from Storage	-13.61	-9.25	2.87	45.88	32.00	3.34	3.29	-1.23	-7.60	-18.09	-22.88	-20.22	-0.46

Table 3.16: Difference in monthly surface water budget (Baseline - Phase 2) in mm/month Wetland NAT-19.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	-0.24	-0.14	-0.07	-0.06	-0.06	-0.04	-0.07	-0.09	-0.09	-0.09	-0.22	-0.23
Precip. added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.01	-0.01	0.04	0.03	0.07	0.08	0.06	0.02	0.01	0.00
Groundwater Recharge	0.18	0.12	0.05	-0.05	-0.04	-0.06	-0.06	-0.05	-0.04	-0.02	0.02	0.07
Runoff to Streams	-0.09	-0.11	-0.07	-0.07	-0.03	-0.02	-0.03	-0.04	-0.04	-0.03	-0.05	-0.04
Runoff Out	0.21	0.22	0.17	0.16	0.09	0.07	0.08	0.09	0.08	0.09	0.13	0.14

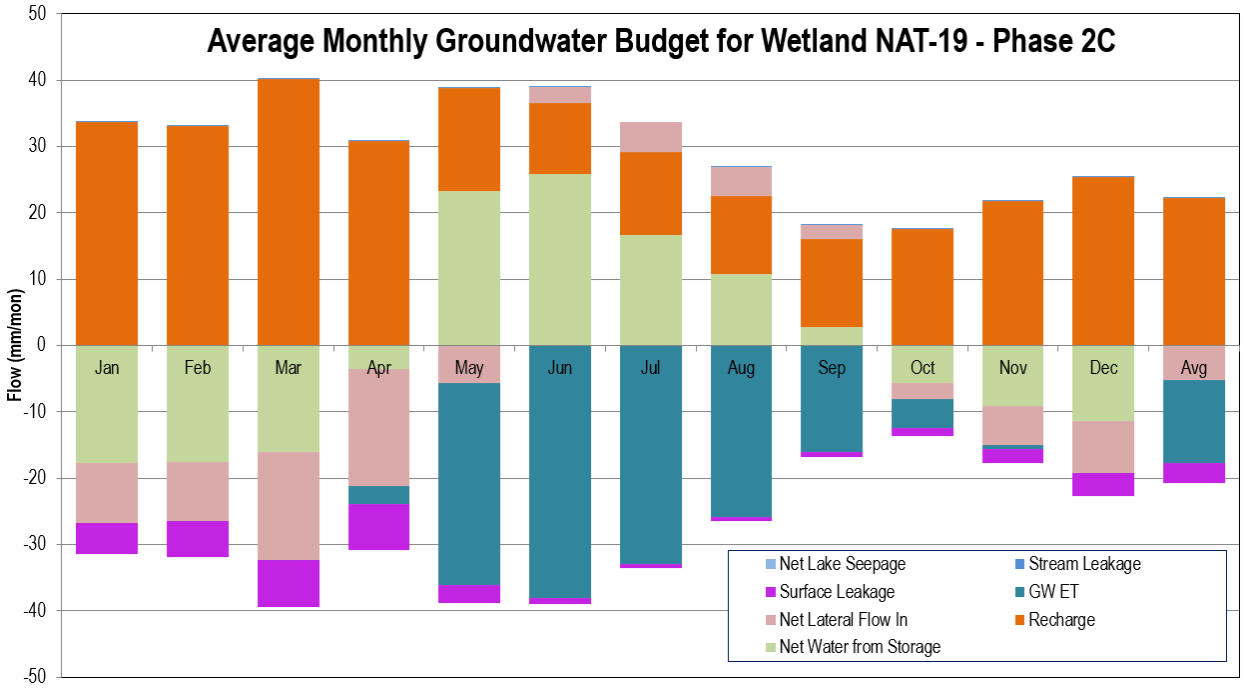


Figure 3.37: Groundwater budget for NAT-19

Table 3.17: Monthly groundwater budget under Phase 2 Conditions (in mm/month) Wetland NAT-19

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-17.76	-17.51	-16.08	-3.59	23.27	25.87	16.62	10.84	2.79	-5.70	-9.10	-11.36	-0.14
Recharge	33.69	33.14	40.14	30.89	15.53	10.68	12.62	11.67	13.23	17.61	21.79	25.48	22.21
Net Lateral Flow In	-8.98	-8.98	-16.26	-17.56	-5.70	2.48	4.51	4.43	2.16	-2.43	-5.92	-7.91	-5.01
GW ET	-0.01	-0.02	-0.04	-2.67	-30.40	-38.12	-32.88	-25.89	-16.07	-4.34	-0.60	-0.01	-12.59
Surface Leakage	-4.69	-5.43	-7.09	-6.98	-2.71	-0.90	-0.63	-0.65	-0.73	-1.13	-2.08	-3.43	-3.04
Stream Leakage	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Lake Seepage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 3.18: Difference in monthly groundwater budget (Baseline - Phase 2) in mm/month - Wetland NAT-19

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	-2.52	-3.29	-4.78	-1.92	-4.26	-3.47	0.79	2.78	5.25	7.87	4.46	1.56
Recharge	6.68	7.64	10.42	7.75	2.53	0.88	0.73	0.77	0.96	1.38	2.40	3.98
Net Lateral Flow In	-11.10	-10.99	-13.40	-15.01	-27.00	-32.50	-33.03	-29.62	-24.09	-18.66	-13.63	-11.75
GW ET	0.00	0.00	-0.01	2.07	26.03	34.19	30.65	25.00	15.77	4.28	0.59	0.00
Surface Leakage	4.69	5.43	7.09	6.98	2.71	0.90	0.63	0.65	0.73	1.13	2.08	3.43
Stream Leakage	-0.01	-0.01	-0.01	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Lake Seepage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

3.6.6 Phase 2 Conclusions

The development of Phase 2 will create groundwater drawdown in the central portion of the site, but this will be offset by groundwater mounding created by the infiltration systems. The net effect is small, and the 0.5 m drawdown in the deepest layer extending approximately 1700 m from the excavation.

The drawdowns are, at every location, small relative to the available drawdown in the aquifer (Figure 2.8), indicating that any shallow private wells could be readily deepened if necessary. The drawdown at location GWP-4 (near a new housing development west of Horning's Mills) is approximately 1.1 m (Figure 3.23), while the available drawdown at that location is approximately 25 m (Figure 2.8), so there remains plenty of available well capacity during operations.

The drawdown reduces streamflow and surface leakage into Pond NAT-18. In comparison to Phase 1, the impact on streamflows is similar, with the magnitudes being slightly greater. Hydrographs indicate that the difference between Baseline and Phase 2 streamflow at location STR7 in Horning's Mills is expected to be between 10% and 20%. Of note is that the measured impact on streamflows highlights small headwater streams with low flows throughout the year.

3.7 *Phase 4A Impact Assessment Scenario*

3.7.1 Introduction

Scenario P4A (Phase 4A) represents extraction of bedrock from the second to final Phase 4A cell (Figure 3.38). In this scenario Benches 1, 2 and 3 are all open along the active face in the south east portion of the excavation (Figure 3.38). The location of the open extraction faces is shown as a dotted red line in Figure 3.38. A cross section showing the extraction conditions is shown in Figure 3.39.

Overburden water control barriers have been constructed on four sides of the overburden (green line). Barriers have been constructed along the majority of Bench 1, with the exception of the south face (dark blue line). As noted, an open face exists in Bench 1, 2 and 3 in the Phase 4A cell (dashed red line).

Quarry floor drains have been constructed to distribute inflow to both the infiltration trenches at the northeast portion of the site and the southern infiltration galleries.

During this phase a buried drain constructed along the north western property boundary will collect groundwater so as to reduce groundwater mounding to the west of the property (constructed as per the MHBC site plans). This water is collected and conveyed to the Guelph and Gasport injection wells along the eastern property boundary and any excess is added to the eastern infiltration trenches. The combined injection rate is of 12 L/s. The drain is subdivided into three segments to provide flexibility in diverting and controlling flow, as needed. In this model representation, the north segment diverts 12 L/s directly to the injection wells (with any seasonal excess going to the northern infiltration trench), the middle segment to the southern infiltration trench, and the southern segment discharges into the central infiltration site.

The numerical model was run with the modified inputs for Scenario P4 and model results were post-processed and compared to Baseline Conditions.

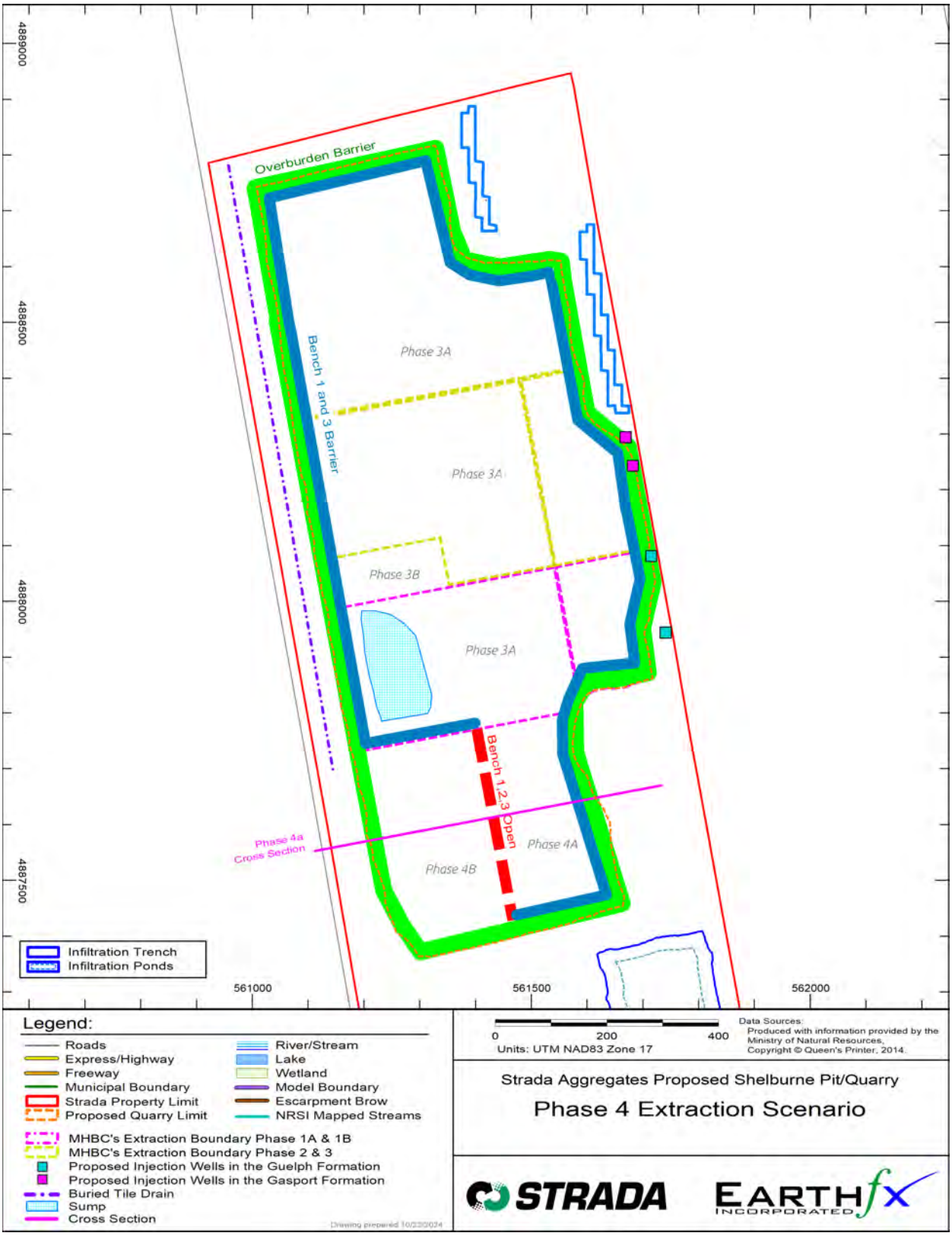


Figure 3.38: Phase 4A extraction scenario: barrier placement and open face location.

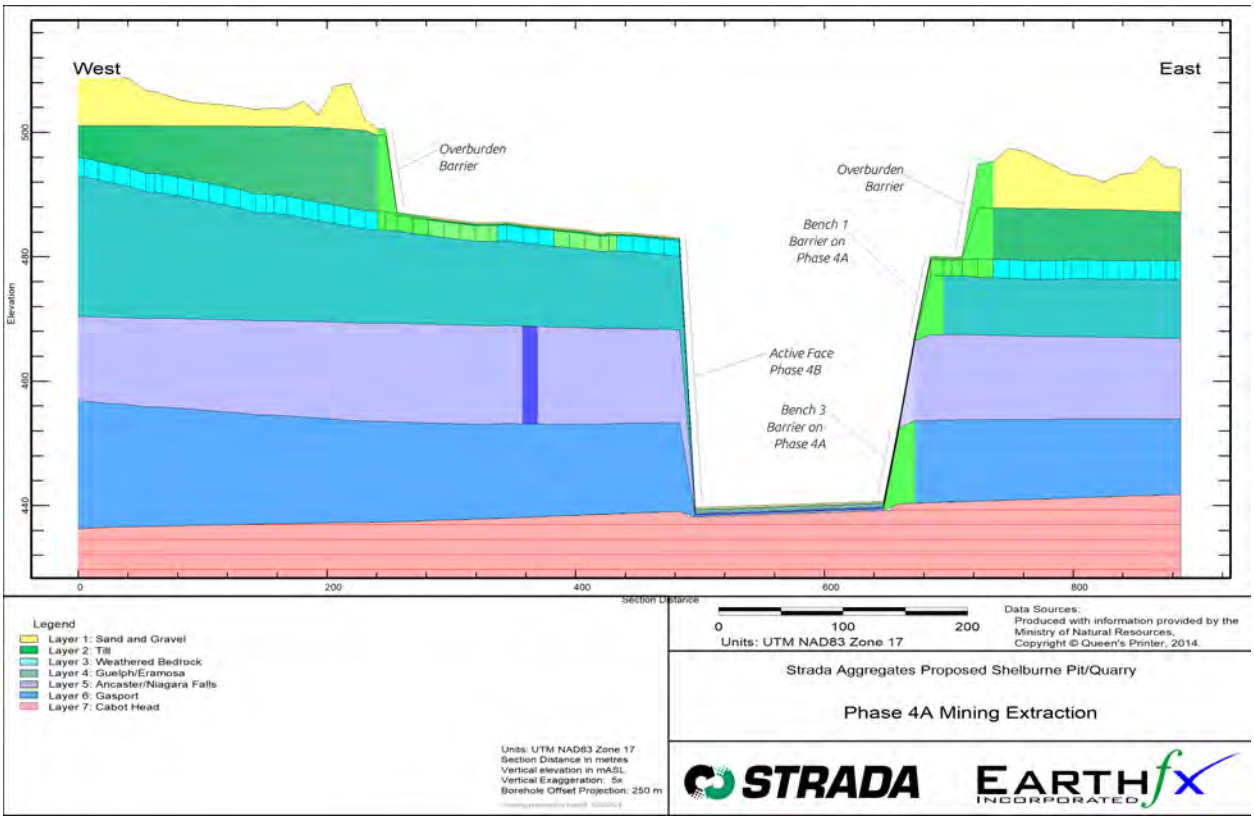


Figure 3.39: Cross section showing Phase 4 extraction

3.7.2 Phase 4A Drawdowns and Change in Surface Water Flow

Figure 3.40 shows the average simulated drawdown between Baseline and P4A extraction in Model Layer 1. Both drawdown (in red) and mounding (in blue) occur in the vicinity of the site, as the infiltration systems leak water into the shallow aquifer system and cause a minor local rise (mounding) in water levels. The simulated drawdowns decrease rapidly with distance from the excavation.

Figure 3.41 and Figure 3.42 show the drawdown in the Layer 4 (Guelph) and Layer 6 (Gasport) aquifers. Like Layer 1, mounding is also evident in the Guelph aquifer, and to a different extent in the confined Gasport aquifer. The mounding to the west of the site in the Gasport (Layer 6), is controlled by the western drain in Layer 1 and 4. The 1 m drawdown in the Gasport extends approximately 1600 m to the east of the site. The water levels in the shallow system beneath the adjacent licenced and proposed pits is fully controlled, as discussed in Section 3.9.3, below.

The drawdowns are, at every location, small relative to the available drawdown in the aquifer (Figure 2.8), indicating that any shallow private wells could be readily deepened if necessary. The drawdown at location GWP-4 (near a new housing development west of Horning's Mills) is approximately 1.25 m (Figure 3.40), while the available drawdown at that location is approximately 25 m (Figure 2.8). In general, 5 m of available drawdown is considered adequate in limestone aquifers such as those encountered in the study area, so there remains plenty of available well capacity during operations.

The effects on adjacent extraction licenses, surface and groundwater permits, agricultural lands and private septic systems are discussed in Section 3.9.

Figure 3.43 and Figure 3.44 show the average simulated increase and decrease in streamflow. There is a modest increase in flows in streams north and south of the site due to the infiltration system. The decrease in streamflow is limited to stream reaches that flow into the NAT-18 pond.

In summary, P4A has a minor impact on local groundwater levels and streams. Despite open extraction faces in the Bench 1 and 2 and 3, the infiltration and tile drain systems mitigate the effects of the drawdowns and mounding.

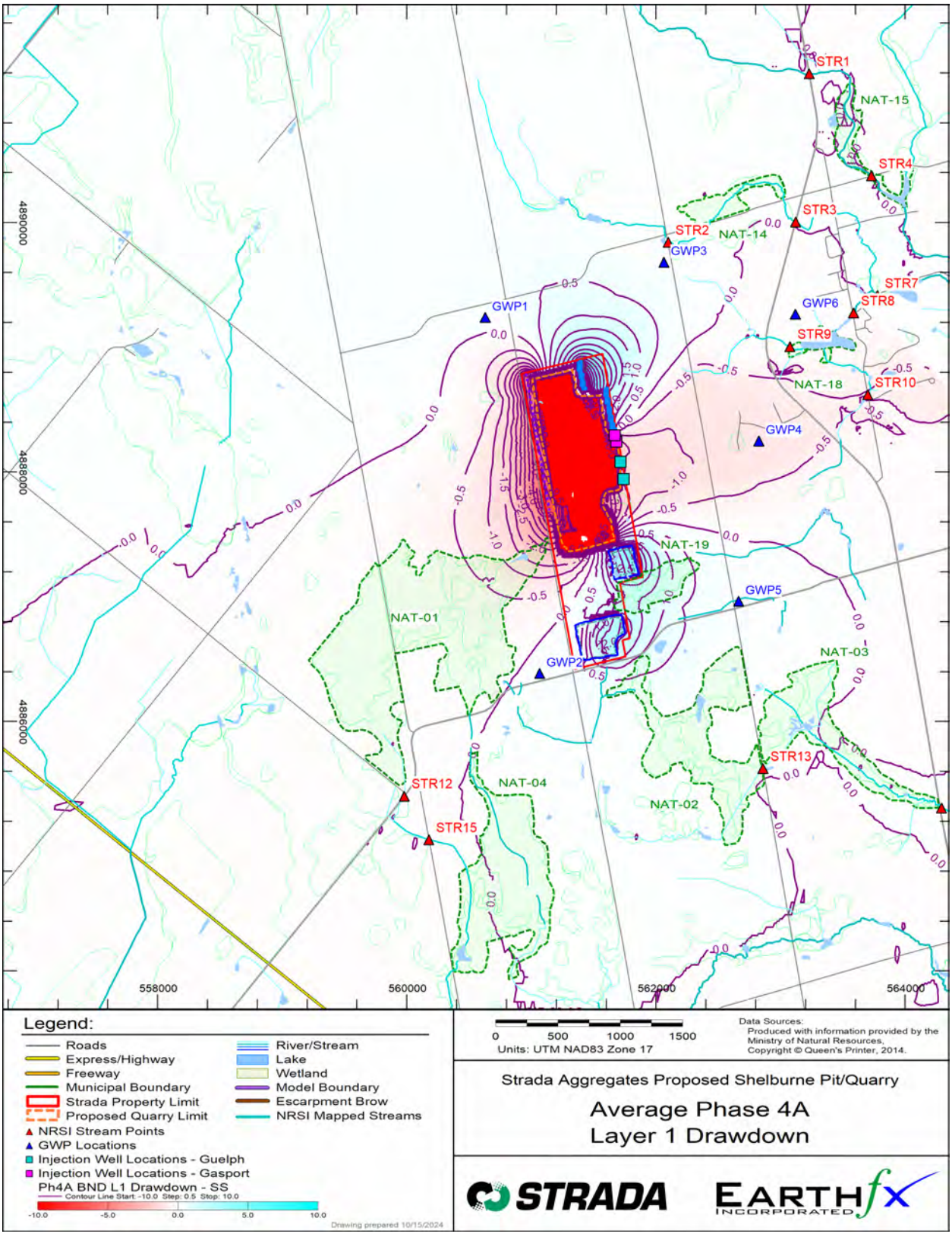


Figure 3.40: Average Phase 4A layer 1 drawdown

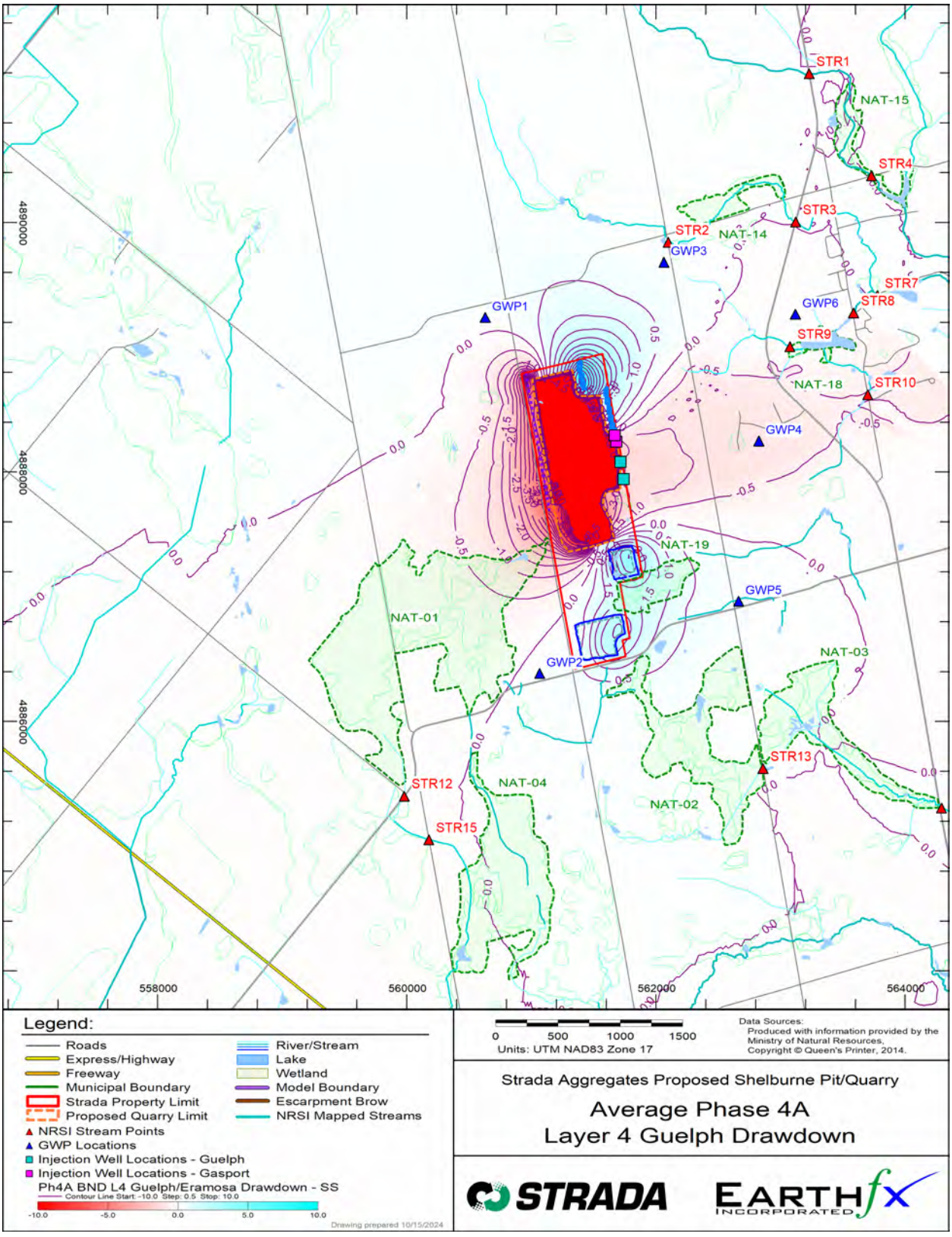


Figure 3.41: Average Phase 4A layer 4 Guelph drawdown

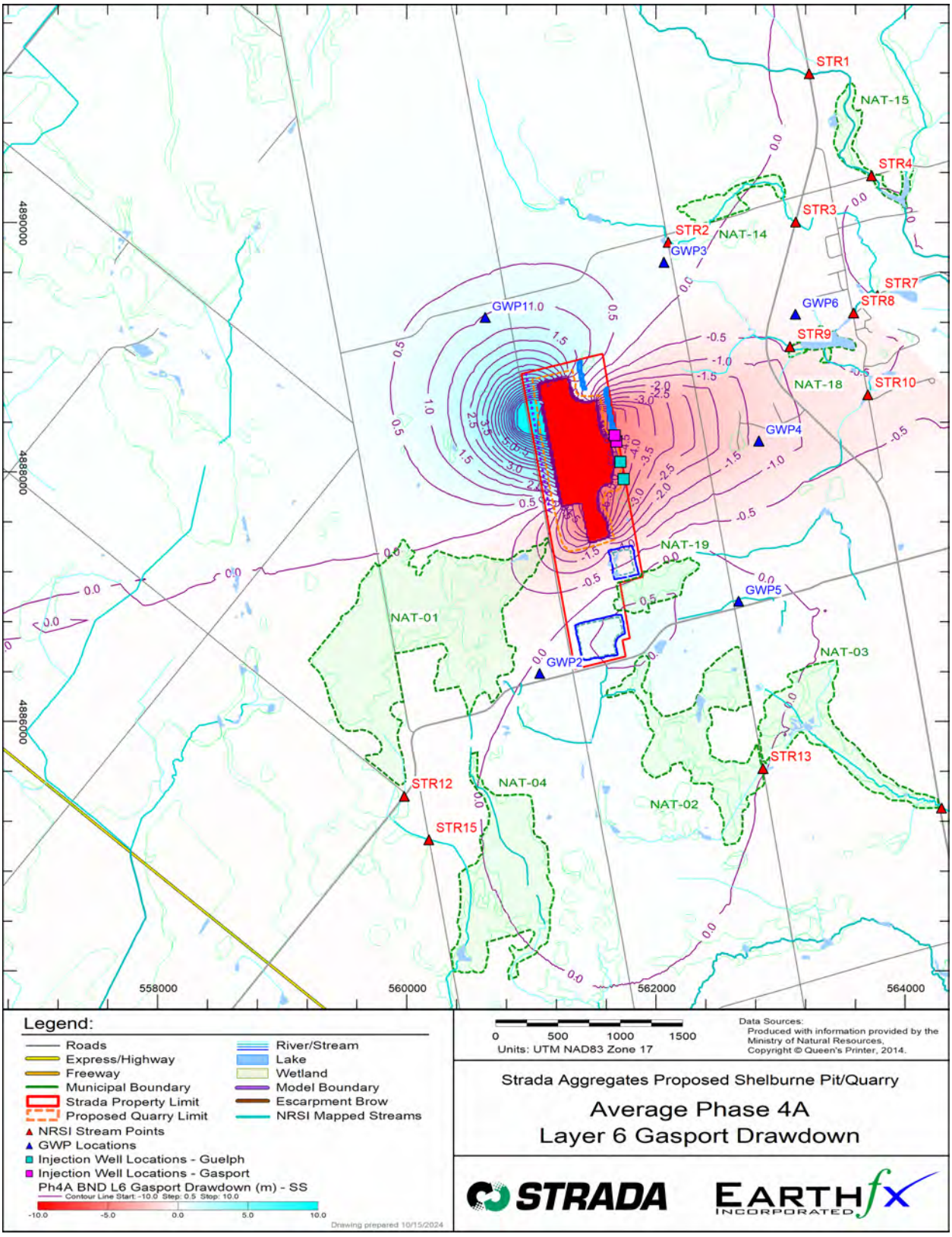


Figure 3.42: Average Phase 4A layer 6 Gasport drawdown

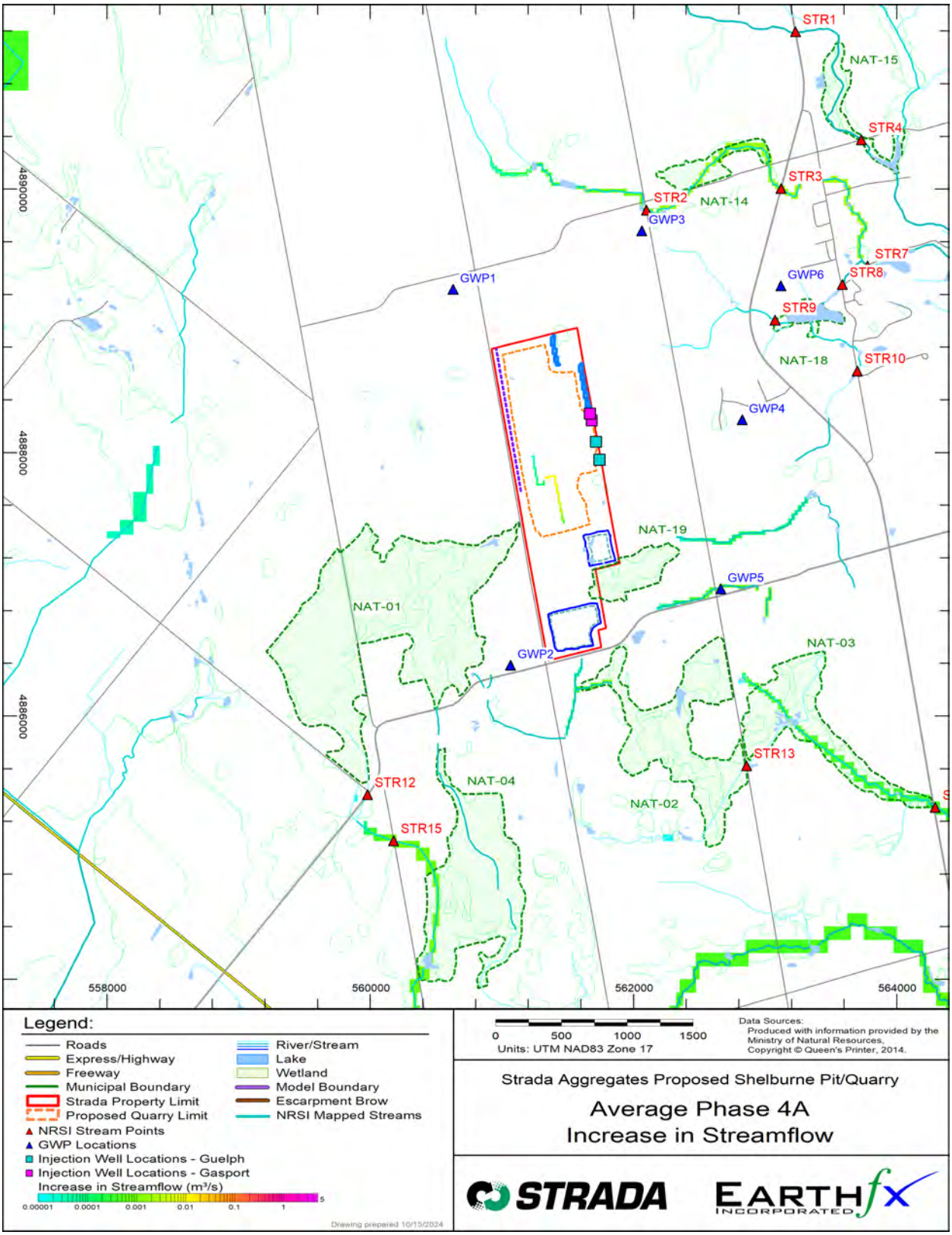


Figure 3.43: Average Phase 4A increase in streamflow

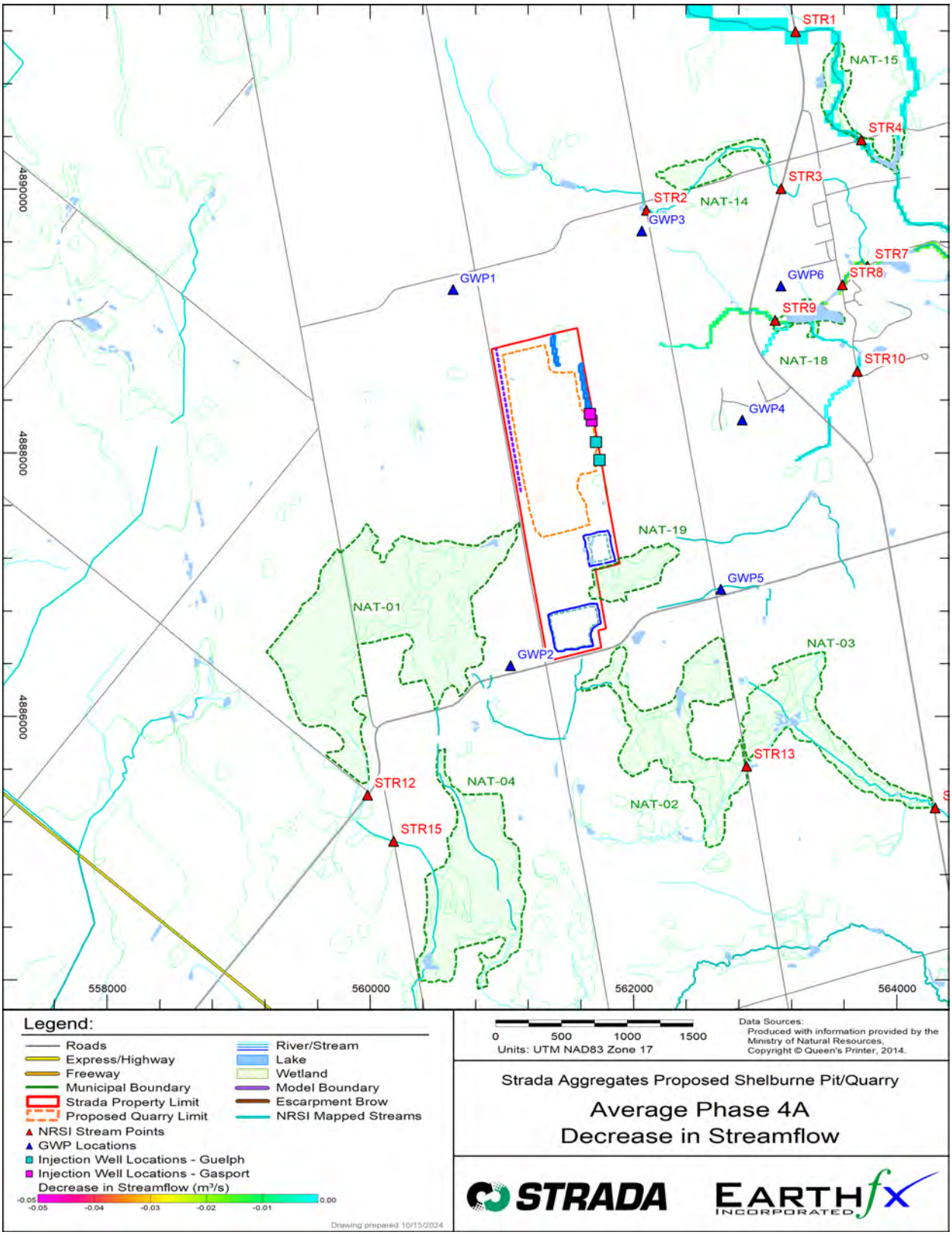


Figure 3.44: Average Phase 4A decrease in streamflow

3.7.3 Phase 4A Seasonal and Inter-Annual Change in Flows and Levels

The transient simulations through 2015-2024 provide insight into the effects of Phase 4A during seasonal and inter-annual variation.

The groundwater levels at two key locations, GWP4 and GWP6 (location shown in Figure 2.11), east of the property have been selected to illustrate the seasonal variation. Groundwater drawdowns at other locations are minimal, and mounding effects are discussed in the feature-based water budgets. Figure 3.45 shows that the change in groundwater levels between Baseline and Phase 4A in the Guelph and Gasport formations at location GWP4 are generally consistent over time, with slightly higher drawdowns during periods of lower water levels. Specifically, drawdowns are approximately 1.0 m in the Guelph, and 1.6 m in the Gasport at location GWP4.

Figure 3.46 shows that the change in groundwater levels between Baseline and Phase 4A in the Guelph and Gasport formations at location GWP6. They are minimal in the Guelph aquifer (approximately 0.1 m) during the wet season, while the water levels in summer are estimated to remain higher than Baseline. in the Gasport formation, drawdowns of 0.6 m can be expected during the wet season, and of 0.1 m during the summer.

Figure 3.47 shows the change in streamflow at STR9 between the Baseline and Phase 4A scenario (location shown in Figure 2.11). Peak flows in this small headwater tributary are more affected than summer low flows. This tributary is only one component of the water budget of Pond NAT-18, and the full water budget for that feature is discussed in the following section. The predicted reduction of streamflow at this location is about 50%.

Figure 3.48 shows the effect of Phase 4A on streamflow down stream of Pond NAT-18 at locations STR8 and STR7. The hydrograph indicates that the difference between Baseline and Phase 4A stream flows at location STR8 average about 15% reduction in streamflow, regardless of the season. At the STR7 location, a minimal streamflow reduction of about 5% can be expected.

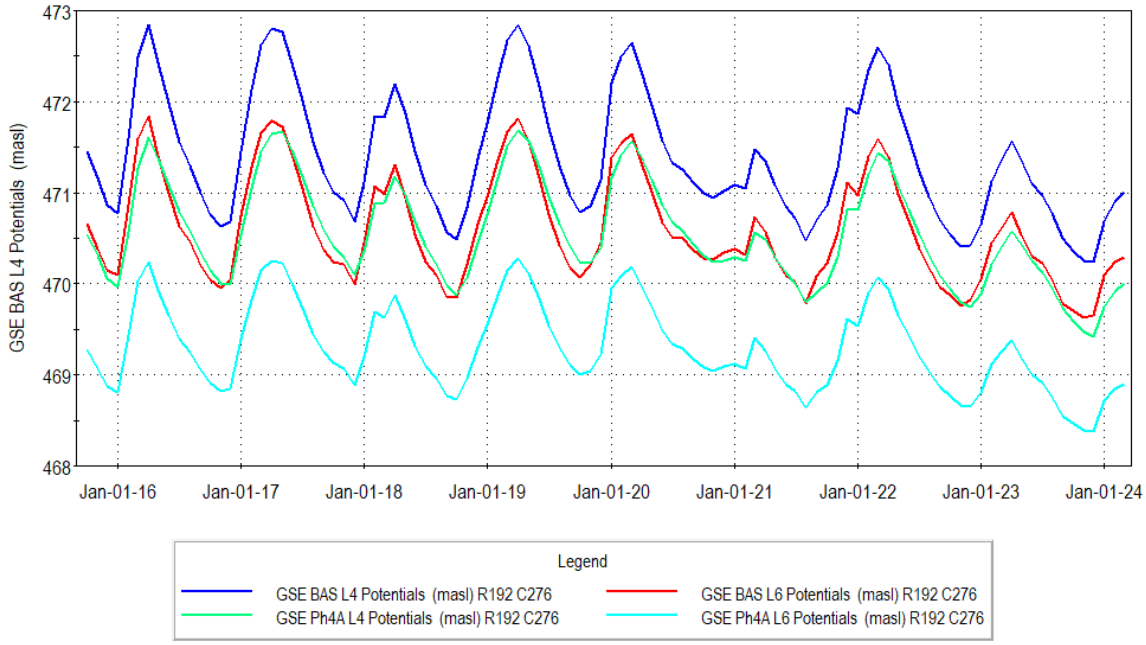


Figure 3.45: Comparison of groundwater levels under Phase 4A at location GWP4. (GSE BAS: GSFLOW of Baseline conditions; GSE Ph4A: GSFLOW of Phase 4A conditions.

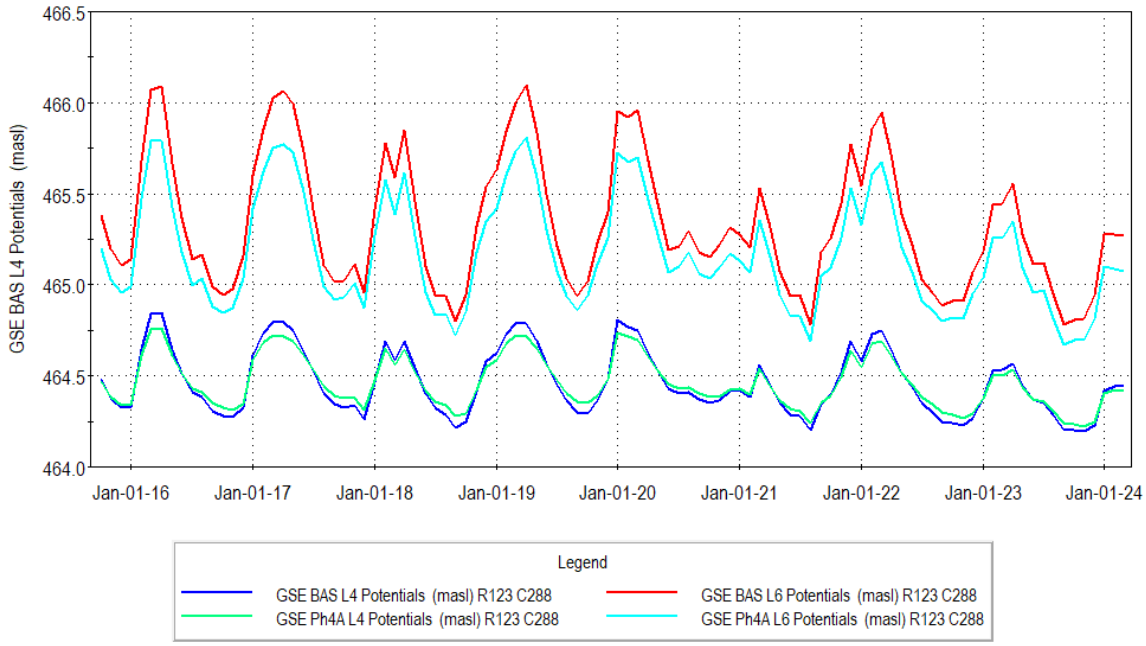


Figure 3.46: Comparison of groundwater levels under Phase 4A at location GWP6

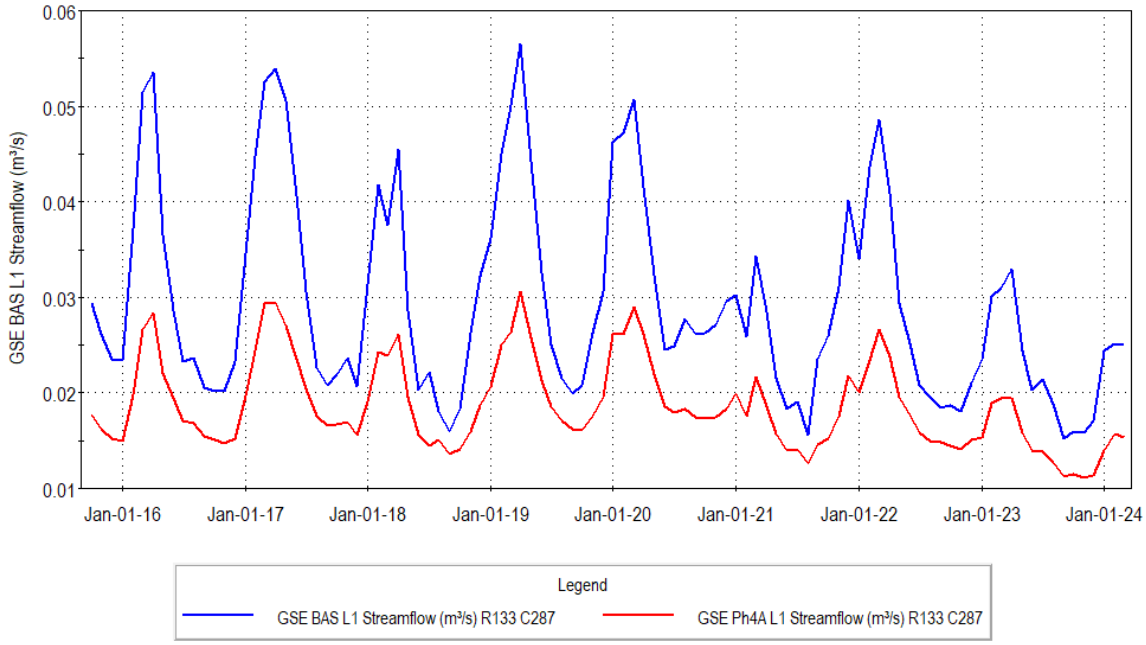


Figure 3.47: Comparison of streamflow at STR9 under Baseline and Phase 4A scenarios

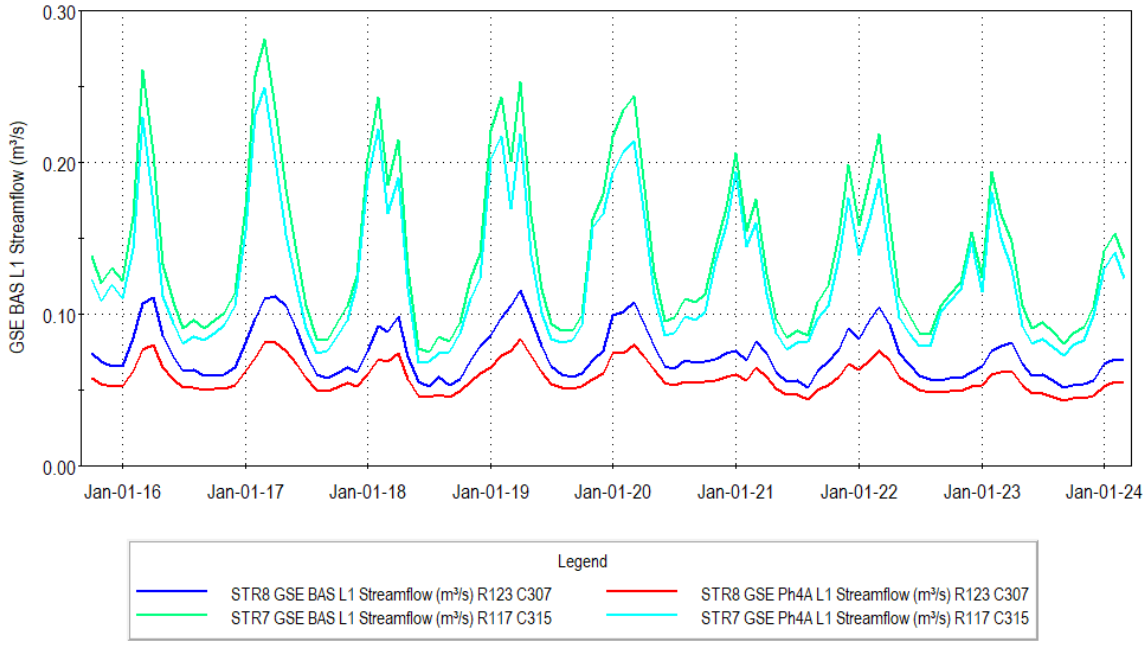


Figure 3.48: Comparison of streamflow under Baseline and Phase 4A at locations STR8 and STR7

3.7.4 **Phase 4A Surface Water/Groundwater Interaction**

The spatial change in average groundwater seepage to wetlands and ponds is shown in Figure 3.49 and Figure 3.50. The wetlands to the south and north east of the development are predicted to receive an increase in surface leakage from the infiltration systems. Wetland NAT-18 will see a modest reduction in surface leakage, as discussed below.

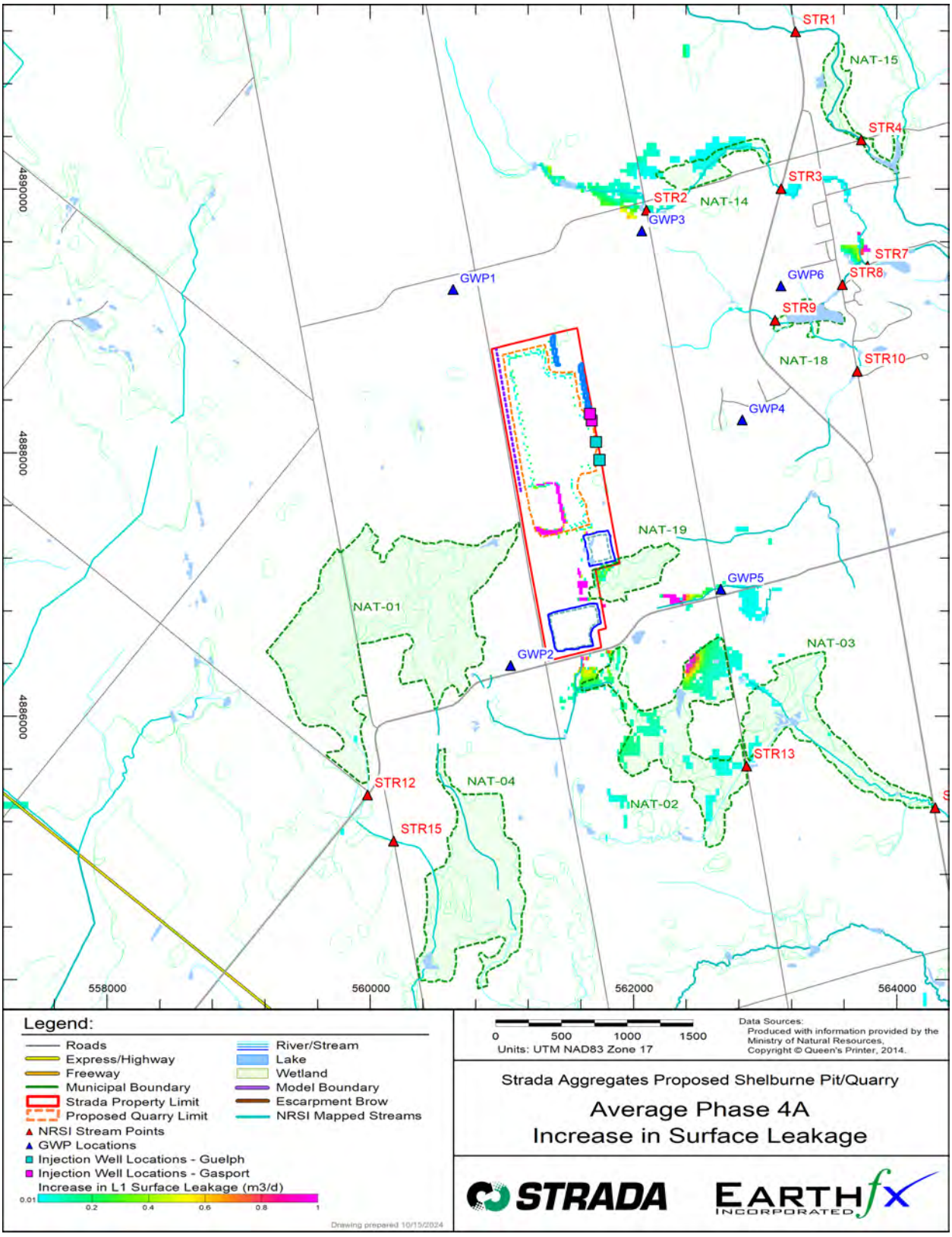


Figure 3.49: Average Phase 4A increase in surface leakage

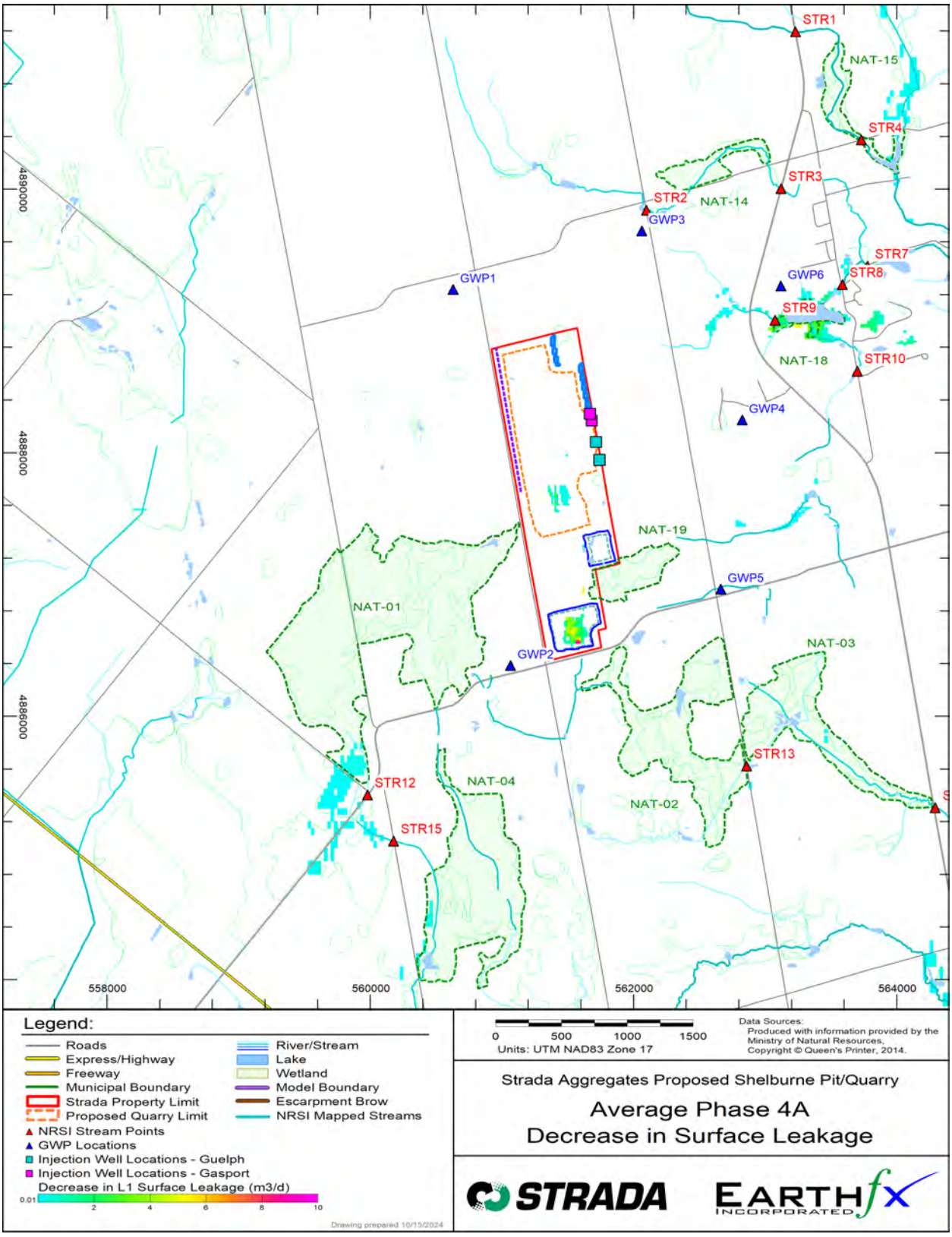


Figure 3.50: Average Phase 4A decrease in surface leakage

3.7.5 **Wetland Water Budgets**

A complete set of wetland water budgets under Phase 4A are included in Section 9.4.

3.7.5.1 Wetland NAT-18

Wetland NAT-18 is the dammed pond near Horning's Mills that is discussed in Section 2.5.2. The surface water and groundwater components of the water budget are presented as bar charts (Figure 3.51 and Figure 3.52) and underlying tables Table 3.19 through Table 3.22 show both the raw values in these figures and their relative differences with respect to the Baseline condition..

The change in the surface water budget is tabulated in Table 3.20 and shows that there is no change in surface water components.

The change in the groundwater budget is documented in Table 3.22. There is a reduction in the net lateral inflow by 67 to 90 mm/month or approximately 10%, The reduction is accompanied by a similar scale decrease in the magnitude of surface leakage and stream leakage. Overall, the changes are moderate.

Simulated stream inflow decreases by 7.4 to 19.4 L/s from baseline conditions due to changes occurring outside the wetland. Inflows to the wetland decrease by about 1.6 L/s to 3.3 L/s. Simulated stage (pond water level) also drops slightly (0.04 to 0.09 m) due to changes in lake inflows.

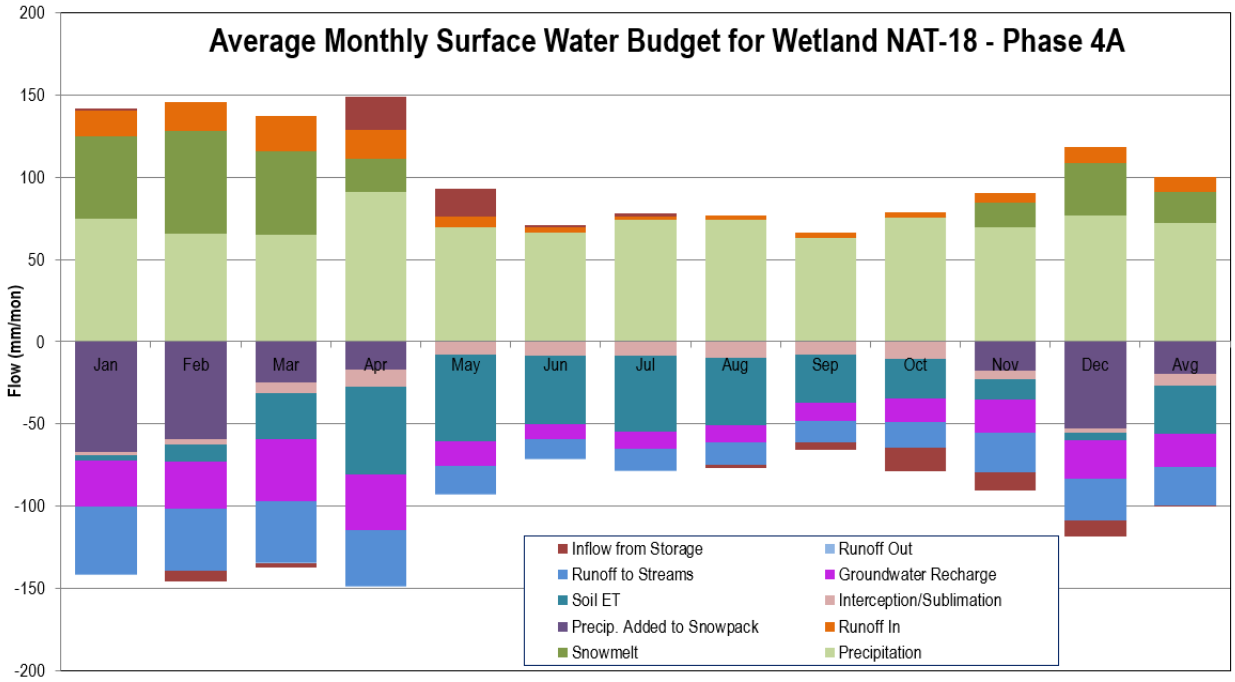


Figure 3.51: Phase 4A surface water budget for NAT-18

Table 3.19: Monthly surface water budget under Phase 4A Conditions (in mm/month) Wetland NAT-18

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	74.83	65.72	65.06	90.70	69.46	66.21	73.84	73.95	63.10	75.60	69.24	76.44	72.01
Snowmelt	50.13	62.60	50.35	20.42	0.00	0.00	0.00	0.00	0.00	0.01	15.10	32.31	19.24
Runoff In	15.24	17.47	22.07	17.72	6.57	3.00	2.42	2.83	2.87	2.93	5.82	9.69	9.05
Precip. Added to Snowpack	-67.29	-59.48	-24.71	-17.17	0.00	0.00	0.00	0.00	0.00	-0.01	-17.29	-52.53	-19.87
Interception/Sublimation	-1.49	-3.00	-6.58	-9.89	-8.10	-8.47	-8.74	-9.50	-7.72	-10.39	-5.60	-2.74	-6.85
Soil ET	-3.22	-10.35	-27.90	-53.86	-52.29	-41.89	-46.15	-41.01	-29.55	-24.01	-12.48	-4.84	-28.96
Groundwater Recharge	-28.49	-28.55	-37.47	-33.88	-15.38	-9.02	-10.33	-10.75	-10.61	-14.49	-20.22	-23.04	-20.19
Runoff to Streams	-40.72	-37.63	-37.40	-33.30	-16.69	-11.47	-12.87	-13.83	-13.18	-15.57	-23.52	-25.46	-23.47
Runoff Out	-0.39	-0.47	-0.69	-0.62	-0.21	-0.08	-0.05	-0.05	-0.06	-0.05	-0.12	-0.23	-0.25
Inflow from Storage	1.40	-6.30	-2.72	19.87	16.65	1.71	1.88	-1.64	-4.87	-14.00	-10.94	-9.59	-0.71

Table 3.20: Difference in monthly surface water budget (Baseline - Phase 4A) in mm/month Wetland NAT-18

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precip. Added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater Recharge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff to Streams	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

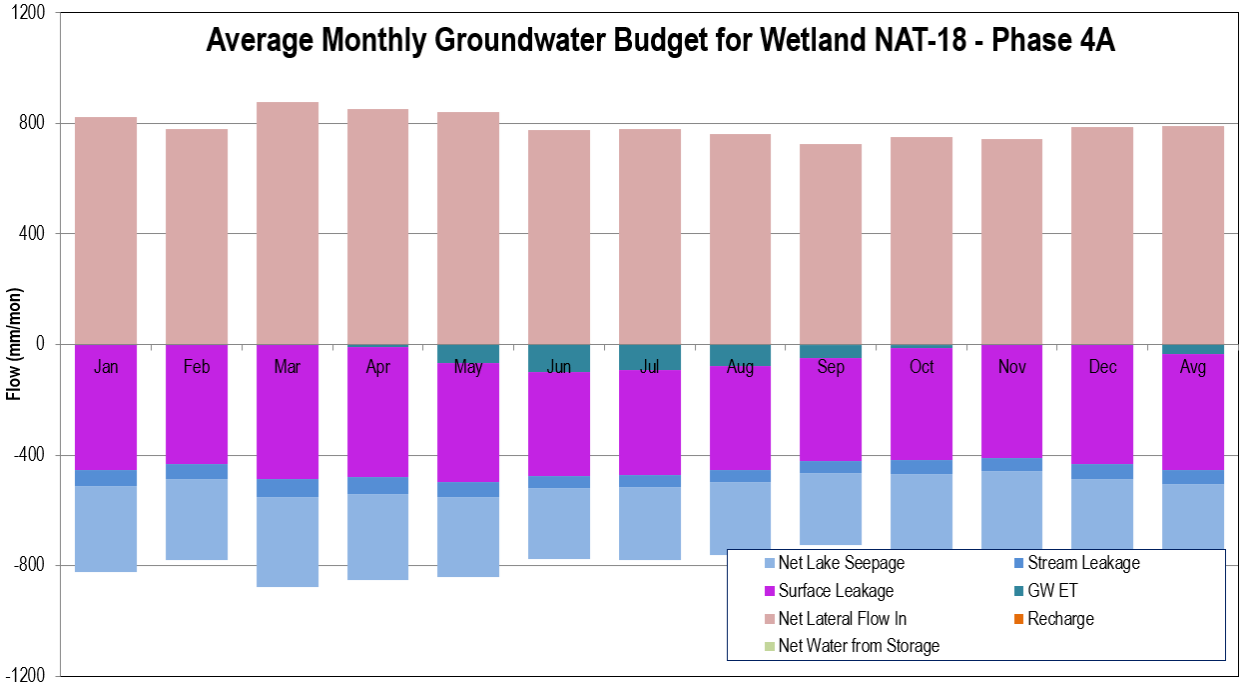


Figure 3.52: Groundwater budget for NAT-18

Table 3.21: Monthly groundwater budget under Phase 4A Conditions (in mm/month) Wetland NAT-18

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-0.55	-0.48	-0.36	0.12	1.58	1.44	0.36	0.18	-0.32	-0.74	-0.51	-0.41	0.03
Recharge	2.42	2.16	2.95	2.65	1.30	0.86	1.09	0.93	1.14	1.51	1.95	2.23	1.77
Net Lateral Flow In	822.5	777.5	873.7	851.3	837.0	775.7	778.7	761.5	725.5	749.1	740.2	785.4	789.8
GW ET	-0.38	-0.58	-1.79	-10.52	-66.34	-98.69	-91.67	-76.70	-47.54	-11.82	-1.87	-0.39	-34.02
Surface Leakage	-453.5	-430.6	-486.0	-470.1	-430.7	-376.9	-380.9	-377.1	-374.2	-406.5	-406.7	-433.3	-418.9
Stream Leakage	-56.97	-55.43	-63.86	-61.99	-53.50	-44.69	-44.41	-43.58	-43.43	-48.02	-48.89	-52.95	-51.48
Net Lake Seepage	-311.3	-291.8	-324.6	-311.4	-289.4	-257.7	-262.5	-263.5	-260.7	-282.9	-282.6	-299.8	-286.5
Streamflow In (L/s)	35.6	38.8	41.3	42.0	36.6	32.7	31.0	29.8	29.2	29.6	30.7	32.4	34.1
Streamflow Out (L/s)	61.5	65.8	69.3	70.4	62.3	55.9	53.7	51.1	51.3	52.7	54.6	57.2	58.8
Avg. Lake Stage (masl)	450.7	450.7	450.7	450.7	450.7	450.7	450.7	450.7	450.7	450.7	450.7	450.7	450.7

Table 3.22: Difference in monthly groundwater budget (Baseline - Phase 4A) in mm/month Wetland NAT-18

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	0.25	0.23	0.17	-0.05	-0.81	-0.73	-0.17	-0.10	0.19	0.38	0.23	0.21
Recharge	-0.11	-0.12	-0.40	-0.31	-0.06	-0.03	-0.02	-0.01	-0.02	-0.03	-0.07	-0.13
Net Lateral Flow In	81.53	76.93	90.04	84.97	80.40	72.44	72.88	68.46	67.44	71.57	71.83	75.57
GW ET	0.00	0.00	0.00	-0.04	-0.83	-1.22	-1.10	-0.85	-0.51	-0.10	-0.01	0.00
Surface Leakage	-45.70	-43.64	-51.10	-49.44	-46.26	-40.48	-39.73	-38.91	-35.59	-37.13	-38.69	-41.09
Stream Leakage	-10.32	-10.32	-12.53	-12.03	-10.01	-8.02	-7.66	-7.37	-6.96	-7.53	-8.06	-8.92
Net Lake Seepage	-25.81	-23.28	-24.84	-23.12	-22.42	-21.96	-24.80	-22.58	-24.05	-25.78	-25.38	-25.81
Streamflow In (L/s)	15.0	17.7	19.0	19.4	14.1	10.3	9.1	7.4	7.3	8.0	9.9	11.8
Streamflow Out (L/s)	17.3	20.2	21.8	22.4	17.3	13.2	10.7	10.7	9.8	10.3	12.1	14.1
Avg. Lake Stage (masl)	0.07	0.08	0.09	0.09	0.07	0.06	0.07	0.05	0.04	0.05	0.05	0.06

3.7.5.2 Wetland NAT-19

Wetland NAT-19 is located immediately adjacent to the Strada property. The surface water and groundwater components of the water budget are presented as bar charts (Figure 3.53 and Figure 3.54) and underlying tables Table 3.23 through Table 3.26 show both the raw values in these figures and their relative differences with respect to the Baseline condition.

Under Phase 4A, there are very small changes (less than 1 mm/month) in groundwater recharge and runoff into the wetland, likely due to rejected recharge due to a higher water table (Table 3.24). The groundwater water budget shows more significant change in the pattern of the response with increased surface leakage and increased groundwater ET, indicative of a high-water table. Net lateral groundwater flow out of the wetland decreases compared to baseline conditions. At the same time, groundwater recharge is predicted to decrease as a portion of the area has changed to a groundwater discharge zone and the recharge provided by the surface water model is rejected. The effect of changing from a perched wetland to groundwater-fed wetland (similar to the other wetlands analyzed) on wetland habitat is discussed under separate cover (NRSI, 2024).

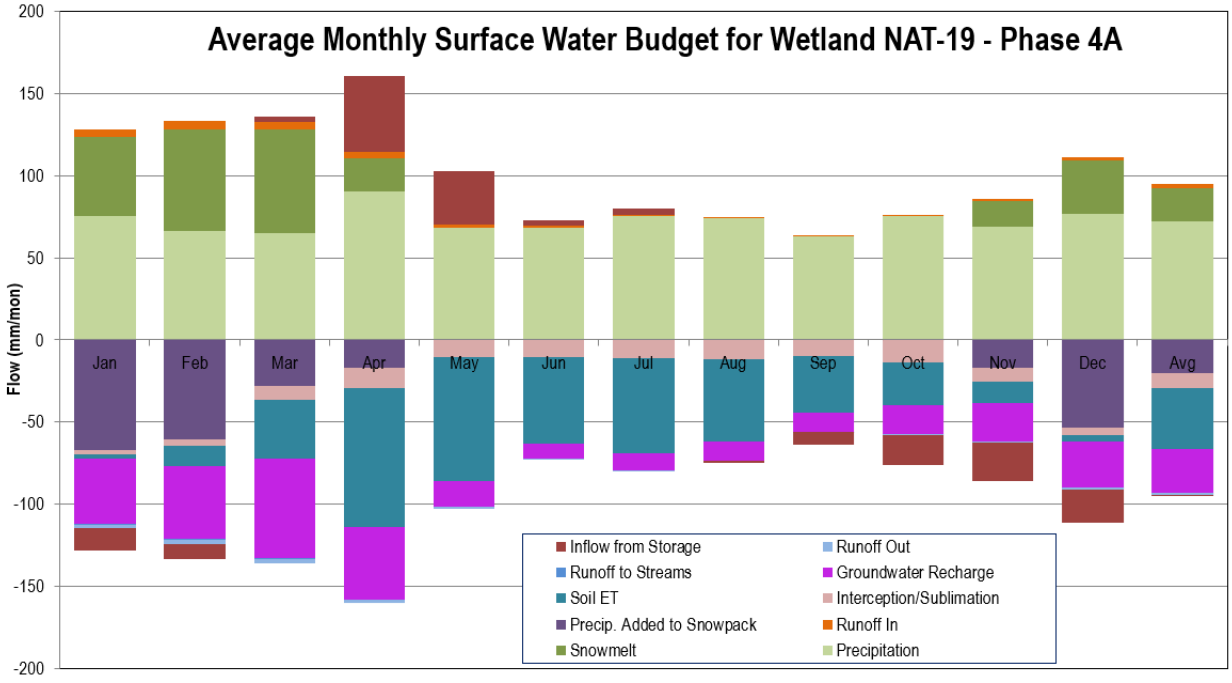


Figure 3.53: Surface water budget for NAT-19.

Table 3.23: Monthly surface water budget under Phase 4A Conditions (in mm/month) Wetland NAT-19.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	75.51	66.41	65.25	90.65	68.47	68.53	75.62	74.12	63.06	75.28	69.12	76.54	72.38
Snowmelt	48.27	61.65	62.56	19.94	0.00	0.00	0.00	0.00	0.00	0.01	15.08	32.35	19.99
Runoff In	4.34	5.27	4.96	3.86	1.71	0.85	0.67	0.73	0.75	0.75	1.37	2.25	2.29
Precip. added to Snowpack	-67.00	-60.61	-28.07	-16.82	0.00	0.00	0.00	0.00	0.00	-0.01	-17.12	-53.09	-20.23
Interception/Sublimation	-2.58	-3.82	-8.25	-12.29	-10.21	-10.40	-11.02	-11.86	-9.78	-13.62	-8.19	-4.57	-8.88
Soil ET	-2.82	-12.09	-36.11	-84.85	-75.43	-52.98	-57.63	-50.12	-34.26	-26.39	-12.83	-3.89	-37.45
Groundwater Recharge	-39.78	-44.67	-60.48	-44.25	-15.98	-8.95	-10.71	-11.28	-11.71	-17.47	-23.80	-28.22	-26.44
Runoff to Streams	-0.16	-0.20	-0.20	-0.13	-0.05	-0.03	-0.03	-0.06	-0.06	-0.05	-0.07	-0.06	-0.09
Runoff Out	-2.10	-2.64	-2.53	-1.96	-0.86	-0.39	-0.27	-0.30	-0.33	-0.32	-0.60	-1.02	-1.11
Inflow from Storage	-13.67	-9.30	2.86	45.85	32.34	3.38	3.36	-1.24	-7.66	-18.18	-22.96	-20.28	-0.46

Table 3.24: Difference in monthly surface water budget (Baseline - Phase 4A) in mm/month Wetland NAT-19.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	-0.90	-0.91	-0.86	-0.69	-0.37	-0.25	-0.27	-0.29	-0.27	-0.30	-0.48	-0.60
Precip. added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.01	0.05	0.56	0.26	0.31	0.24	0.15	0.07	0.02	0.00
Groundwater Recharge	0.84	0.92	0.90	0.53	0.11	-0.03	-0.02	-0.01	0.01	0.06	0.20	0.41
Runoff to Streams	-0.10	-0.12	-0.07	-0.07	-0.03	-0.02	-0.03	-0.04	-0.04	-0.03	-0.05	-0.04
Runoff Out	0.15	0.15	0.11	0.11	0.07	0.06	0.07	0.08	0.08	0.08	0.12	0.11

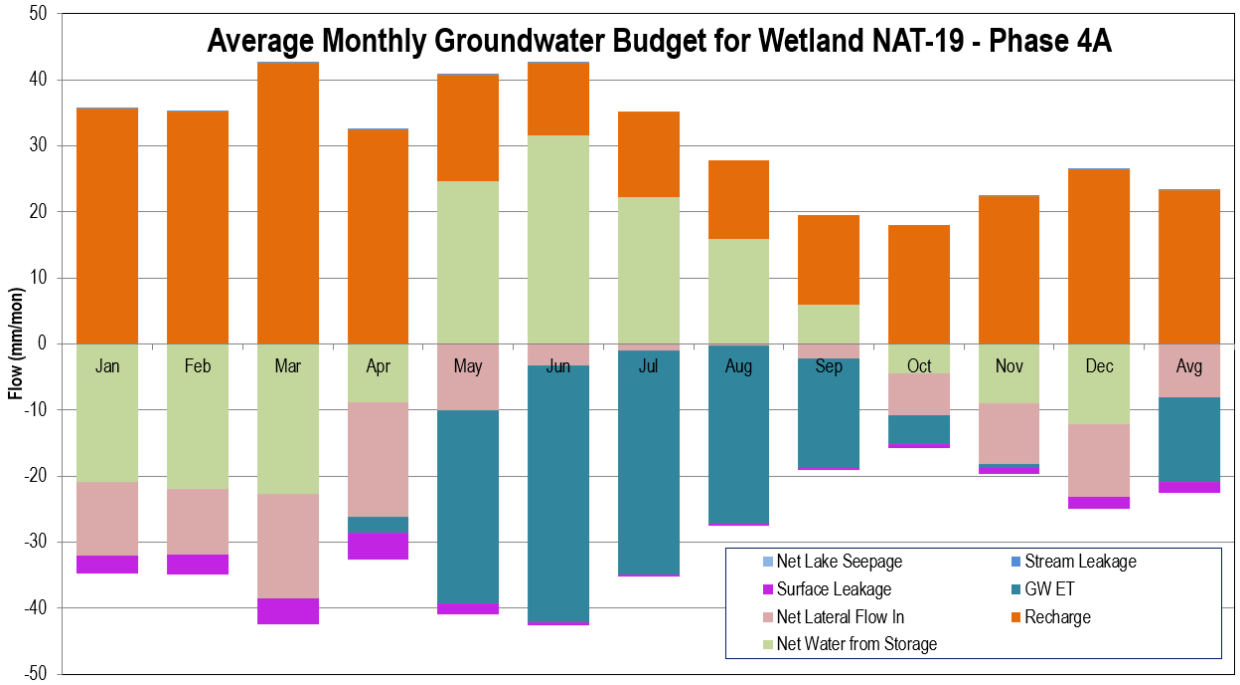


Figure 3.54: Groundwater budget for NAT-19.

Table 3.25: Monthly groundwater budget under Phase 4A Conditions (in mm/month) Wetland NAT-19

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-20.90	-21.93	-22.73	-8.81	24.72	31.61	22.26	15.84	5.93	-4.52	-8.93	-12.14	0.03
Recharge	35.67	35.28	42.66	32.56	16.14	10.96	12.94	11.96	13.58	18.07	22.45	26.52	23.23
Net Lateral Flow In	-11.15	-9.96	-15.73	-17.42	-10.08	-3.20	-0.93	-0.17	-2.12	-6.34	-9.21	-10.98	-8.11
GW ET	-0.01	-0.01	-0.03	-2.32	-29.27	-38.92	-33.94	-27.05	-16.60	-4.31	-0.56	-0.01	-12.75
Surface Leakage	-2.63	-3.07	-4.01	-4.07	-1.56	-0.48	-0.30	-0.31	-0.37	-0.57	-1.05	-1.85	-1.69
Stream Leakage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Lake Seepage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 3.26: Difference in monthly groundwater budget (Baseline - Phase 4A) in mm/month - Wetland NAT-19.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	0.62	1.12	1.88	3.30	-5.71	-9.21	-4.85	-2.21	2.11	6.68	4.30	2.34
Recharge	4.71	5.50	7.90	6.08	1.92	0.60	0.41	0.48	0.61	0.93	1.75	2.95
Net Lateral Flow In	-8.93	-10.01	-13.93	-15.15	-22.62	-26.83	-27.60	-25.01	-19.82	-14.76	-10.34	-8.69
GW ET	0.00	0.00	-0.02	1.71	24.89	34.99	31.71	26.16	16.30	4.24	0.55	0.00
Surface Leakage	2.63	3.07	4.01	4.07	1.56	0.48	0.30	0.31	0.37	0.57	1.05	1.85
Stream Leakage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Lake Seepage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

3.7.6 **Phase 4A Conclusions**

The development of Phase 4A will create groundwater drawdown in the central portion of the site, but this will be offset by groundwater mounding related to the infiltration systems. The net effect is a small, and the 1 m drawdown in the deepest layer extends approximately 2000 m from the excavation.

The drawdowns are, at every location, small relative to the available drawdown in the aquifer (Figure 2.8), indicating that any shallow private wells could be readily deepened if necessary. The drawdown at location GWP-4 (near a new housing development west of Horning's Mills) is approximately 2.5 m (Figure 3.40), while the available drawdown at that location is approximately 25 m (Figure 2.8). In general, 5 m of available drawdown is considered adequate in limestone aquifers such as those encountered in the study area, so there remains plenty of available well capacity during operations.

The drawdown reduces streamflow and surface leakage into Pond NAT-18. Hydrographs indicate that the difference between Baseline and Phase 4A streamflows at location STR7, downstream of the pond are significant during the summer and moderate during the wet season. Streamflow at location STR8, a low order stream, is expected to be significantly reduced throughout the year. Of note is that the measured impact on streamflows tends to highlight both headwater streams with low flows throughout the year.

3.8 *Site Rehab Impact Assessment Scenario*

3.8.1 Introduction

The Rehab Scenario represents conditions after final rehabilitation and closure of the pit and quarry.

At this time all on-site water control and infiltration systems will be modified and/or removed so as to allow groundwater and surface water conditions to return to near baseline conditions *without any active long-term water management*.

Water control barriers that were constructed on all four sides of the pit/quarry in the overburden and Bench 1 will remain in place for the purpose of slope rehabilitation (Figure 3.55). The exception to this is that a 365-m portion of the eastern overburden barrier will be opened to allow lateral seepage into the shallow system east of the property. The area of barrier opening is shown as a thick orange line in Figure 3.55. Seepage from this opening will eliminate drawdowns and support streamflow in the tributary that flows into NAT-18.

The barriers constructed on Bench 3 will remain in place, however a small portion of the Gasport formation along the western face of Phase 4 will remain open to the quarry lake to help ensure that the lake does not over-top and discharge as surface water. The location of the extraction face that will remain open is shown as a dotted red line in Figure 3.55.

Water from the western tile drain will no longer be infiltrated into the bedrock injection wells. The wells will be sealed and decommissioned. The northern segment of the tile drain will be opened so as to freely drain into the quarry lake (see Figure 3.55). This will prevent long-term groundwater mounding west of the quarry.

All of the infiltration ponds and trenches will be re-graded and converted into appropriate future land uses, as outlined on the closure site plans. The southern portion of the site, west of the constructed wetland and Wetland NAT-19, will be re-graded so that runoff and interflow can enter and support the constructed wetland. Any excess water in the constructed wetlands will be allowed to overflow into Wetland NAT-18.

In summary, the site will be returned to a condition that restores local and regional surface and groundwater conditions, with no need for any form of active water management.

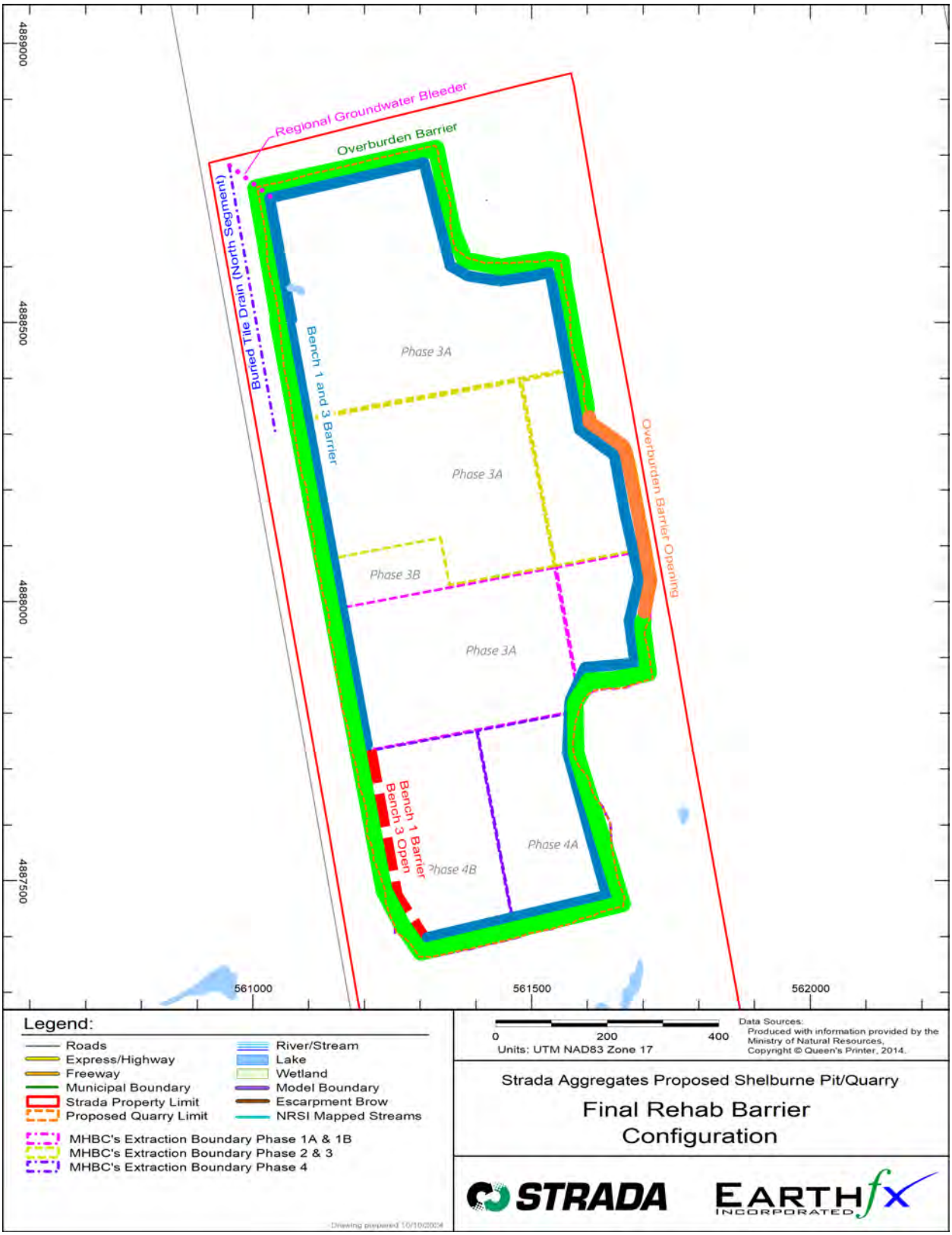


Figure 3.55: Rehab extraction scenario: barrier placement and open face location.

3.8.2 Rehab Drawdowns and Change in Surface Water Flow

Figure 3.56 shows the average simulated drawdown between Baseline and Rehab in Model Layer 1. Overall, the change in water levels from baseline around the quarry lake will be less than 1 m. Within the quarry lake will flatten

As discussed above, this is enabled by three site changes, including:

1. A small window into the Gasport aquifer will be left open in the bottom of the quarry lake,
2. A connection from the western drain into the lake will reduce groundwater mounding west of the site
3. The removal of a portion of the overburden barrier on the eastern boundary.

These changes ensure that the lake will not overflow and flood adjacent properties and wetlands. The changes also serve to recharge the shallow aquifer that feeds the stream network and the NAT-18 pond.

The proposed final grading and land use in the south provides runoff to the constructed wetland (see site plan for detailed closure condition contours). Hydrographs and a discussion of the water levels and flows in the constructed wetland are included in Section 6.2. Figure 3.56 shows that a small groundwater mound will develop underneath the constructed wetland.

Figure 3.56 also shows that groundwater levels will also rise, relative to baseline, in the vicinity of the southern infiltration pond once the pond has been filled and re-graded. This rise is groundwater levels is due to the infilling of the current (baseline) topographic depression.

Figure 3.57 and Figure 3.58 show the drawdown in the Layer 4 (Guelph) and Layer 6 (Gasport) aquifers. Like Layer 1, there is generally a small degree of mounding and drawdown from baseline conditions in each of the lower layers, in both cases due to the flattening of the water table in the final quarry lake, relative to the sloping water levels of the baseline conditions.

The final drawdowns are, at every location, small relative to the available drawdown in the aquifer (Figure 2.8), indicating that any shallow private wells could be readily deepened if necessary. The final water levels at location GWP-4 (near a new housing development west of Horning's Mills) are essentially the same as baseline conditions (Figure 3.56). The available drawdown at that location is approximately 25 m (Figure 2.8). In general, 5 m of available drawdown is considered adequate in limestone aquifers such as those encountered in the study area, so there remains plenty of available well capacity after rehab.

The effects on adjacent extraction licenses, surface and groundwater permits, agricultural lands and private septic systems are discussed in Section 3.9.

Figure 3.59 and Figure 3.60 show the average simulated increase and decrease in streamflow. Increases in streamflow occur along in some of the tributaries that flow into NAT-18 pond, while a small reduction in streamflow is predicted to occur at except STR9. A detail analysis of NAT-18 fluxes during this scenario is examined in Section 3.8.5.1.

In summary, Rehab flows and levels are similar to baseline water levels, and the lake will be connected to both the shallow and deep flow system to ensure that water levels can naturally equilibrate.

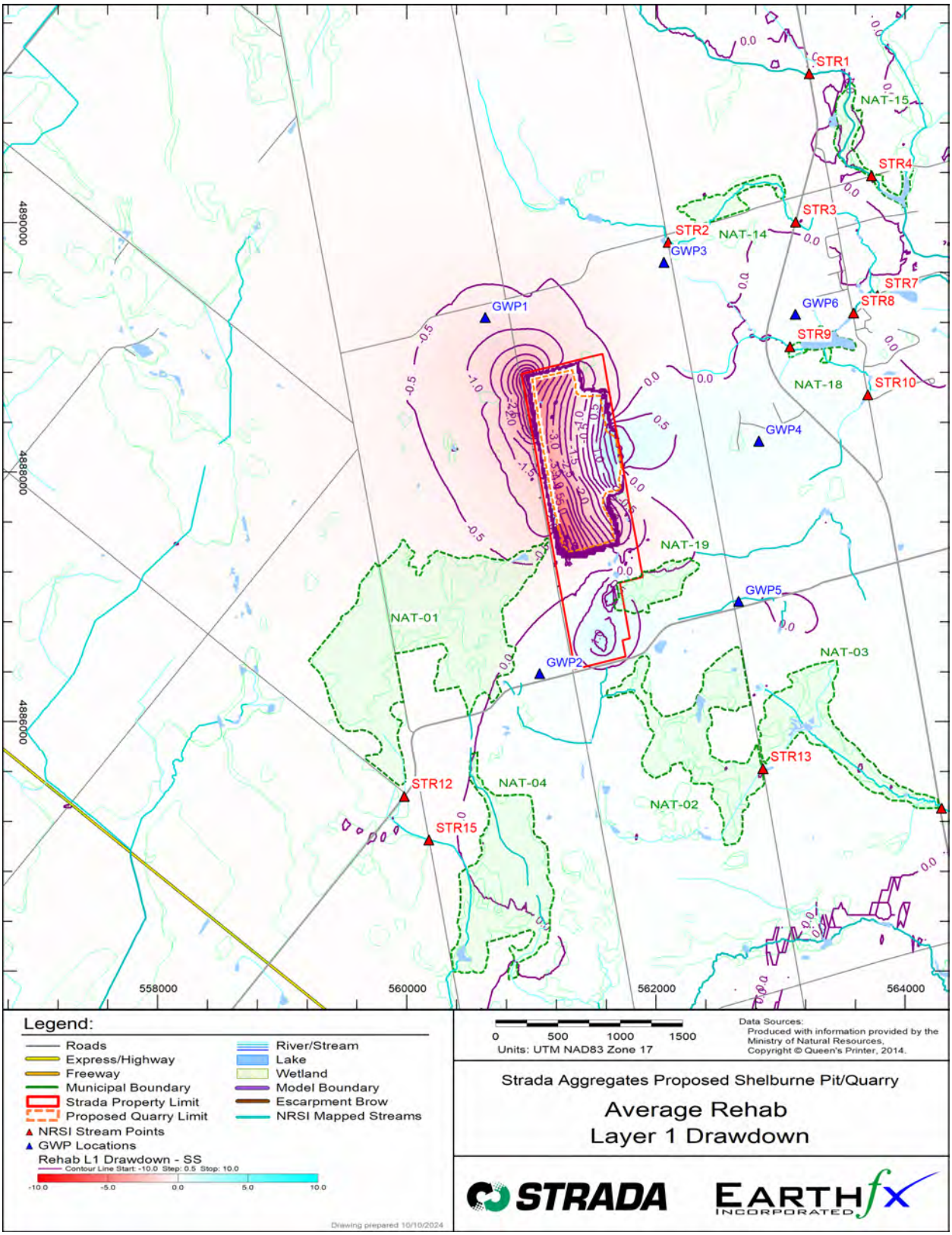


Figure 3.56: Average Rehab layer 1 drawdown

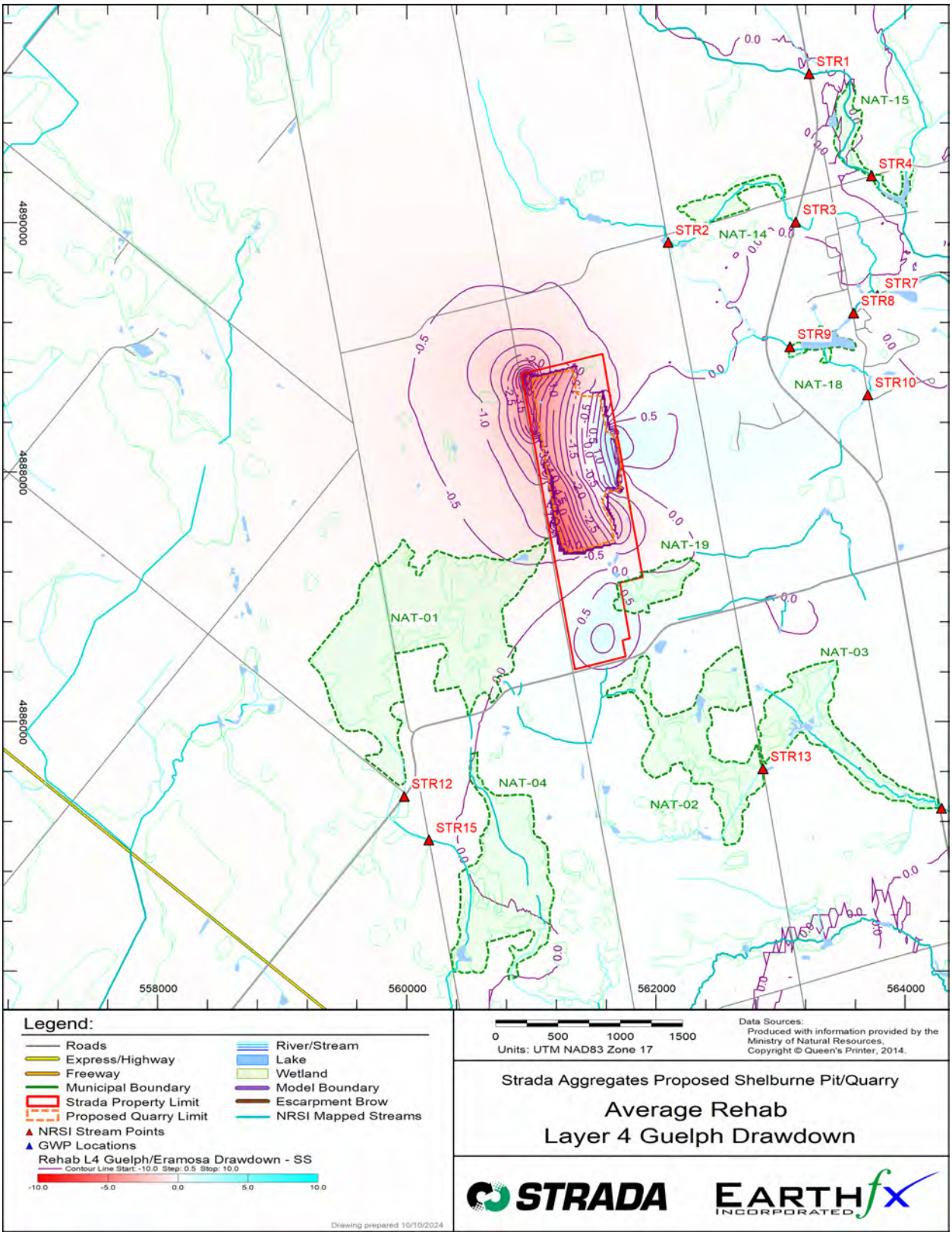


Figure 3.57: Average Rehab layer 4 Guelph drawdown

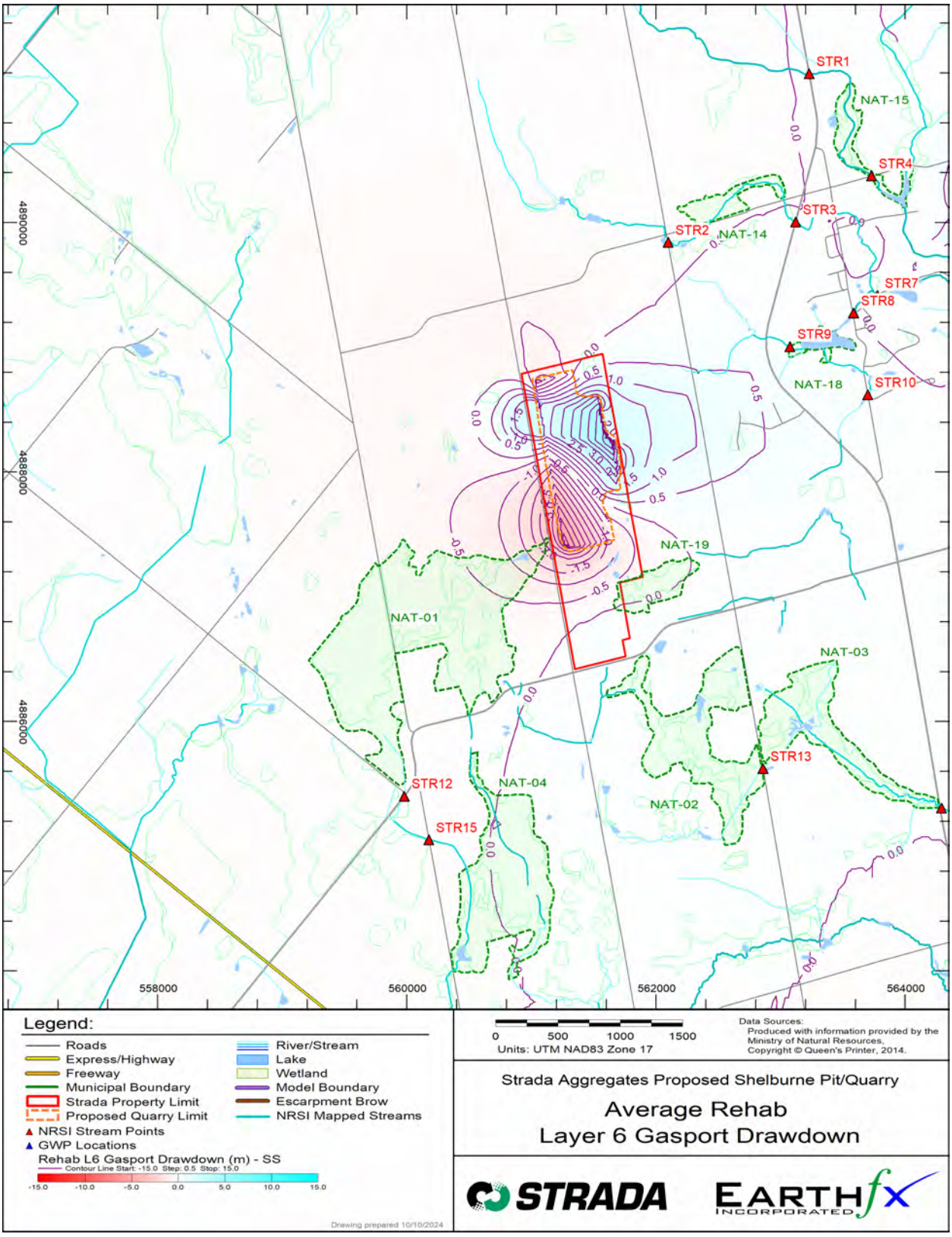


Figure 3.58: Average Rehab layer 6 Gasport drawdown

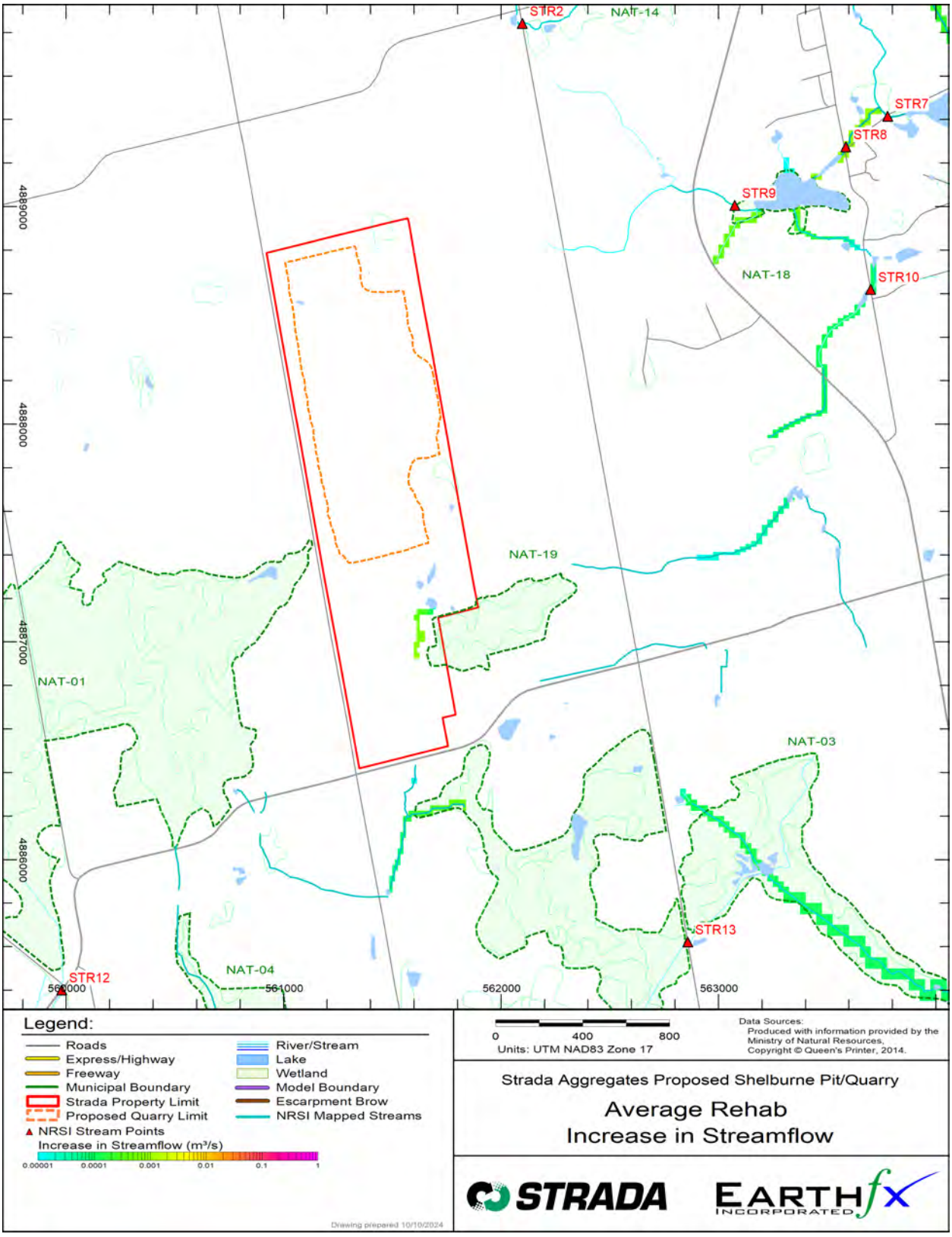


Figure 3.59: Average Rehab increase in streamflow

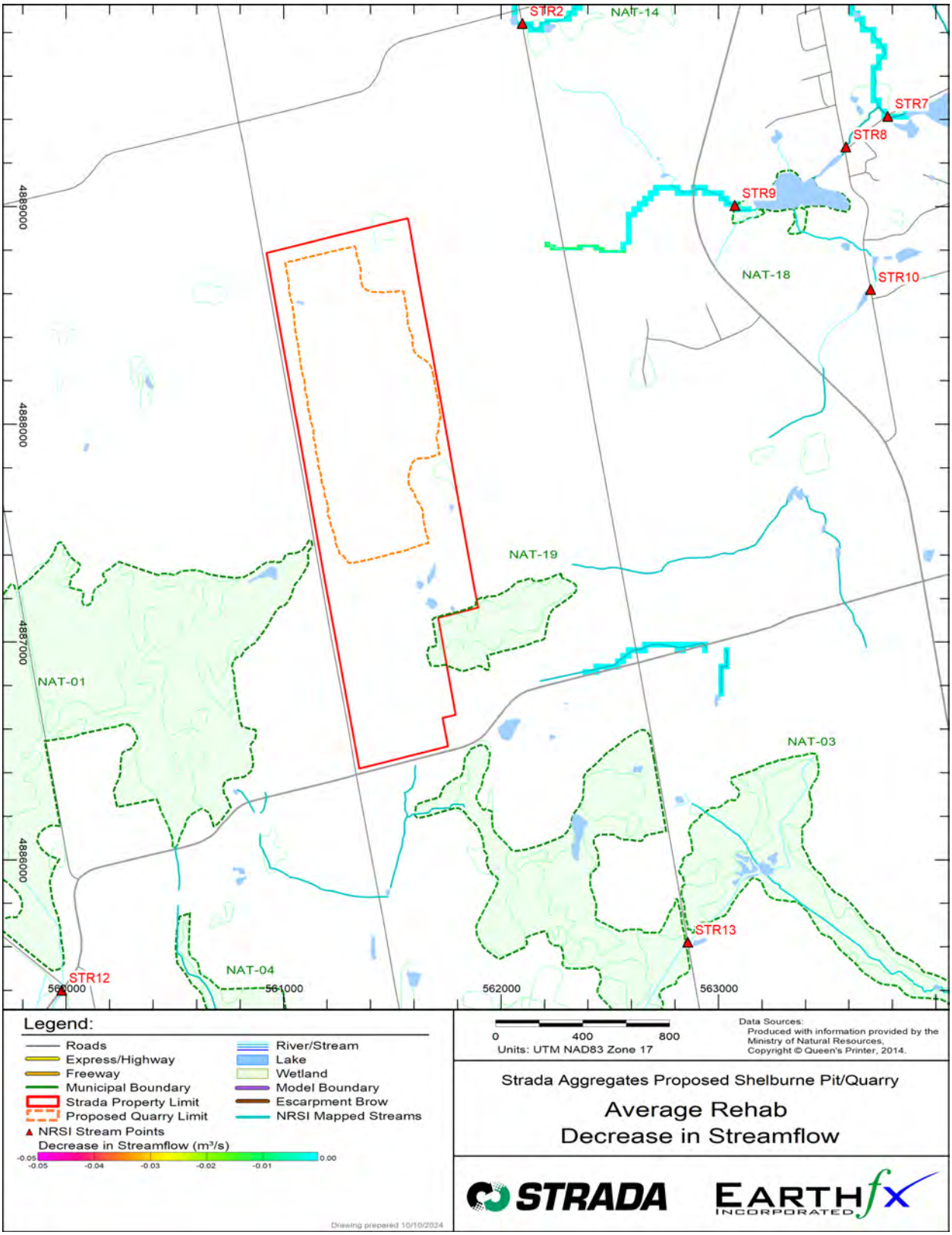


Figure 3.60: Average Rehab decrease in streamflow

3.8.3 Rehab Seasonal and Inter-Annual Change in Flows and Levels

The transient simulations through 2015—2024 provide insight into Rehab conditions during seasonal and inter-annual variation.

The groundwater levels at two key locations, GWP4 and GWP6 (location shown in Figure 2.11), east of the property have been selected to illustrate the seasonal variation. Groundwater drawdowns at other locations are minimal. Figure 3.61 shows that the change in groundwater levels between Baseline and Rehab in the Guelph and Gasport formations at location GWP4 are generally consistent over time, with slightly greater (approximately 0.4 m to 0.6 m) higher groundwater levels than Baseline during the summer months.

Figure 3.62 shows that the change in groundwater levels between Baseline and Rehab in the Guelph and Gasport formations at location GWP6 are small, with groundwater levels a few centimetres higher during the summer in both formations.

Figure 3.63 shows that the streamflow at STR9 between the Baseline and Rehab scenario is dependent of the season. During the wet season, a reduction of streamflow in order of 20 to 28% can be expected, while during the summer, there is an increase of streamflow ranging from 11 to 15%.

Figure 3.64 shows the streamflow below Pond NAT-18 at locations STR8 and STR7. The hydrograph indicates that the differences between Baseline and Rehab at STR8 during the wet season range between 7 to 20% streamflow reduction; while during the summer, a predicted increase in streamflow of 5 to 10% can be expected. Further downstream, at STR7, baseline and rehab flows are nearly identical.

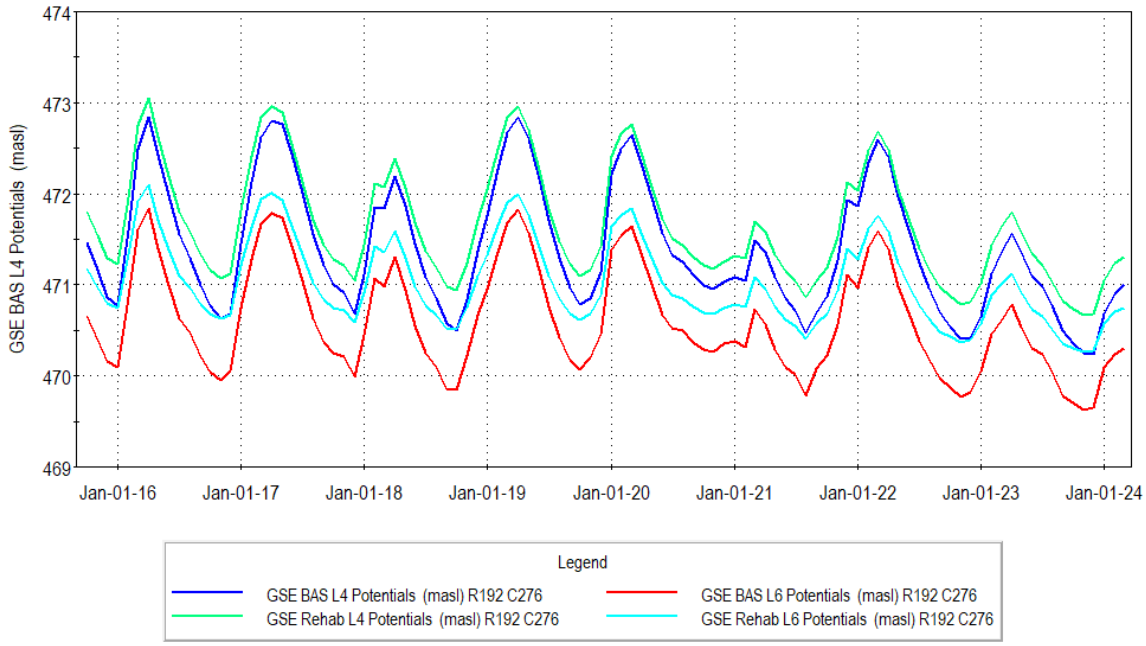


Figure 3.61: Comparison of Groundwater Levels under Rehab at location GWP4. GSE BAS: GSFLOW of Baseflow conditions; GSE Rehab: GSFLOW of Rehab condition.

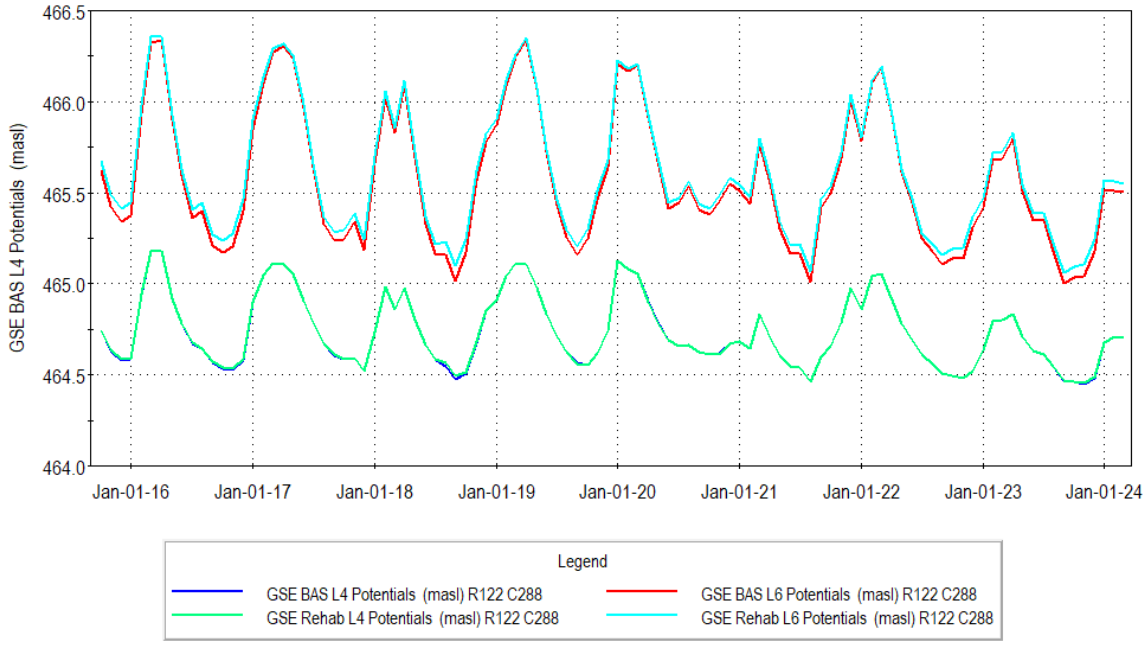


Figure 3.62: Comparison of Groundwater Levels under Rehab at location GWP6

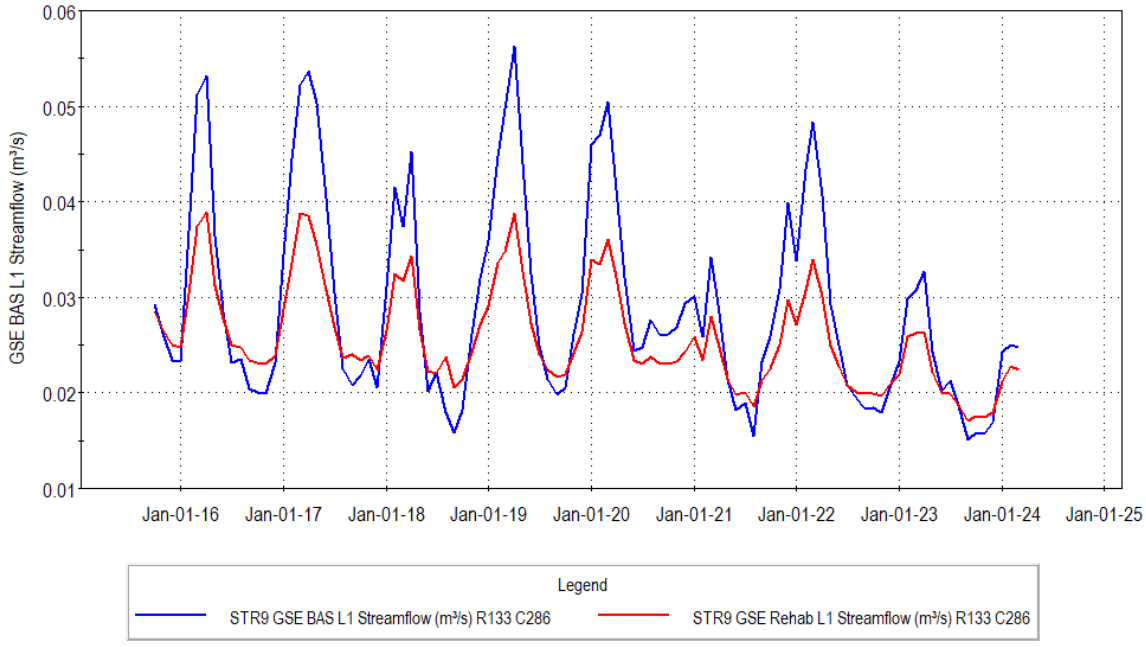


Figure 3.63: Comparison of Streamflow at STR9 under Baseline and Rehab scenarios

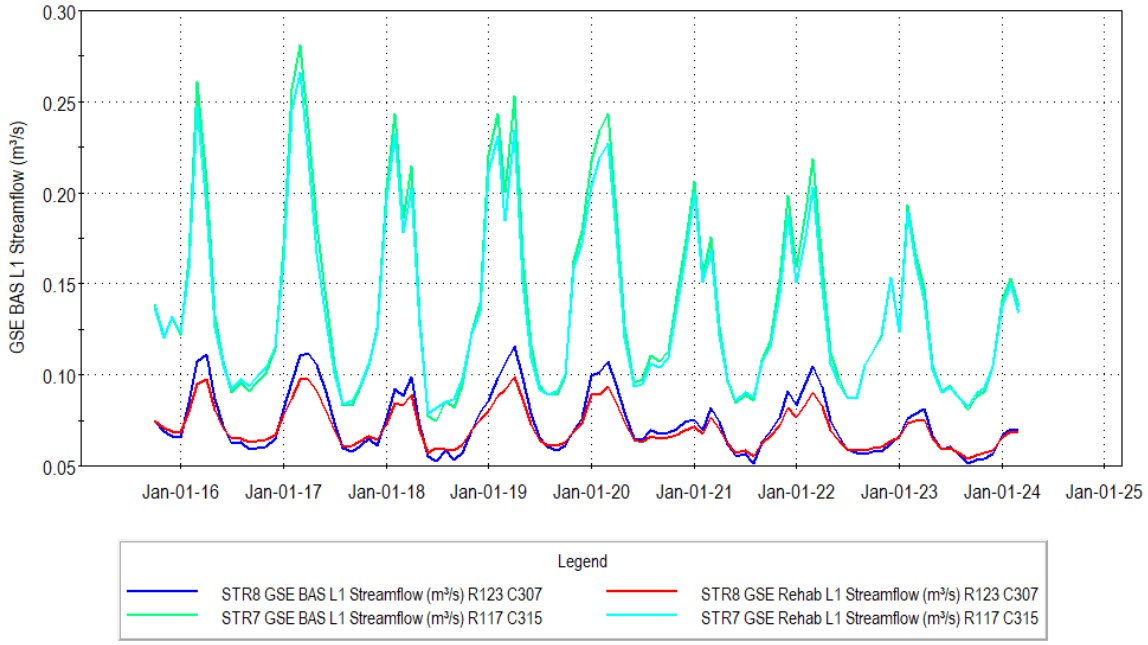


Figure 3.64: Comparison of streamflow under Baseline and Rehab at locations STR8 and STR7

3.8.4 Rehab Surface Water/Groundwater Interaction

The spatial change in average groundwater seepage to wetlands and ponds is shown in Figure 3.65 and Figure 3.66. A small increase in surface leakage extends to the south and east, while the loss of surface leakage minimal.

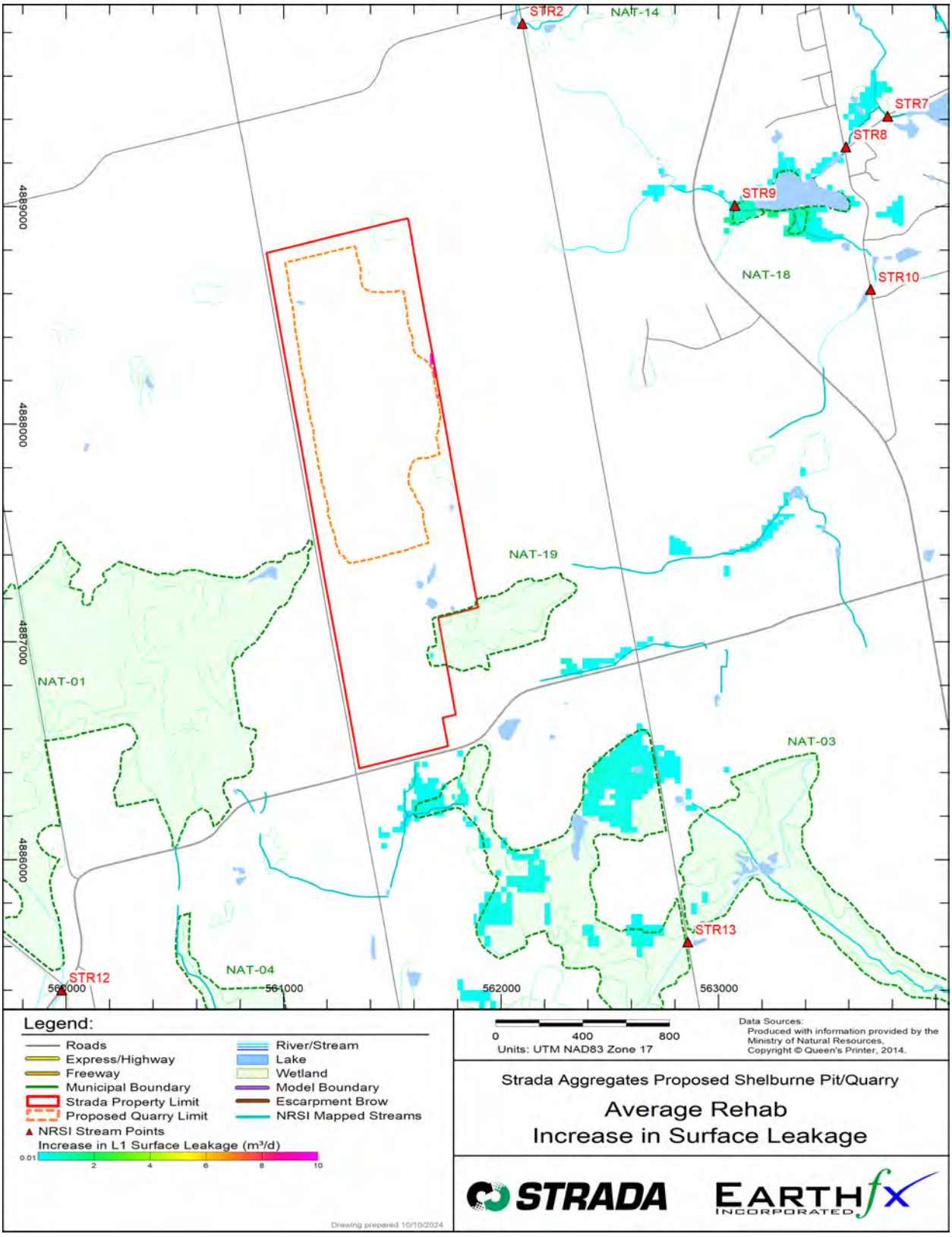


Figure 3.65: Average Rehab increase in surface leakage

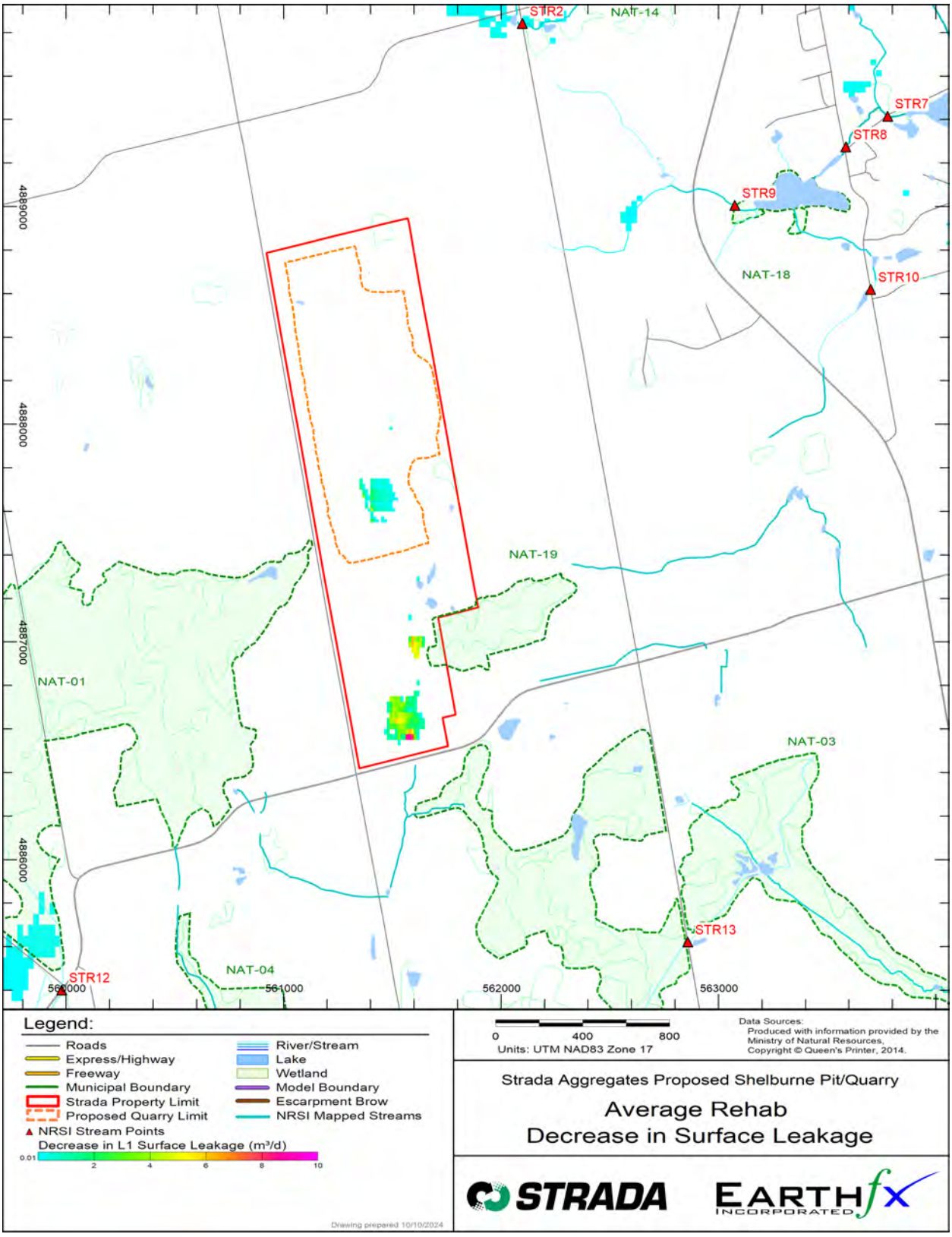


Figure 3.66: Average Rehab decrease in surface discharge

3.8.5 **Wetland Water Budgets**

A complete set of wetland water budgets under Rehab are included in Section 9.5.

3.8.5.1 Wetland NAT-18

Wetland NAT-18 is the dammed pond near Horning's Mills and is described in Section 2.5.2. The surface water and groundwater components of the water are presented as bar charts (Figure 3.67 and Figure 3.68) and underlying tables Table 3.27 through Table 3.30 show both the raw bar-chart values and their relative differences with respect to the Baseline condition.

The change in the surface water budget is tabulated in Table 3.28 and shows that there is no change in surface water flows.

The change in the groundwater budget is documented in Table 3.30. There are small changes in the water budget, but overall, the outfall hydrograph shown in Figure 3.64 illustrates that the changes are small. The maps presented above indicate that the surface water system has mostly recovered to baseline, and the monthly pond stage elevation presented in Table 3.30 is within 0.03 m of the Baseline Conditions level.

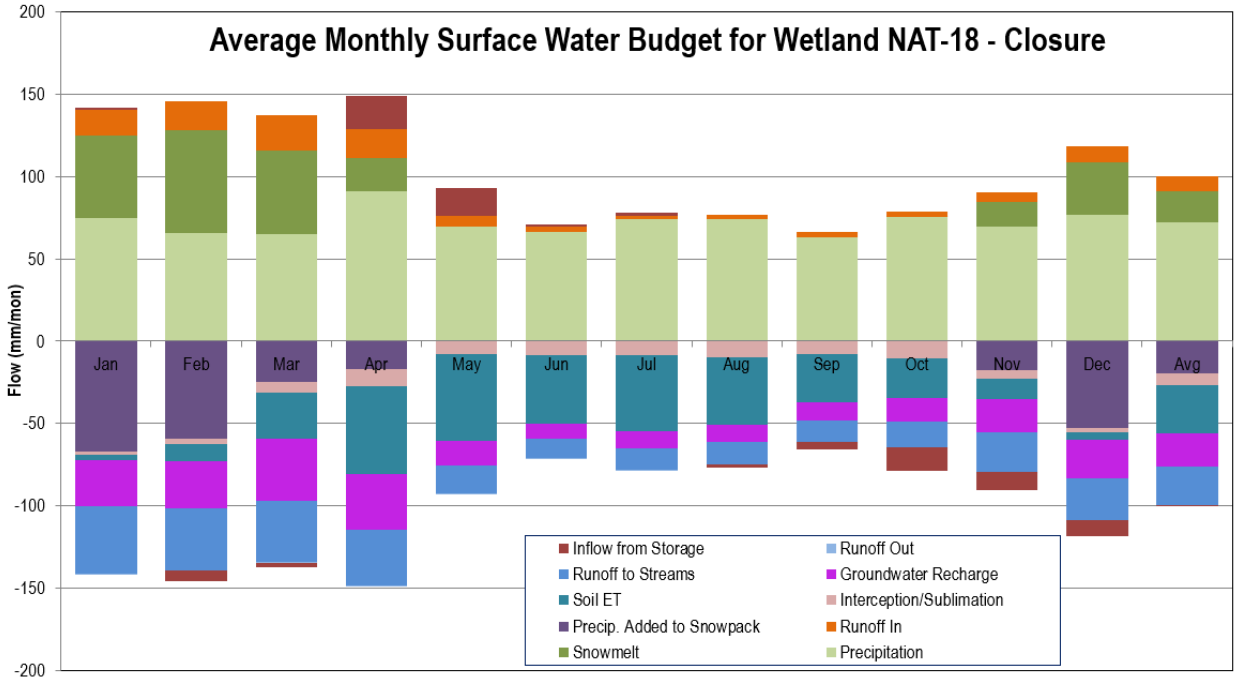


Figure 3.67: Rehab surface water budget for NAT-18

Table 3.27: Monthly surface water budget under Rehab Conditions (in mm/month) Wetland NAT-18

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	74.83	65.72	65.06	90.70	69.46	66.21	73.84	73.95	63.10	75.60	69.24	76.44	72.01
Snowmelt	50.13	62.60	50.35	20.42	0.00	0.00	0.00	0.00	0.00	0.01	15.10	32.31	19.24
Runoff In	15.24	17.47	22.07	17.72	6.57	3.00	2.42	2.83	2.87	2.93	5.82	9.69	9.05
Precip. Added to Snowpack	-67.29	-59.48	-24.71	-17.17	0.00	0.00	0.00	0.00	0.00	-0.01	-17.29	-52.53	-19.87
Interception/Sublimation	-1.49	-3.00	-6.58	-9.89	-8.10	-8.47	-8.74	-9.50	-7.72	-10.39	-5.60	-2.74	-6.85
Soil ET	-3.22	-10.35	-27.90	-53.86	-52.29	-41.89	-46.15	-41.01	-29.55	-24.01	-12.48	-4.84	-28.96
Groundwater Recharge	-28.49	-28.55	-37.47	-33.88	-15.38	-9.02	-10.33	-10.75	-10.61	-14.49	-20.22	-23.04	-20.19
Runoff to Streams	-40.72	-37.63	-37.40	-33.30	-16.69	-11.47	-12.87	-13.83	-13.18	-15.57	-23.52	-25.46	-23.47
Runoff Out	-0.39	-0.47	-0.69	-0.62	-0.21	-0.08	-0.05	-0.05	-0.06	-0.05	-0.12	-0.23	-0.25
Inflow from Storage	1.40	-6.30	-2.72	19.87	16.65	1.71	1.88	-1.64	-4.87	-14.00	-10.94	-9.59	-0.71

Table 3.28: Difference in monthly surface water budget (Baseline - Rehab) in mm/month Wetland NAT-18

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precip. Added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater Recharge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff to Streams	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

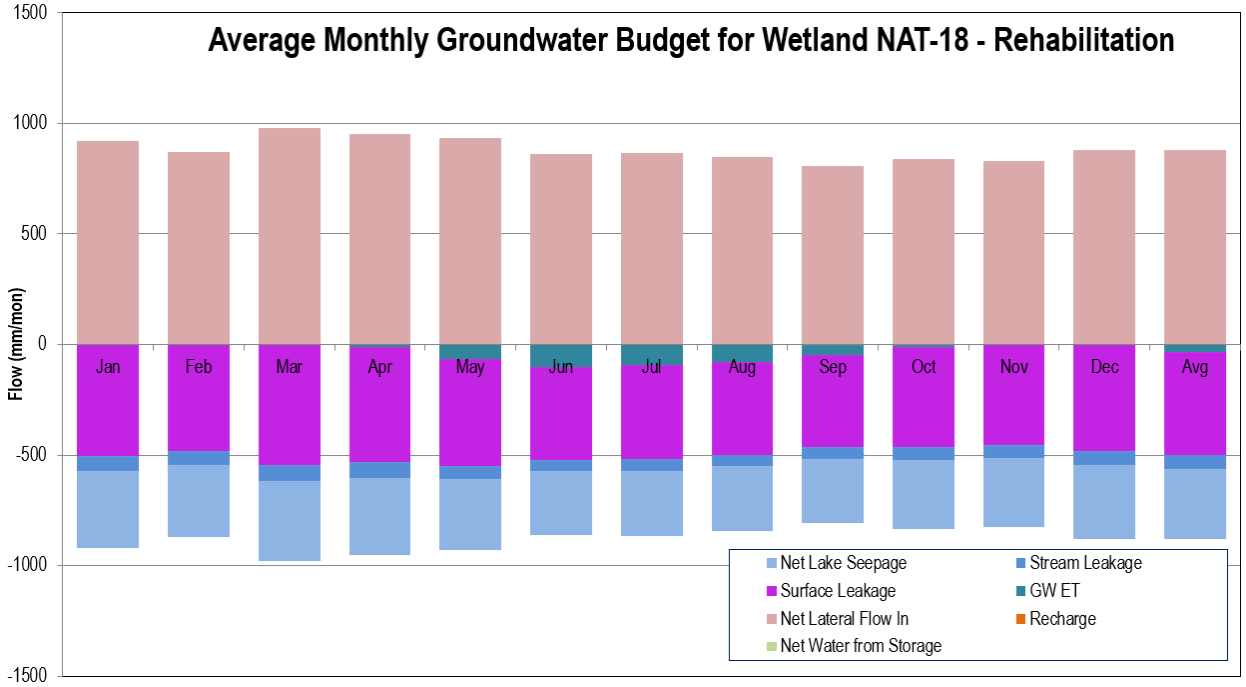


Figure 3.68: Groundwater budget for NAT-18

Table 3.29: Monthly groundwater budget under Rehab Conditions (in mm/month) Wetland NAT-18

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-0.27	-0.22	-0.18	0.08	0.77	0.68	0.16	0.07	-0.16	-0.37	-0.26	-0.18	0.01
Recharge	2.29	2.04	2.74	2.46	1.21	0.81	1.05	0.90	1.12	1.42	1.86	2.06	1.66
Net Lateral Flow In	914.4	863.9	971.6	943.8	924.4	854.9	858.9	840.0	803.6	832.1	824.1	873.6	875.4
GW ET	-0.38	-0.58	-1.79	-10.55	-67.13	-99.90	-92.80	-77.61	-48.14	-11.94	-1.89	-0.39	-34.42
Surface Leakage	-506.6	-479.9	-541.6	-523.2	-481.0	-422.7	-427.3	-424.2	-419.1	-454.4	-455.7	-484.1	-468.3
Stream Leakage	-68.01	-65.99	-76.15	-73.63	-63.71	-53.43	-53.19	-52.51	-52.11	-57.59	-58.65	-63.34	-61.52
Net Lake Seepage	-339.4	-318.3	-353.8	-338.9	-314.5	-280.4	-286.9	-286.0	-284.1	-308.1	-308.6	-326.8	-312.1
Streamflow In (L/s)	45.9	49.3	51.9	52.3	45.7	41.2	39.4	38.3	37.8	38.7	40.2	42.2	43.6
Streamflow Out (L/s)	74.8	79.5	83.2	84.0	74.5	67.0	64.0	62.7	62.6	64.5	67.0	69.9	71.1
Avg. Lake Stage (masl)	450.8	450.8	450.8	450.8	450.8	450.7	450.7	450.7	450.7	450.7	450.7	450.7	450.7

Table 3.30: Difference in monthly groundwater budget (Baseline - Rehab) in mm/month Wetland NAT-18

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	-0.03	-0.03	-0.01	-0.01	0.00	0.03	0.03	0.01	0.03	0.01	-0.02	-0.02
Recharge	0.02	0.01	-0.18	-0.11	0.02	0.02	0.02	0.02	0.01	0.05	0.02	0.03
Net Lateral Flow In	-10.43	-9.47	-7.85	-7.53	-6.93	-6.76	-7.31	-10.08	-10.63	-11.44	-12.01	-12.64
GW ET	0.00	0.00	0.00	0.00	-0.04	-0.01	0.03	0.06	0.09	0.02	0.00	0.00
Surface Leakage	7.38	5.66	4.51	3.62	4.05	5.27	6.67	8.22	9.25	10.79	10.24	9.75
Stream Leakage	0.72	0.24	-0.24	-0.39	0.20	0.72	1.11	1.55	1.73	2.04	1.69	1.46
Net Lake Seepage	2.28	3.20	4.36	4.31	2.71	0.72	-0.42	0.01	-0.67	-0.51	0.61	1.20
Streamflow In (L/s)	4.7	7.2	8.3	9.1	4.9	1.8	0.7	-1.1	-1.3	-1.0	0.4	1.9
Streamflow Out (L/s)	4.0	6.5	7.9	8.9	5.2	2.0	0.4	-0.9	-1.5	-1.4	-0.2	1.3
Avg. Lake Stage (masl)	0.02	0.03	0.03	0.03	0.02	0.01	0.00	0.00	-0.01	-0.01	0.00	0.01

3.8.5.2 Wetland NAT-19

Wetland NAT-19 is located immediately adjacent to the Strada property. The surface water and groundwater components of the water budget are presented as bar charts (Figure 3.69 and Figure 3.70) and underlying tables Table 3.31 through Table 3.34 show both the raw values in these figures and their relative differences with respect to the Baseline condition.

Under Rehabilitation, the surface water groundwater budget has returned to conditions similar to Baseline Conditions although groundwater recharge is slightly lower in the winter and higher in the summer (Table 3.34). Conditions are very similar to Baseline Conditions yet the groundwater mounding under the constructed wetland to the west creates a slightly higher amount on groundwater ET in the summer in NAT-19. Further details and discussion are included in the NRSI (2024) report.

Very rare overflow from the constructed wetland to the west will add a very small amount of water to NAT-19. Hydrographs and a discussion of the water levels and flows in the constructed wetland are included in Section 6.2.

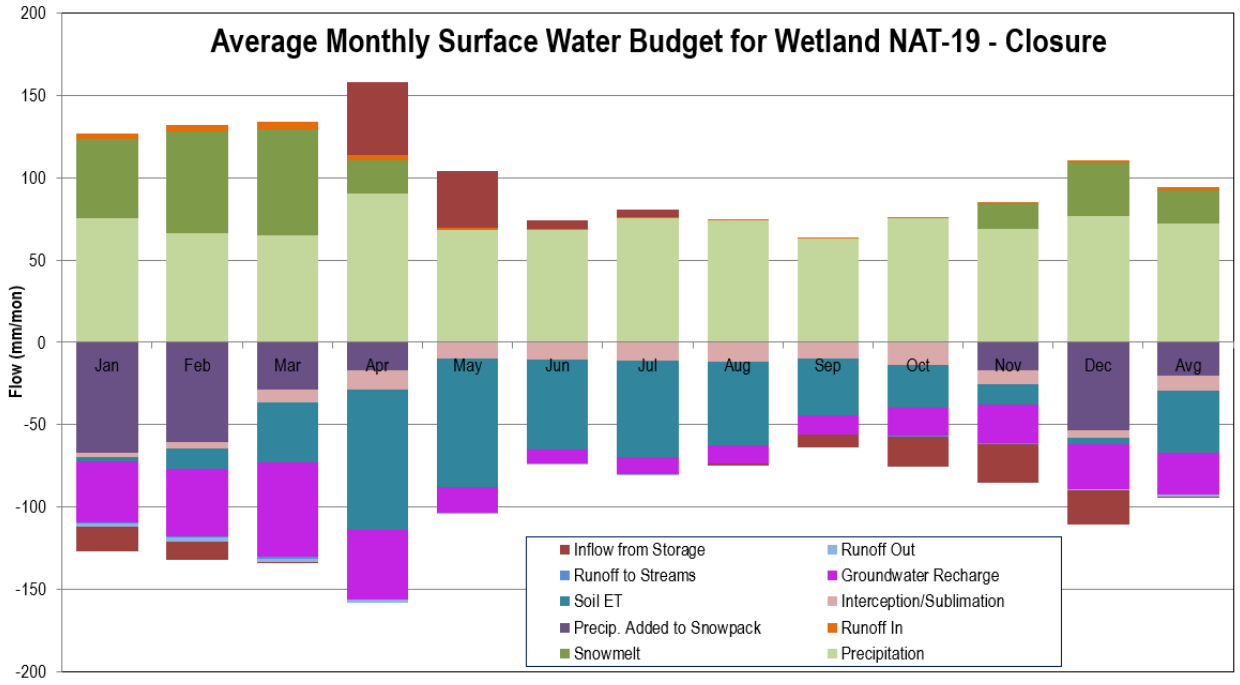


Figure 3.69: Surface water budget for NAT-19

Table 3.31: Monthly surface water budget under Rehab Conditions (in mm/month) Wetland NAT-19

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	75.51	66.41	65.25	90.65	68.47	68.53	75.62	74.12	63.06	75.28	69.12	76.54	72.38
Snowmelt	48.13	61.35	63.87	19.66	0.00	0.00	0.00	0.00	0.00	0.01	15.06	32.47	20.05
Runoff In	3.42	4.37	4.60	3.18	1.35	0.61	0.45	0.51	0.64	0.50	0.98	1.60	1.85
Precip. added to Snowpack	-66.88	-60.69	-28.43	-16.66	0.00	0.00	0.00	0.00	0.00	-0.01	-17.05	-53.25	-20.25
Interception/Sublimation	-2.69	-3.85	-8.19	-12.18	-10.11	-10.28	-10.92	-11.74	-9.69	-13.55	-8.24	-4.66	-8.84
Soil ET	-2.73	-12.11	-36.30	-84.96	-77.69	-54.84	-58.92	-50.81	-34.63	-26.22	-12.78	-3.81	-37.98
Groundwater Recharge	-37.16	-41.17	-57.44	-42.01	-15.42	-8.60	-10.38	-10.93	-11.46	-17.12	-23.40	-27.25	-25.20
Runoff to Streams	-0.52	-0.59	-0.91	-0.45	-0.12	-0.05	-0.05	-0.09	-0.17	-0.08	-0.20	-0.20	-0.29
Runoff Out	-1.79	-2.29	-2.27	-1.72	-0.73	-0.31	-0.19	-0.21	-0.24	-0.23	-0.45	-0.84	-0.94
Inflow from Storage	-15.30	-11.44	-0.18	44.47	34.27	4.93	4.39	-0.85	-7.50	-18.58	-23.04	-20.60	-0.79

Table 3.32: Difference in monthly surface water budget (Baseline - Rehab) in mm/month Wetland NAT-19

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.14	0.29	-1.31	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.02	-0.11
Runoff In	0.02	0.00	-0.50	-0.01	-0.01	-0.01	-0.05	-0.07	-0.16	-0.05	-0.09	0.05
Precip. added to Snowpack	-0.12	0.08	0.36	-0.17	0.00	0.00	0.00	0.00	0.00	0.00	-0.07	0.15
Interception/Sublimation	0.10	0.03	-0.06	-0.11	-0.09	-0.12	-0.10	-0.12	-0.09	-0.07	0.05	0.09
Soil ET	-0.09	0.01	0.20	0.16	2.82	2.12	1.60	0.92	0.52	-0.10	-0.03	-0.08
Groundwater Recharge	-1.79	-2.58	-2.14	-1.72	-0.44	-0.37	-0.35	-0.36	-0.25	-0.28	-0.20	-0.56
Runoff to Streams	0.26	0.28	0.64	0.25	0.04	-0.01	-0.01	0.00	0.08	0.00	0.08	0.09
Runoff Out	-0.16	-0.20	-0.15	-0.12	-0.06	-0.03	-0.01	-0.01	-0.01	-0.01	-0.03	-0.07

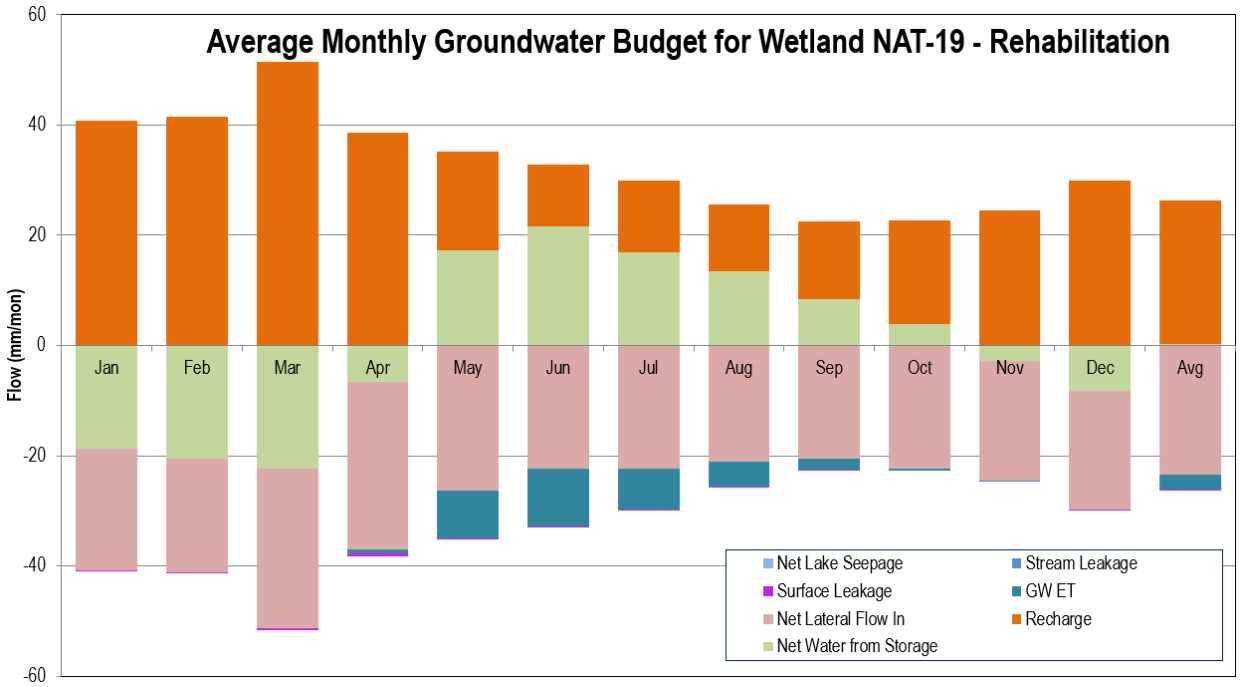


Figure 3.70: Groundwater budget for NAT-19

Table 3.33: Monthly groundwater budget under Rehab Conditions (in mm/month) Wetland NAT-19

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-18.72	-20.61	-22.28	-6.59	17.31	21.68	16.85	13.41	8.42	3.81	-2.78	-8.21	0.19
Recharge	40.80	41.56	51.53	38.64	17.83	11.22	13.04	12.17	14.13	18.97	24.49	29.95	26.20
Net Lateral Flow In	-22.11	-20.61	-29.11	-30.42	-26.29	-22.39	-22.33	-21.16	-20.58	-22.34	-21.66	-21.62	-23.39
GW ET	0.00	0.00	0.00	-0.80	-8.65	-10.39	-7.51	-4.40	-1.97	-0.45	-0.04	0.00	-2.85
Surface Leakage	-0.05	-0.11	-0.24	-0.42	-0.33	-0.11	-0.05	-0.02	0.00	0.00	0.00	-0.01	-0.11
Stream Leakage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Lake Seepage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 3.34: Difference in monthly groundwater budget (Baseline - Rehab) in mm/month - Wetland NAT-19

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	-1.56	-0.19	1.42	1.07	1.70	0.72	0.57	0.22	-0.38	-1.65	-1.86	-1.59
Recharge	-0.43	-0.78	-0.97	0.00	0.23	0.35	0.31	0.28	0.05	0.02	-0.30	-0.49
Net Lateral Flow In	2.02	0.65	-0.55	-2.15	-6.41	-7.63	-6.20	-4.02	-1.35	1.25	2.11	1.95
GW ET	-0.01	-0.02	-0.05	0.20	4.28	6.46	5.27	3.52	1.67	0.38	0.03	0.00
Surface Leakage	0.05	0.11	0.24	0.42	0.33	0.11	0.05	0.02	0.00	0.00	0.00	0.01
Stream Leakage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Lake Seepage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

3.8.6 **Rehab Conclusions**

The Rehab conditions will return water levels and flows to baseline conditions, with a small drawdown in the immediate vicinity of the quarry lake. These drawdowns are created (by leaving a small window to the deep Gasport aquifer) so as to ensure that the lake does not overflow to nearby properties.

The final condition drawdowns are small relative to the available drawdown in the aquifer (Figure 2.8), indicating that any shallow private wells could be readily deepened if necessary. The drawdown at location GWP-4 (near a new housing development west of Horning's Mills) is approximately 0.6 m (Figure 3.56), while the available drawdown at that location is approximately 25 m (Figure 2.8). In general, 5 m of available drawdown is considered adequate in limestone aquifers such as those encountered in the study area, so there remains plenty of available well capacity after rehab.

Streamflows at STR locations are expected to still exhibit an impact, albeit small to moderate, depending upon the season.

3.9 *Impacts on Adjacent Land Uses*

3.9.1 Impact on Permitted Groundwater Users

Permitted groundwater takings were represented in numerical model simulations, as discussed in Appendix D (Earthfx Inc., 2024), Section 4.7. None of the permitted groundwater locations are close to the simulated effects of the Strada pit/quarry, and no impacts to permitted groundwater takings are expected. The closest groundwater permit is the Bonnefield irrigation permit (0723-999LFU), which is 2.7 km northwest of the Strada site. A predicted groundwater mound of 0.15 m (15 cm) is expected at that location, as illustrated in Figure 3.71.

3.9.2 Impact on Permitted Surface Water Users

Permitted surface water takings were also represented in numerical model simulations, as discussed in Appendix D (Earthfx Inc., 2024), Section 4.8. None of the surface water permit locations are close to the simulated effects of the Strada pit/quarry, with the exception of Permit PTTW #7121-9Y7HP7, which is located approximately 1 km northeast of the Strada property (Figure 3.71). This is a surface and ground water permit sourced for commercial aquaculture purposes (a “fish farm”).

The model simulations indicate a that there might be a very small (approximately 1 cm) groundwater mound in the vicinity of the fish farm. This will cause a very small increase in cold water discharge to the stream.

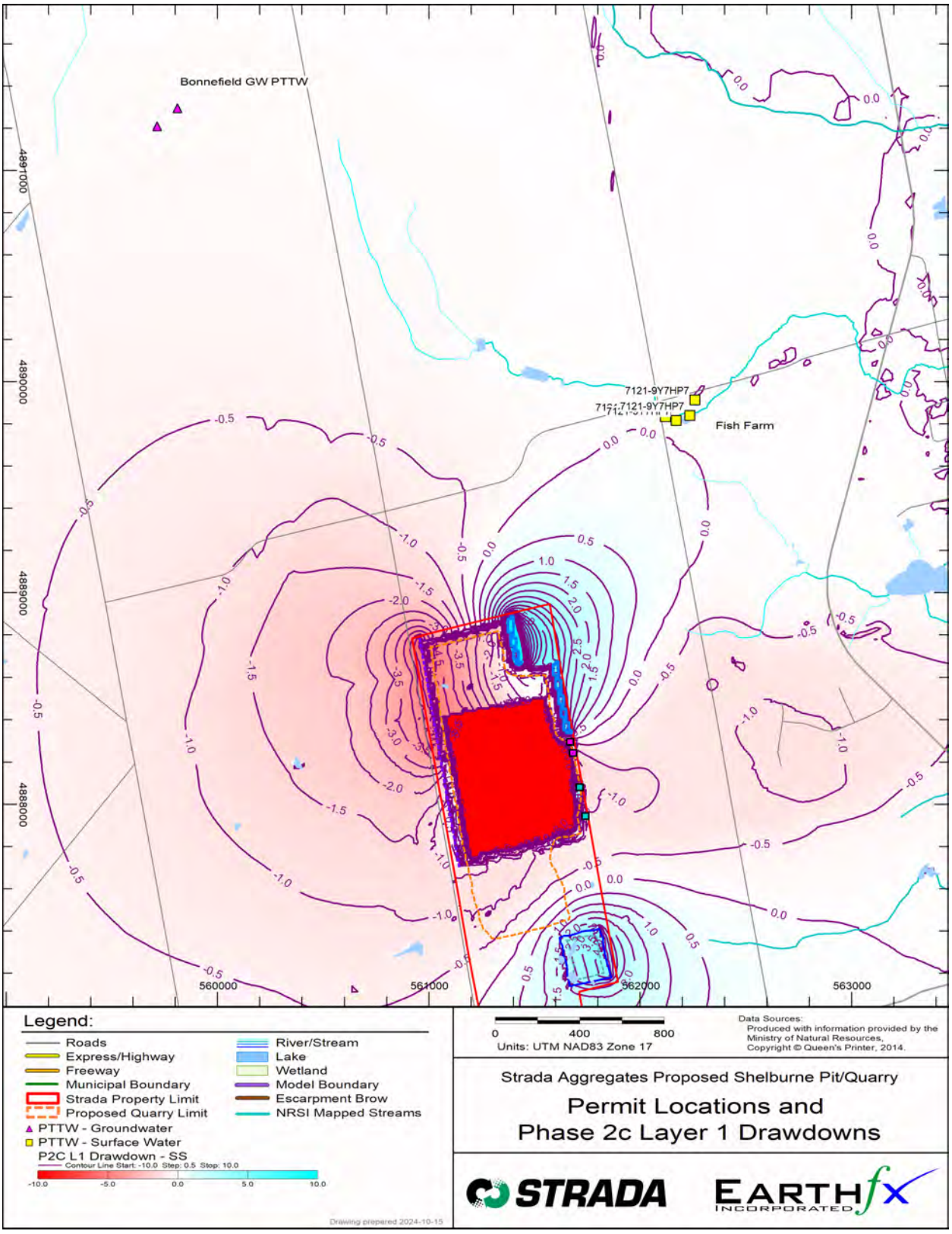


Figure 3.71: Locations of groundwater and surface water permits in the vicinity of the Strada property.

The model simulations of average total streamflow at the fish farm are shown in Table 3.35 (Model row 100, column 249). Streamflow and karst flow (Figure 2.27) and surface discharge (Figure 2.26) at this location are consistent with observations of cold-water conditions. Average streamflow upstream of STR2 is 22 L/sec, while karst discharge at that location is approximately 10 L/sec, for a total of 31.9 L/sec (Table 2.1).

Average flows under each scenario will be approximately 2000 L/minute. The operation is permitted to take a total of 195.2 L/minute, so under every scenario there will be approximately 10 times the flow in the stream in comparison to the permitted extraction rate. The change in streamflow is negligible.

Table 3.35: Average flow at fish farm under baseline and development scenarios

Scenario	Average Flow (m^3/s)	Average Flow (L/s)	Average Flow (L/min)
Baseline	0.0319	31.9	1914
Phase 1	0.0341	34.1	2046
Phase 2c	0.0313	31.3	1878
Phase 4b	0.0338	33.8	2028
Rehab	0.0306	30.6	1836

A hydrograph of the monthly streamflow under each scenario is shown in Figure 3.72. There is no predicted change in low flows, and a minor increase in peak monthly flows. The predicted low summer flow remains at 10 L/sec, or 600 L/minute, which is 3 times the permitted flow rate of 195.2 L/min.

In summary, there will be no predicted impact at the fish farm or any other permitted activity in the area.

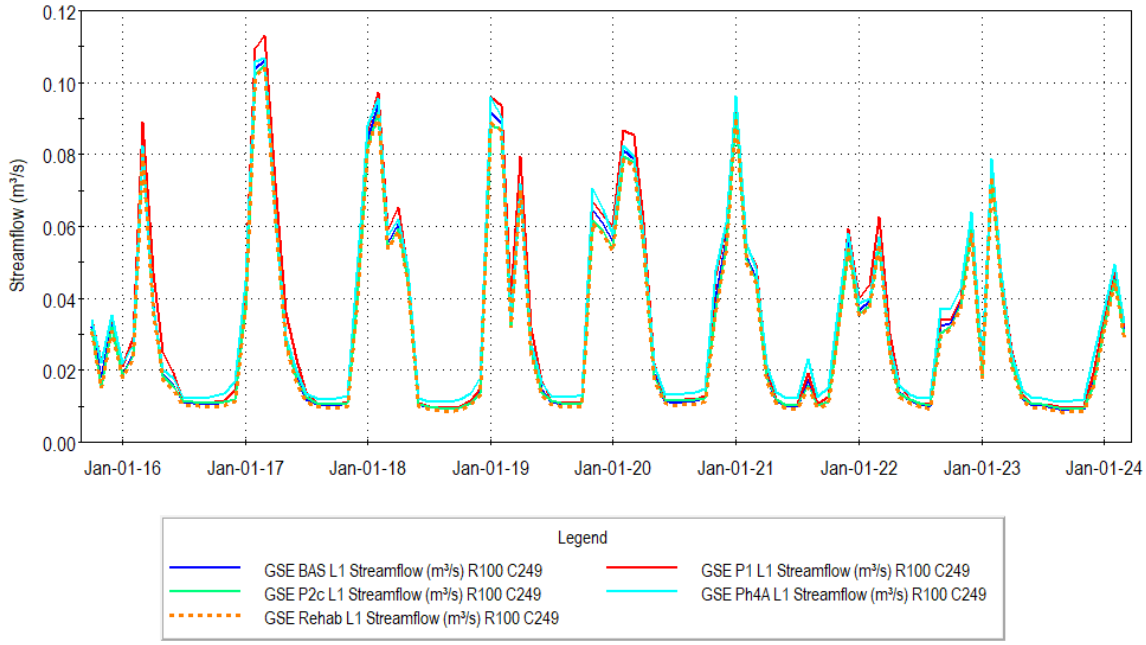


Figure 3.72: Streamflow at the fish farm under baseline and development scenarios.

3.9.3 Impact on Future Extractive Land Use

Immediately to the west and east of the proposed Strada Pit/Quarry site are two licenced gravel pit operations. To the west is the Duivenvoorden Haulage Ltd. Pit, while to the east is the CBM licenced pit. The pit locations are shown in Figure 3.73.

The current licensed Duivenvoorden pit is near full extraction and a proposal for expansion of the pit to the north of the existing property is under review. The proposed pit floor elevation is deeper than the current license and is a sloping surface with a low of 497 masl along the eastern property boundary, as shown in Figure 3.73. To ensure the proposed Strada Pit/Quarry water levels do not impact this proposed Duivenvoorden excavation a tile drain system has been included in the proposed Strada design along the western property boundary at an elevation of 488 masl.

The CBM licensed pit is located immediately east of the proposed Strada pit/quarry. Site plan information was used to delineate the licensed base of the CBM pit, as shown in Figure 3.73. The licenced pit floor slopes from approximately 492 masl in the west to 488 masl in the east.

Figure 3.74 shows a cross section through the Duivenvoorden, Strada and CBM pits. The cross-section location is shown in Figure 3.73, and passes through the deepest portions of the Duivenvoorden and CBM pits. The geologic layers are shown with the proposed Strada pit/quarry excavation. A thick purple line on the cross section shows the current LiDAR ground elevation with the approved CBM excavation depth and proposed Duivenvoorden excavation depth.

The simulated pre-extraction Baseline water levels are shown as a dotted blue line on the section. This illustrates that the proposed Duivenvoorden pit and licenced CBM pit are above water table operations.

The simulated water levels in Layer 1 under Phase 4a operations are shown as a solid blue line on the cross section. The results illustrate that the western Strada drain, at 488 masl, ensures that the water levels during Strada operations remain below the licenced CBM and proposed Duivenvoorden pit floor elevations. Phase 4a water levels under the Duivenvoorden pit are even lower than baseline levels.

Phase 4a water levels under the CBM property show a small mound caused by the Strada eastern infiltration trench, however this mound rapidly dissipates to the east and has no impact on licenced CBM operations.

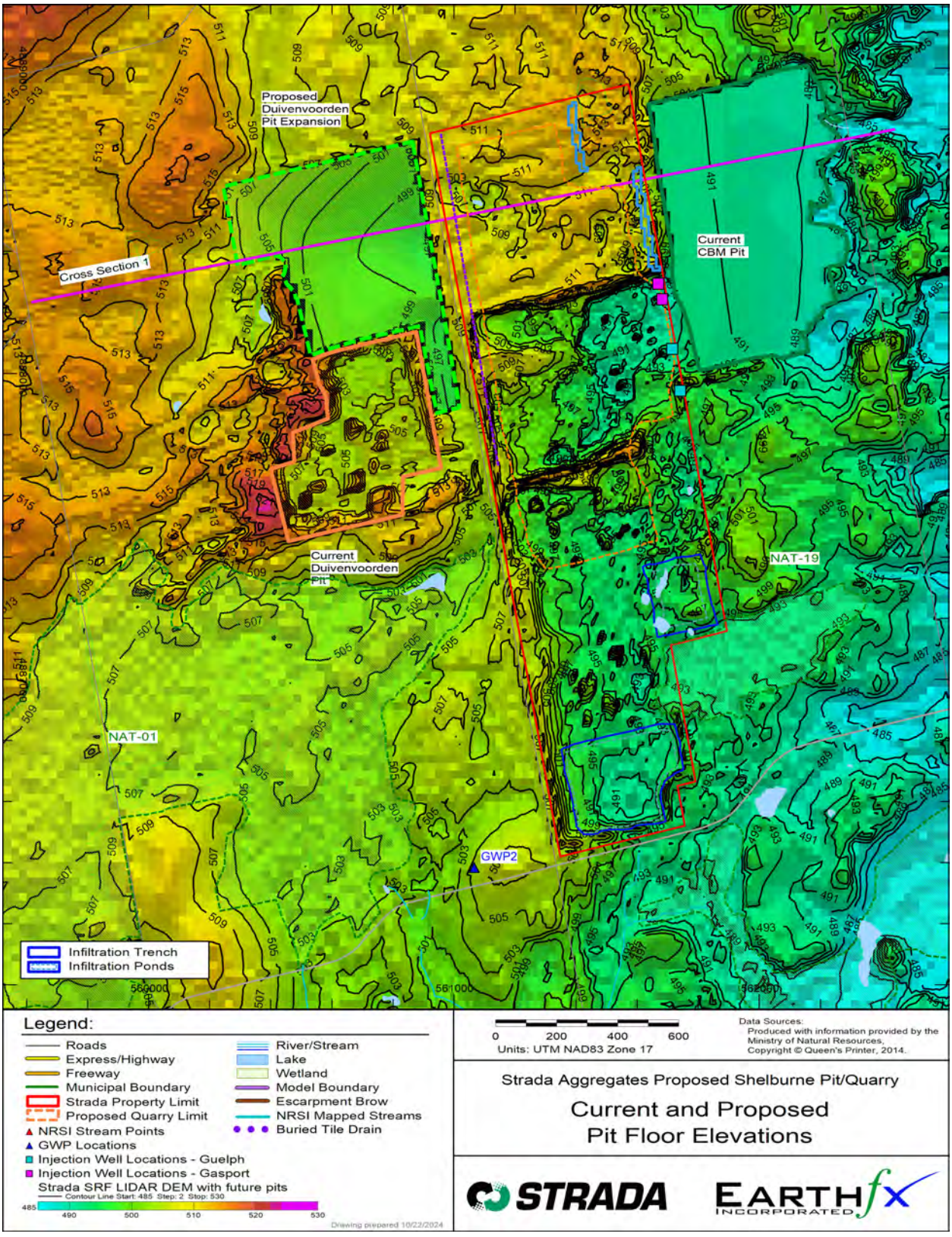


Figure 3.73: Location and elevation of licensed CBM pit floor and proposed Duivenvoorden expansion pit floor.

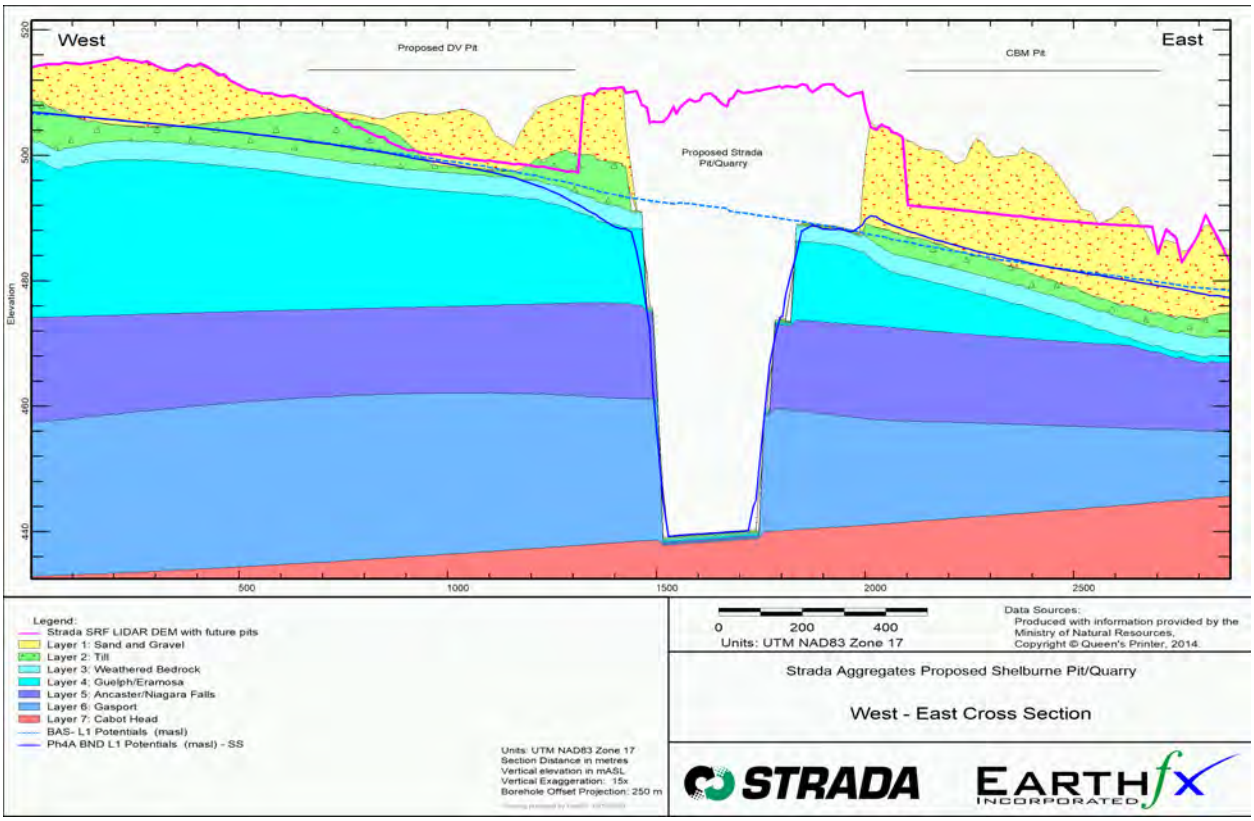


Figure 3.74: Cross section through Duivenvoorden (DV) and CBM properties showing Baseline and Phase 4a water levels in Layer 1 relative to future pit floor elevations (purple line)

3.9.4 Impacts on Residential Properties

Detailed maps showing the effects of the proposed Strada operations have been presented in the previous chapters. The figures show of water table mounding caused by the proposed infiltration system will not affect adjacent pits and residential properties to the west, north and east. To illustrate conditions near the southern infiltration pond, a series of hydrographs have been prepared at the three residential properties immediately south and south east of the Strada property. These hydrographs shown the ground surface elevation and shallow groundwater levels under each scenario. The locations of the three residences are shown in Figure 3.75.

Residence A is located immediately south east of the Strada property. A hydrograph of water levels under baseline, development and rehab scenarios is shown in Figure 3.76. Ground surface is at 495 masl, and baseline water levels are approximately 490.4 masl. During each of the extraction phases, with active groundwater infiltration systems, water levels rise approximately 1 m, leaving 3.5 m depth to water table.

Residence B is located immediately south of the Strada property. A hydrograph of water levels under baseline, development and rehab scenarios is shown in Figure 3.77. Ground surface is at 497.7 masl, and baseline water levels are approximately 492.5 masl. During each of the extraction phases, with active groundwater infiltration systems, water levels rise approximately 0.5 m, leaving 4.7 m depth to water table.



Figure 3.75: Location of residential properties near the southern infiltration pond.

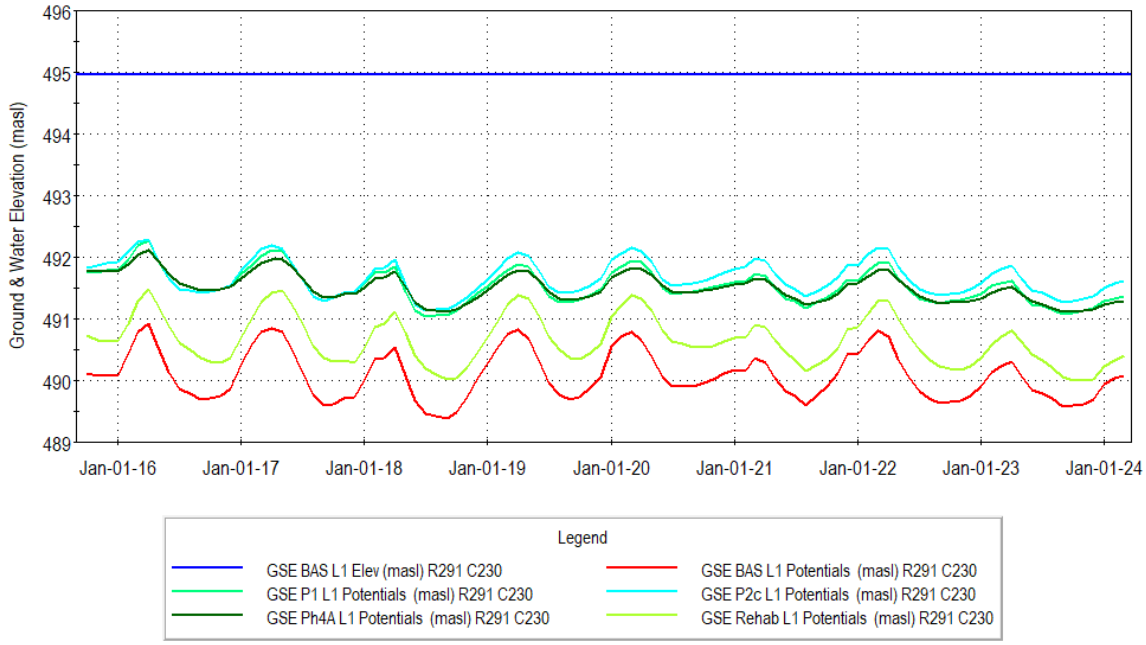


Figure 3.76: Water level hydrograph for Residence A

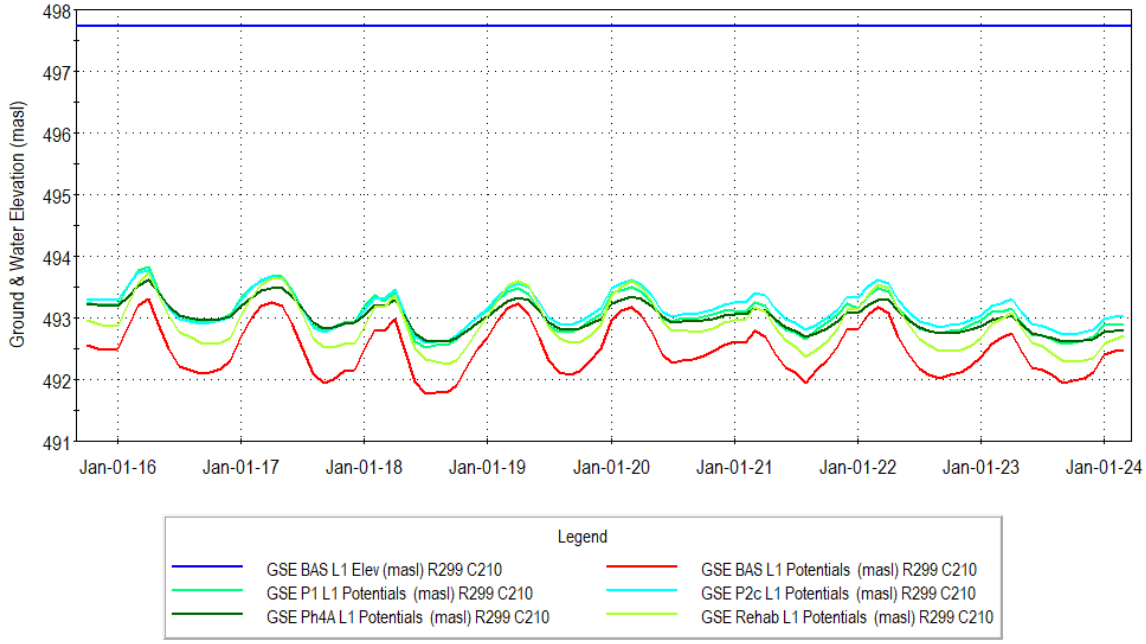


Figure 3.77: Water level hydrograph for Residence B

Residence C is located south east of the Strada property. A hydrograph of water levels under baseline, development and rehab scenarios is shown in Figure 3.78. Ground surface is at 493.2 masl, and baseline water levels are approximately 488 masl. During each of the extraction phases, with active groundwater infiltration systems, water levels rise approximately 0.65 m, leaving 4.1 m depth to water table.

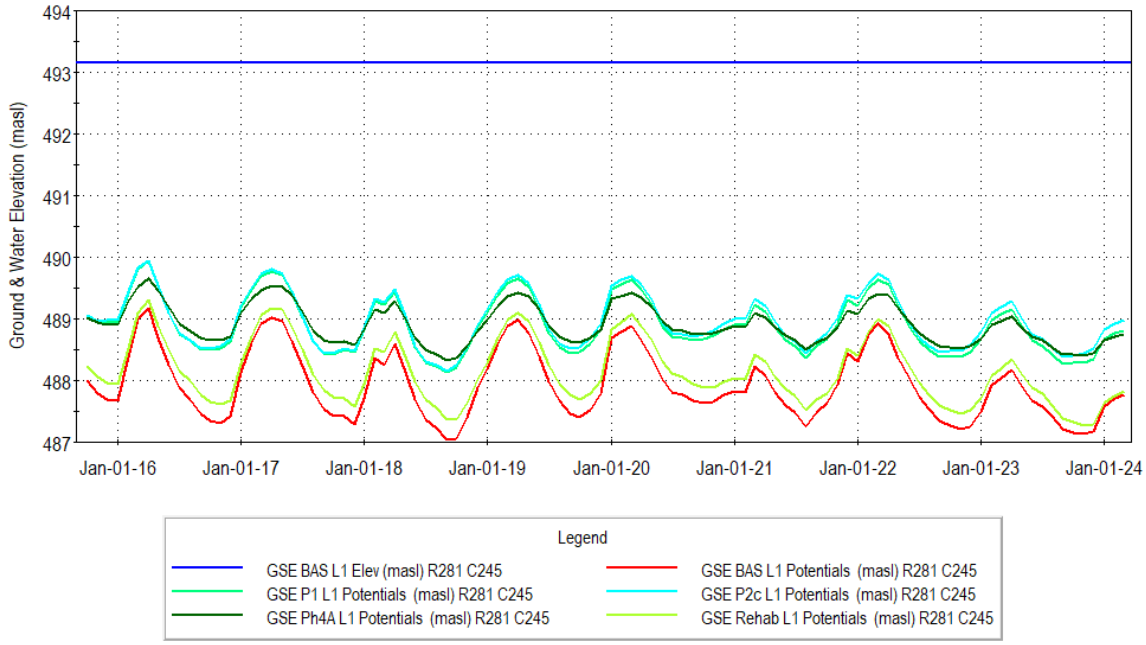


Figure 3.78: Water level hydrograph for Residence C

The hydrographs indicate that groundwater levels will rise modestly in the vicinity of the private residences, but indicate that septic beds will not likely be affected.

3.9.5 **Impact on Agricultural Land**

Impact to agricultural land may occur if the water table rises to within 1 m to 2 m of the ground surface, resulting in excess soil moisture in the root zone. The proposed Strada infiltration systems will cause mounding (water table rise), in the upper aquifer system, but the mounding will not be sufficient to impact cropland in the area.

This highest rate of infiltration will occur during Phase 2C, and the mounding created under those operating conditions is shown in Figure 3.23. Much of the infiltration system mounding will not, however, rise to within 2 m of the ground surface, and therefore will not impact agricultural land. Figure 3.79 illustrates where infiltration mounding rises to within 2 m of ground surface, and this area is limited to a small area south of the Strada site. The effects of mounding on the local residences in this area is not significant (as discussed in the previous section) however Figure 3.79 shows where mounding may occur in low-lying areas.

Figure 3.79 shows that mounding will occur to within 2 m of ground surface in the western portion of Wetland NAT-19. The effect of this is discussed in the companion NRSI report. Further south, some minor rise in the water table will occur in lowlands, wetlands and around existing ponds, but no active agricultural land or residences will be impacted.

(Note that no mounding in the upper aquifer system will occur to the west of the Strada property because of the proposed western buried tile drain that will redirect groundwater to the injection wells on the eastern property boundary. Mounding within the Strada property is not relevant, as the water will be collected and managed by the internal water management system)

In summary, there will be no impact of mounding on agricultural land.

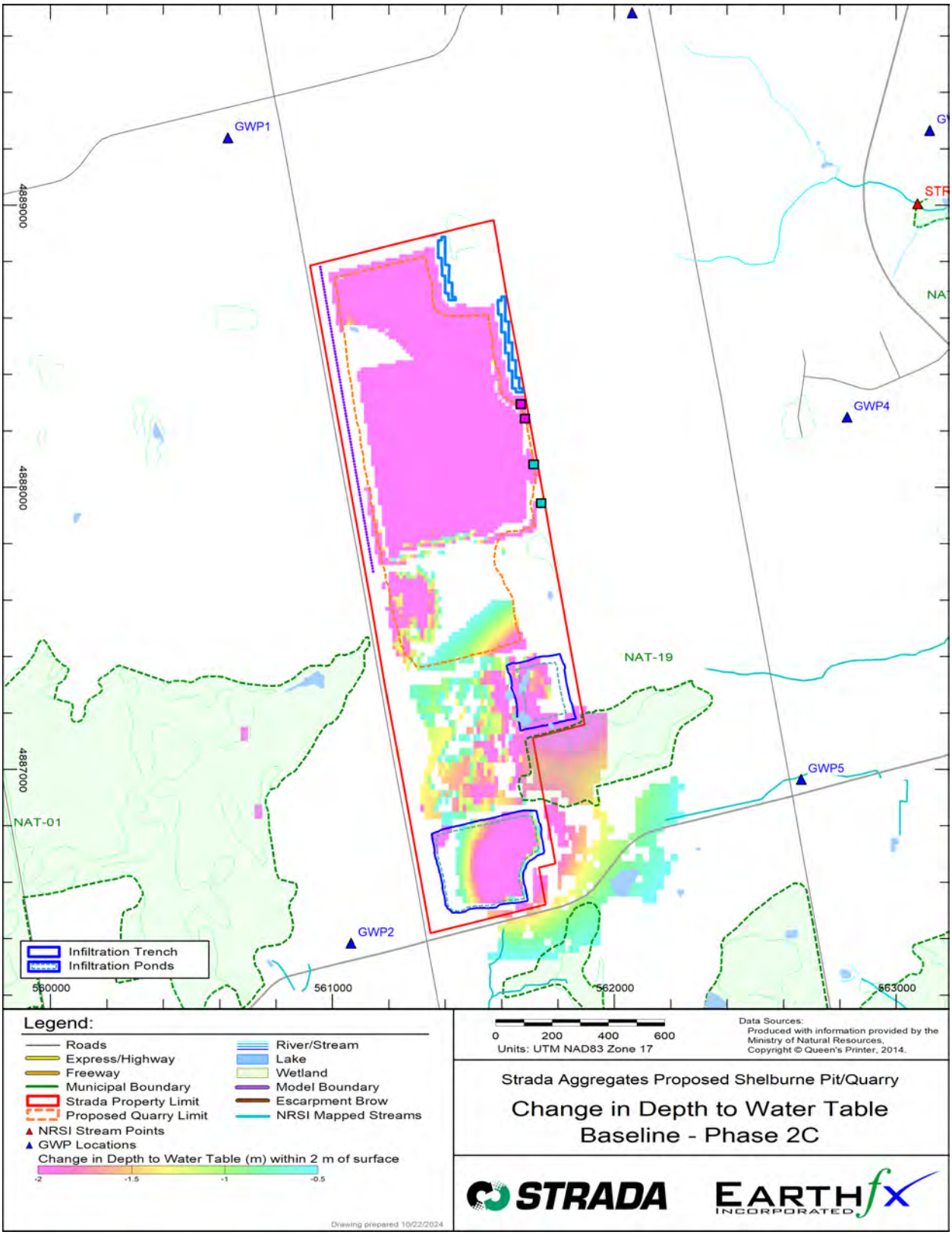


Figure 3.79: Change in Depth to Water Table (Baseline - Phase 2C) where the change occurs within 2 m of ground surface.

3.9.6 **Impact on Boyne Watershed**

The southern edge of the Strada property is located at the divided between the Pine and Boyne River watersheds. The wetlands immediately south of the site drain into the Boyne River, and will receive additional seepage from the central and southern infiltration ponds.

To assess changes in watershed flows, the average flow at location STR14 (see location in Figure 2.11) is summarized in Table 3.36 under each of the scenarios.

The change in flow at STR14 under Phase 2C will reach 4.2% of the baseline flow at that location. Upon Rehab, the long-term change in flow will be 0.4% of baseline.

Table 3.36: Change in flow at Location STR14.

Scenario	Average Flow (m^3/s)	Average Flow (L/s)	Average Flow (L/min)	Change (L/s)	Change Percent
Baseline	0.0265	26.5	1590		
Phase 1	0.0276	27.6	1656	1.10	4.2%
Phase 2c	0.0276	27.6	1656	1.10	4.2%
Phase 4b	0.0270	27.0	1620	0.50	1.9%
Rehab	0.0266	26.6	1596	0.10	0.4%

Location STR14 is located high in the Boyne River watershed and represents only a small component of flow in the catchment. For comparison, the average flow in the Boyne River at Earl Row Park is 2.18 m^3/sec or 2180 L/sec (See Appendix D (Earthfx Inc., 2024), Table 3.6). Under Phase 2C, the 1.1 L increase in flow at STR14 will increase flow at Earl Rowe Park by 0.05%. Under Rehab, the 0.1 L increase in flow at STR14 will increase flow at Earl Rowe Park by 0.0045%.

4 Groundwater Monitoring Program

4.1 *On-Site Groundwater Monitoring Wells*

Key groundwater monitoring wells have been selected and incorporated into the long-term groundwater monitoring program. The groundwater monitoring program consists of water level and water quality monitoring. The on-site groundwater monitoring wells are shown on Figure 4.1. Details are provided in Table 4.1.

As discussed in Appendix A: Field Program Methodology and Results the groundwater monitoring network consists of well nests, which monitor discrete intervals in the overburden and bedrock aquifer. Well nests have monitoring wells with either A, B, or C following the well label (for example: OW4A, OW4B, and OW4C). The “A” monitor is constructed at the base of the sand and gravel unit (water table aquifer). The “B” monitor is constructed at the base of the Tavistock Till (just above the bedrock contact). The “C” monitor is constructed within the bedrock aquifer.

Water levels will be collected continuously with automatic water level transducers, with manual measurements collected monthly.

Select groundwater monitoring wells will be sampled semi-annually for general water quality and oil and grease. A complete list of the groundwater quality parameters is provided in Table 4.2.

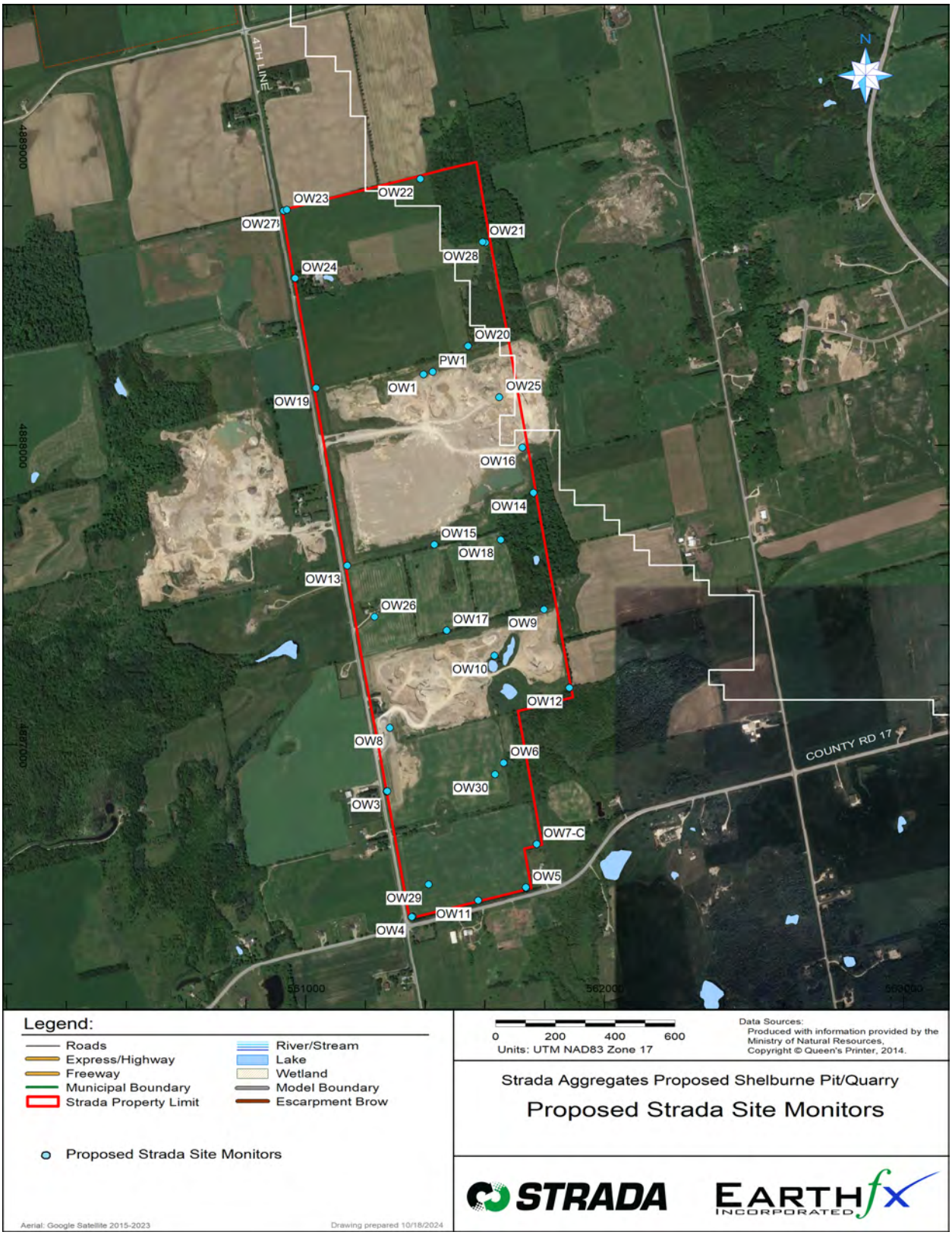


Figure 4.1: Proposed Strada Site Monitors

Table 4.1: Groundwater Monitoring Network

WELL NEST ID	MONITORING ID	LOCATION	WELL DEPTH (m)	HYDROSTATIC UNIT	WATER LEVEL MONITORING	WATER QUALITY MONITORING
PW1	PW1	17T 4888246N, 561425E	48.76	Bedrock	Yes	No
OW1	OW1	17T 4888238N, 561395 E	48.76	Bedrock	Yes	No
OW3	OW3B	17T 4886844N, 561273E	9.75	Tavistock Till and Bedrock Contact	Yes	Semi-Annual
	OW3C	17T 4886844N, 561271E	12.49	Bedrock	Yes	Semi-Annual
OW4	OW4A	17T 4886425N, 561355E	7.92	Sand and Gravel Overburden	Yes	Semi-Annual
	OW4B	17T 4886425N, 561355E	13.72	Tavistock Till and Bedrock Contact	Yes	Semi-Annual
	OW4C	17T 4886425N, 561359E	16.46	Bedrock	Yes	Semi-Annual[1]
OW5	OW5A	17T 4886523N, 561738E	5.70	Sand and Gravel Overburden	Yes	Semi-Annual & Annual
	OW5B	17T 4886523N, 561738E	10.05	Tavistock Till and Bedrock Contact	Yes	Semi-Annual
	OW5C	17T 4886520N, 561738E	13.10	Bedrock	Yes	Semi-Annual[1]
OW6	OW6A	17T 4886939N, 561663E	7.80	Sand and Gravel Overburden	Yes	Semi-Annual & Annual
OW7	OW7A	17T 4886674N, 561771E	10.05	Sand and Gravel Overburden	Yes	Semi-Annual & Annual
	OW7C	17T 4886668N, 561773E	30.60	Bedrock	Yes	Semi-Annual

OW8	OW8A	17T 4887057N, 561282E	12.0	Sand and Gravel Overburden	Yes	Semi-Annual & Annual
OW9	OW9B	17T 4887451N, 561798E	18.20	Tavistock Till and Bedrock Contact	Yes	Semi-Annual & Annual
OW10	OW10B	17T 4887297N, 561632E	19.20	Tavistock Till and Bedrock Contact	Yes	Semi-Annual & Annual
OW12	OW12A	17T 4887192N, 561882E	7.62	Sand and Gravel Overburden	Yes	Semi-Annual & Annual
	OW12B	17T 4887190N, 561882E	21.03	Tavistock Till and Bedrock Contact	Yes	Semi-Annual[1]
OW13	OW13A	17T 4887598N, 561140E	14.34	Sand and Gravel Overburden	Yes	Semi-Annual
	OW13C	17T 4887598N, 561140E	18.94	Bedrock	Yes	Semi-Annual
OW14	OW14A	17T 4887841N, 561763E	12.40	Sand and Gravel Overburden	Yes	Semi-Annual
	OW14C	17T 4887841N, 561763E	20.00	Bedrock	Yes	Semi-Annual & Annual
OW16	OW16A	17T 4887994N, 561726E	11.81	Sand and Gravel Overburden	Yes	No
	OW16C	17T 4887993N, 561726E	27.30	Bedrock	Yes	Semi-Annual & Annual
OW18	OW18A	17T 4887685N, 561653E	19.80	Sand and Gravel Overburden	Yes	Semi-Annual & Annual
	OW18C	17T 4887685N, 561653E	23.70	Bedrock	Yes	Semi-Annual
OW19	OW19A	17T 4888192N, 561036E	14.40	Sand and Gravel Overburden	Yes	Semi-Annual
	OW19C	17T 4888192N,	35.50	Bedrock	Yes	Semi-Annual

		561036E				
OW20	OW20A	17T 4888333N, 561544E	21.64	Sand and Gravel Overburden	Yes	No
	OW20C	17T 4888333N, 561544E	26.40	Bedrock	Yes	Semi-Annual & Annual
OW21	OW21A	17T 4888680N, 561593E	22.20	Sand and Gravel Overburden	Yes	Semi-Annual[1]
	OW21C	17T 4888680N, 561593E	25.30	Bedrock	Yes	Semi-Annual & Annual
OW22	OW22A	17T 4888890N, 561384E	24.30	Sand and Gravel Overburden	Yes	Semi-Annual[1]
	OW22C	17T 4888890N, 561384E	27.50	Bedrock	Yes	Semi-Annual
OW23	OW23A	17T 4888787N, 560938E	20.40	Sand and Gravel Overburden	Yes	Semi-Annual[1]
	OW23C	17T 4888787N, 560938E	29.50	Bedrock	Yes	Semi-Annual
OW24	OW24A	17T 4888558N, 560965E	30.57	Sand and Gravel Overburden	Yes	Semi-Annual[1]
	OW24C	17T 4888558N, 560965E	66.69	Bedrock	Yes	Semi-Annual[1]
OW25	OW25A	17T 4888161N, 561648E	19.23	Sand and Gravel Overburden	Yes	No
	OW25C	17T 4888161N, 561648E	46.08	Bedrock	Yes	No
OW26	OW26A	17T 4887427N, 561231E	30.41	Sand and Gravel Overburden	Yes	Semi-Annual[1]
	OW26C	17T 4887427N, 561231E	54.88	Bedrock	Yes	Semi-Annual[1]

OW27	OW27C	17T 4888785N, 560927E	71.88	Bedrock	Yes	Semi-Annual[1]
OW28	OW28A	17T 4888675N, 561602E	37.18	Sand and Gravel Overburden	Yes	Semi-Annual[1]
	OW28C	17T 4888678N, 56160E	67.59	Bedrock	Yes	Semi-Annual[1]
OW29	OW29A	17T 4886532N, 561413E	25.96	Sand and Gravel Overburden	Yes	Semi-Annual[1]
	OW29C	17T 4886533N, 561412E	62.76	Bedrock	Yes	Semi-Annual[1]
OW30	OW30C	17T 4886901N, 561634E	56.62	Bedrock	Yes	Semi-Annual[1]
Injection Well 1	IW1	TBD	TBD	Guelph Bedrock	Yes	Semi-Annual[1]
Injection Well 2	IW2	TBD	TBD	Guelph Bedrock	Yes	Semi-Annual[1]
Injection Well 3	IW3	TBD	TBD	Gasport Bedrock	Yes	Semi-Annual[1]
Injection Well 4	IW4	TBD	TBD	Gasport Bedrock	Yes	Semi-Annual[1]

Note:

1. Not currently monitored as part of the existing Integrated Monitoring Program but are suggested as additional monitoring requirements moving forward.

Table 4.2: Groundwater Quality Monitoring

WATER QUALITY SAMPLING FREQUENCY	PARAMETER
Semi-Annual	pH, Conductivity, Alkalinity, Bicarbonate, Chloride, Metals (Antimony, Arsenic, Barium, Beryllium, Boron, Cadmium, Calcium, Cobalt, Copper, Lead, Iron, Magnesium, Manganese, Mercury, Molybdenum, Nickel, Potassium, Selenium, Sodium, Silver, Strontium, Sulfur, Thallium, Thorium, Tin, Titanium, Tungsten, Uranium, Vanadium, Zinc), Nitrate/Nitrite, Sulphate
Annual	Petroleum Hydrocarbons Fractions F1 to F4, Benzene, Toluene, Ethylbenzene and Xylenes (BTEX), and Oil and Grease

4.2 *Off-Site Domestic Water Wells*

The MECP requires that all PTTW holders take the necessary actions to ensure residents and their water supplies are protected from potential impacts associated with the water takings at aggregate operations. To be proactive and to alleviate the complaint driven process, Strada shall implement a voluntary domestic water well monitoring program to those residents located within the Target Participation Area (TPA) as shown on Figure 4.2. The TPA extends south of County Road 17, and is bound to the east by Mulmur/Melancthon Townline, extends north of Sideroad 15 to the north, extends west of County Road 124. This program will be designed to act as an early warning system and would identify any potential adverse interference that may compromise the integrity of the domestic water supply.

A preliminary private door-to-door water well survey was completed as part of the on-going compliance monitoring for the Strada pits. As part of the survey five private domestic water wells located within 1 km of the Strada lands were visited. The purpose of the water well survey was to collect baseline information on the local water use (quality and quantity) to ensure the sustained quality and quantity of the water supply. Of the 5 homes visited, all 5 indicated that they were interested in participating in a monitoring program (Figure 4.3) and, as a result, have been added to the current groundwater monitoring program (Table 4.3).

Further Strada is currently engaging with homeowners within the identified TPA to participate in a WELLness Check where baseline information on well condition and water use (quantity and quality) can be established. The WELLness Check (i.e. water well survey) would be completed by a Certified Well Inspector (i.e. licensed well technician as per O.Reg.903). As of July, 2024 198 property owners within the TPA had registered to have a WELLness Check completed. Following the completion of the WELLness Check select wells will be identified by a Profession Geoscientist/Professional Engineer to be included in a long-term groundwater monitoring program. This monitoring program is designed to establish baseline conditions of existing domestic water wells. Wells will be selected based on location, accessibility and compliance with O.Reg.903, and this monitoring program will be completed only at locations where permission has been granted by the property owner.

The current domestic water well monitoring locations are summarized in Table 4.3. Water levels will be collected continuously with automatic water level transducers, with manual measurements taken monthly.

Select groundwater monitoring wells will be sampled semi-annually for general water quality. A complete list of the groundwater quality parameters is provided in Table 4.4.

Furthermore, Strada's website will have a page dedicated to the WELLness Check Private Well Monitoring Program, including details on the monitoring program. The website will also have a contact form that will allow a resident to schedule a meeting with Strada personnel to discuss having their well added to the WELLness Check program.

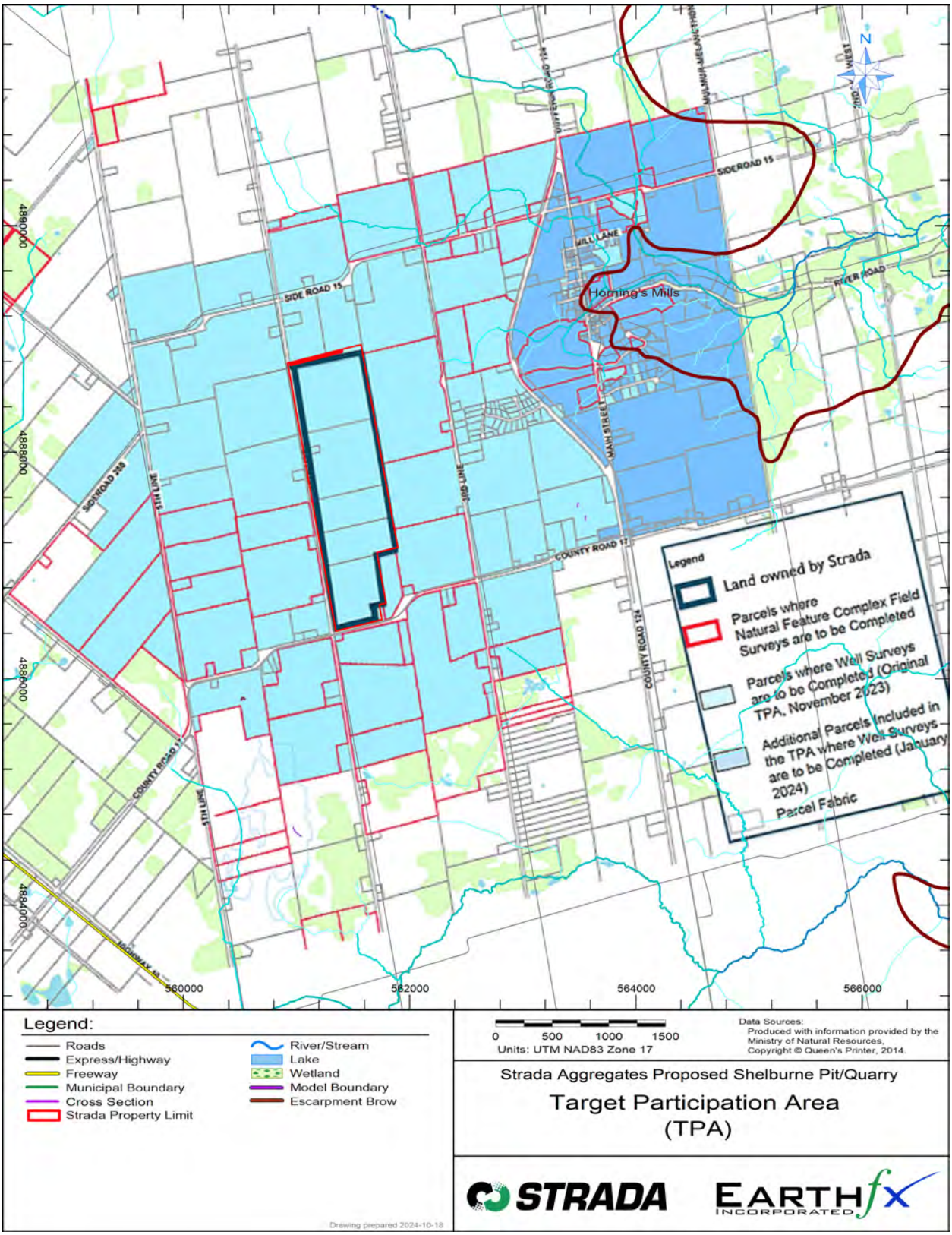


Figure 4.2: Target Participation Area

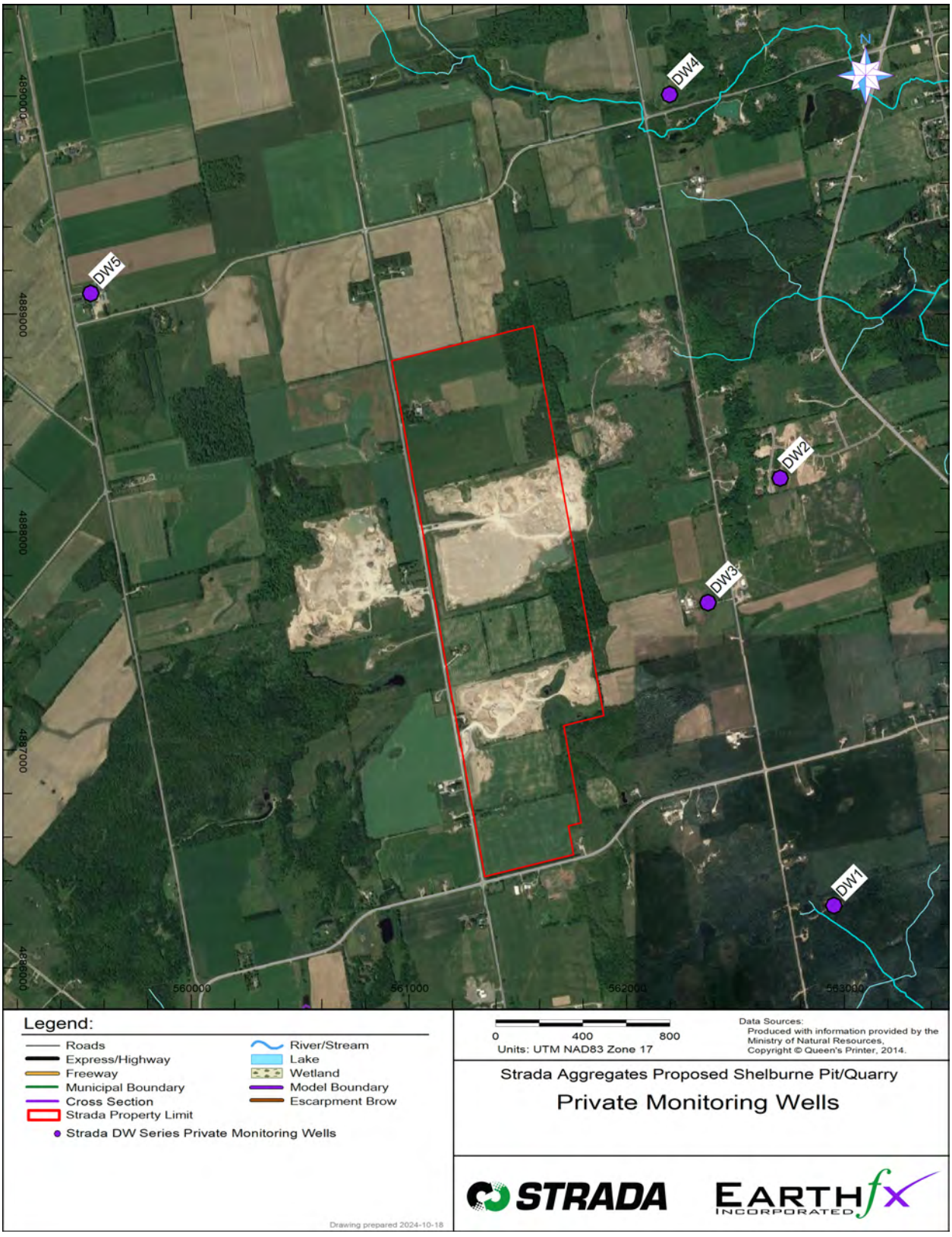


Figure 4.3: Private Monitoring Wells

Table 4.3: Groundwater Monitoring Network

WELL LOCATION	LOCATION	MECP WELL ID	WELL DEPTH (m)	HYDROSTATIC UNIT	WATER LEVEL MONITORING	WATER QUALITY MONITORING
DW1	17T 4886286N, 562950E	1706362	11.5	Bedrock	Yes	Semi-Annual
DW2[1]	17T 4888248N, 562704E	7199024	44.8	Bedrock	Yes	Semi-Annual
DW3[1]	17T 4887676N, 562373E	NA	--	--	Yes	Semi-Annual
DW4	17T 4890007N, 562196E	7122047	24.4	Bedrock	Yes	Semi-Annual
DW5	17T 4889094N, 559538E	NA	--	--	Yes	Semi-Annual

Note:
1. Recommended Sentry Wells for long-term monitoring.

Table 4.4: Groundwater Quality Monitoring

WATER QUALITY SAMPLING FREQUENCY	PARAMETER
Semi-Annual	pH, Conductivity, Alkalinity, Bicarbonate, Chloride, Metals (Antimony, Arsenic, Barium, Beryllium, Boron, Cadmium, Calcium, Cobalt, Copper, Lead, Iron, Magnesium, Manganese, Mercury, Molybdenum, Nickel, Potassium, Selenium, Sodium, Silver, Strontium, Sulfur, Thallium, Thorium, Tin, Titanium, Tungsten, Uranium, Vanadium, Zinc), Nitrate/Nitrite, Sulphate

4.3 *Well Response Program*

A comprehensive complaints response program has been established for the site for the purpose of responding to water well interference complaints for water well users in the vicinity of the proposed pit/quarry. The program includes the following:

- Following receipt of a complaint from a water well user, Strada will notify the MNRF and MECP.
- Strada will ensure a Certified Well Inspector (i.e. licensed water well technician) and/or qualified hydrogeologist visits the site within 24 hours of receiving the complaint to investigate. The Certified Well Inspector and/or hydrogeologist will complete a well inspection including a review of the pump, well condition, pump depth and condition, etc.
- Strada will provide a temporary water supply to the well owner within 48 hours of receiving the complaint and thereafter until such time as the cause of the disruption has been determined. Strada will arrange temporary water system hook up and removal, and the first and subsequent loads of water to the system. Strada shall fund the temporary solution.
- If the well complaint can be definitively determined to not be a result of the pit/quarry operations (i.e. mechanical failure), Strada will continue to provide water for an additional week to allow the well owner to make alternative water supply arrangements.
- If the well complaint cannot be definitively determined to not be a result of the pit/quarry operations after the initial site visit, a hydrogeologist will review the water well inspection report and supporting information, water level data and on-going operations at the quarry/pit to provide an assessment of the cause of the complaint. The hydrogeologist will prepare an opinion letter to be provided to the MECP as to the likelihood the well complaint is related to the quarry/pit operation.
- Following the MECPs review if the well interference is determined to not be a result of the pit/quarry operations, Strada will continue to provide water for an additional week to allow the well owner to make alternative water supply arrangements.
- Following the MECPs review if the well interference is determined to be attributed to the quarry/pit operations and activities and the water supply is at risk, a water supply restoration program will be implemented.
- The water supply restoration program includes:
    - Step 1: Well system rehabilitation: this includes the replacement or lowering of pumps, flushing the pump lines, well deepening, etc.
    - Step 2: Well Replacements: if system rehabilitation is not an option, the well could be replaced with a new well further from the pit.
    - Step 3: Water treatment considerations: appropriate water treatment will be incorporated into any restored water supply.

5 Surface Water Monitoring Program

A surface water monitoring program has been developed and implemented to establish existing baseline conditions for the surface water features on-site and in the surrounding area. The surface water program includes the monitoring of streamflow, wetland hydroperiod, and shallow groundwater levels. In 2024, baseflow was measured at 13 locations at two points in time (spring and summer).

The surface water monitoring will continue during the operational lifespan of the pit/quarry to:

- Monitor streamflow, water quality, wetland hydroperiods and surface and groundwater interactions during operations and upon closure of the Strada Pit/Quarry;
- Assess potential unforeseen changes and impacts to the surface water and natural heritage features on-site and in the surrounding area resulting from extraction and dewatering of the quarry; and
- Establish the cause of any potential unforeseen changes and impacts to the surface water and natural heritage features and determine if mitigation is required to address the changes/impacts.

5.1 *Surface Water Monitoring Network*

The surface water monitoring program consists of water level monitoring. The on-site surface water monitoring locations are shown on Figure 5.1 enclosed. Details are provided in Table 5.1.

A continuously recording pressure transducer measuring water level and water temperature has been installed in a drive point well in each wetland and pond location. Manual in-situ water level measurements are collected monthly at each shallow groundwater monitoring location. The field measurements are used to calibrate the continuously recording pressure transducer data.

Surface water monitoring locations will be sampled semi-annually for general water quality. A complete list of the surface water quality parameters is provided in Table 5.2.

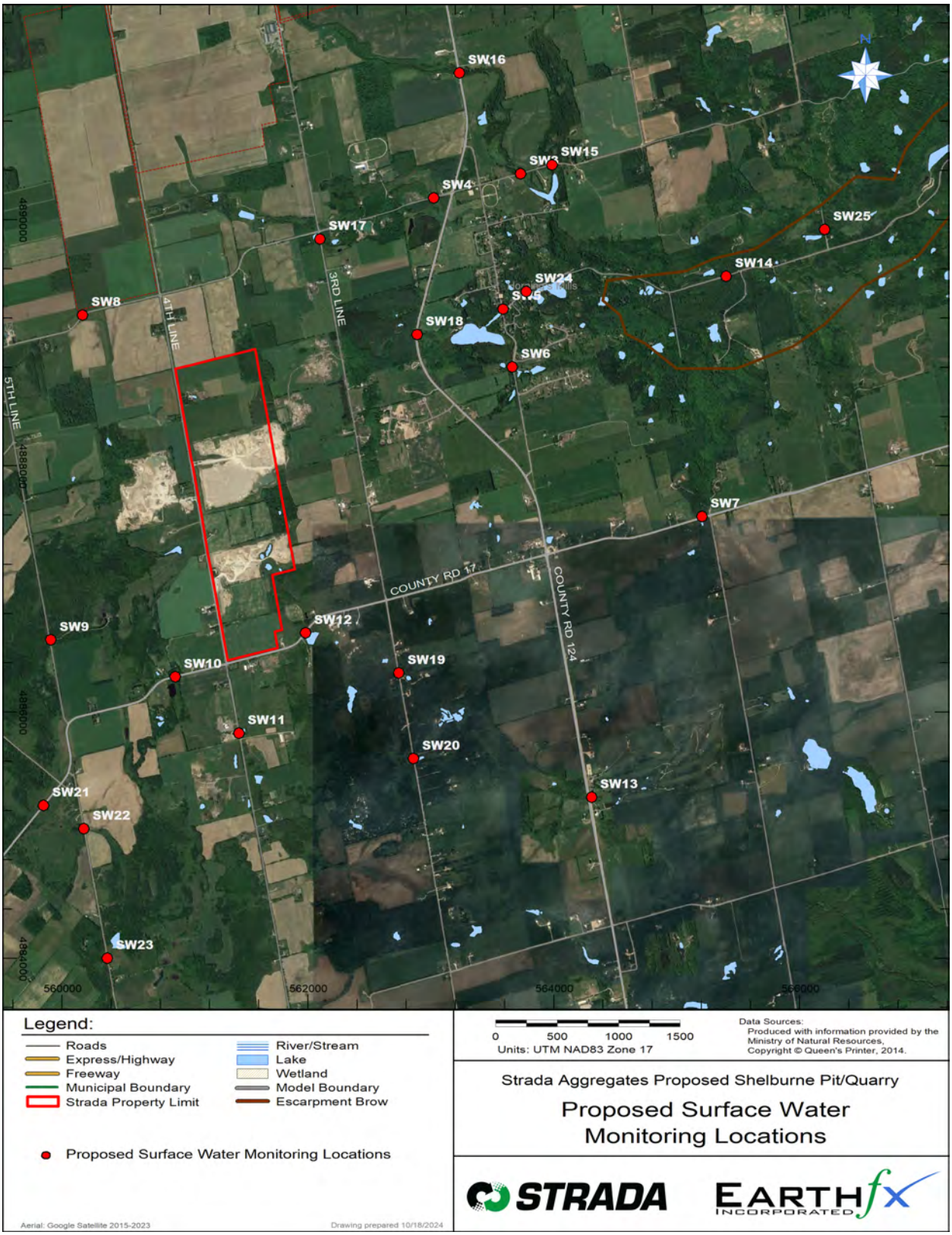


Figure 5.1: Surface Water Monitoring Locations

Table 5.1: Surface Water Level Monitoring Network

MONITORING LOCATION	LOCATION	WATER LEVEL MONITORING	WATER QUALITY MONITORING
North Pond	17T 4887268N, 561630E	Yes	Semi-Annual[1]
South Pond	17T 4887155N, 561778E	Yes	Semi-Annual[1]
SW1 (Wetland)	17T 4887622N, 561767E	Yes	Semi-Annual[1, 2]
SW2 (Vernal Pool)	17T 4887538N, 561734E	Yes	Semi-Annual[1, 2]
NAT-18	TBD	Yes[1]	Semi-Annual[1]
NAT-19	TBD	Yes[1]	Semi-Annual[1]

Note:

1. Not currently monitored as part of the existing Integrated Monitoring Program but are suggested as additional monitoring requirements moving forward.
2. Monitoring to discontinue when wetland has been removed and monitoring locations should be relocated and replaced in the reconstructed wetland.

Table 5.2: Surface Water Quality Monitoring

SAMPLING FREQUENCY	PARAMETER
Semi-Annual	Dissolved Oxygen, Conductivity, pH, Temperature

Streamflow monitoring has been implemented to establish existing baseflow conditions for 13 monitoring locations in the vicinity of the Strada property, as shown on Figure 5.1. Manual in-situ streamflow measurements have been collected at each streamflow monitoring location in May and August 2024. Details are provided in Table 5.3.

Table 5.3: Streamflow Monitoring Network

Monitoring Location	Location	May 30, 2024		August 15, 2024	
		Stream Flow Rate (L/s)	Temperature	Stream Flow Rate (L/s)	Temperature
SW3	17T 4890372N, 563730E	241.1	7.6	45.3	10.6
SW4	17T 4890176N, 563023E	65.5	12.3	61.7	16.0
SW5	17T 4889273N, 563588E	177.1	14.5	139.7	17.1
SW6	17T 4888803N, 563662E	54.5	7.5	38	13.3
SW7	17T 4887588N, 565205E	Dry		Dry	
SW8	17T 4889224N, 560167E	<1	17.9	Dry	
SW9	17T 4886586N, 559909E	Dry		Dry	
SW10	17T 4886286N, 560921E	<1	13.8	Dry	
SW11	17T 4885828N, 561440E	Dry		Dry	
SW12	17T 4886643N, 561981E	3.3	15.5	Dry	
SW13	17T 4885308N, 564308E	99.6	16.5	28.2	20.5
SW14	17T 4889540N, 565402E	--		449.5	16.1
SW15	17T 4890444N, 563986E	62.2	7.5	5.3	9.2
SW16	17T 4891192N, 563232E	--		36.9	9.3
SW17	17T 4889841N, 562098E	--		38.9	15.7
SW18	17T 4889066N, 562888E	--		Dry	
SW19	17T 4886317N, 562739E	--		8	16.4
SW20	17T 4885622N, 562859E	--		10.9	18.2
SW21	17T 4885241N, 559850E	--		<1	14.7
SW22	17T 4885052N, 560178E	--		1.1	18.6
SW23	17T 4884000N, 560368E	--		<1	15.6
SW24	17T 4889416N, 563777E	--		211.4	16.5
SW25	17T4889920N, 566202E	883.4	10.9	332.5	16.1

6 Stormwater Management

The infiltration systems are designed to provide complete capture and control of all groundwater inflows, precipitation and stormwater on the site. The transient simulations demonstrate that the on-site water management works across both seasonal and inter-annual climate conditions. The system has extra capacity and flexibility to infiltrate additional water, and it can accommodate specific needs to satisfy ecological hydro-periods and protect surrounding wetlands. A summary of the fluxes is included in Table 6.1.

No offsite discharge is necessary under any operating or closure scenario.

Table 6.1: Summary of water management fluxes.

Flux Components	Flux (L/s)	Percentage (%)
PHASE 1		
Total Flux of water from quarry	29.5	
Flux to Northern Trench	11.6	39%
Flux between Trenches	0	0%
Flux to Southern Trench	4.3	15%
Flux to Central Infiltration Site	13.1	44%
Flux to South Infiltration Site	0.52	2%
PHASE 2C		
Total Flux of water from quarry	71.0	
Flux to Northern Trench	25.5	36%
Flux between Trenches	0	0%
Flux to Southern Trench	19.5	27%
Flux to Central Infiltration Site	21.6	30%
Flux to South Infiltration Site	4.4	6%
Flux From Buried Tile Drain to Injection Wells [1]	12.0	
PHASE 4A		
Total Flux of water from quarry	40.9	
Flux to Northern Trench	13.0	30%
Flux between Trenches	0	0%
Flux to Southern Trench	11.3	27%
Flux to Central Infiltration Site	16.6	39%
Flux to South Infiltration Site	1.8	4%
Flux From Buried Tile Drain to Injection Wells [1]	12.0	

[1] Flux to injection wells not included in total flux from quarry.

6.1 *Infiltration Feature Water Levels*

An examination of the predicted water levels at each of its infiltration demonstrates their performance under the different operating and closure scenarios (Figure 6.1 through Figure 6.4). Figure 6.1 shows that only under Phase 2C spring conditions will the water levels in the northern infiltration trench overtop the water control outflow elevation (509 masl) and flow into the southern portion of the infiltration trench.

The predicted water levels in the southern infiltration trench (Figure 6.2) reach a maximum at 503 masl during Phase 2C, leaving 3 m of freeboard (below 506 masl) before any off-site discharge were to occur.

The central infiltration feature receives the primary sump discharge and overflows, at 494 masl, into the southern infiltration feature and northern trench each spring (Figure 6.3). Phase 1 water level variability is the greatest, followed by Phase 2C then Phase 4A.

The flux into the southern infiltration site has been kept to a minimum so as to reduce potential impacts to the south (See Section 3.9 for a detailed discussion). Figure 6.4 shows that occasionally, in Phase 2C, water levels in the southern feature reach a water control elevation 494 masl, at which point the overflow is routed to the northern trenches.

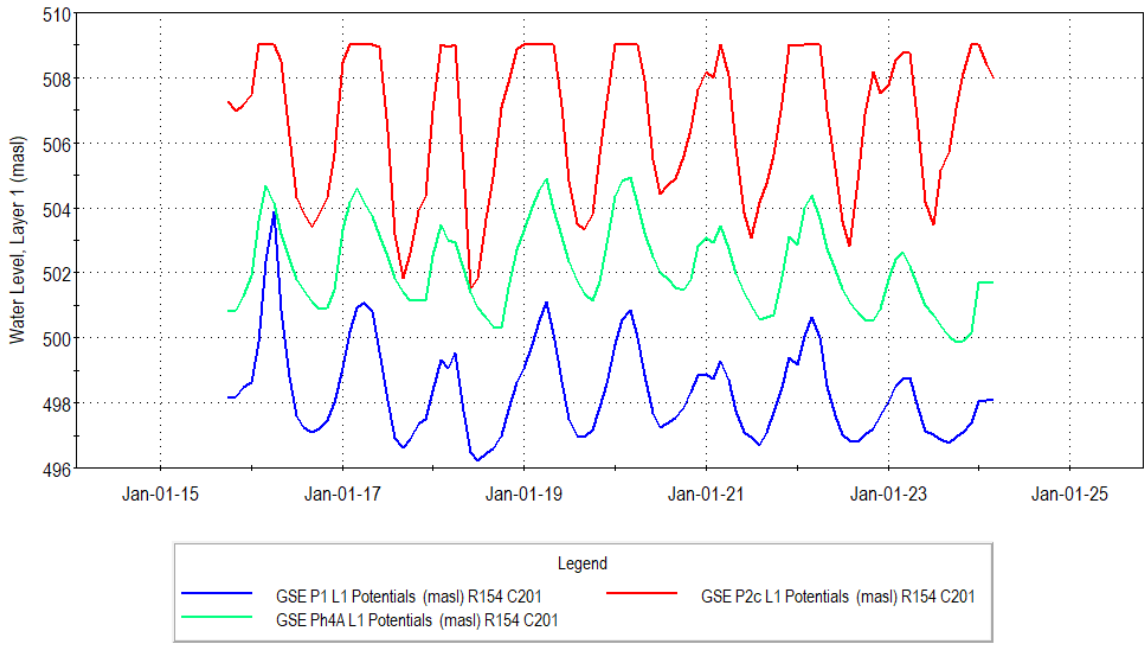


Figure 6.1: Water levels predicted at the northern infiltration trench in all scenarios.

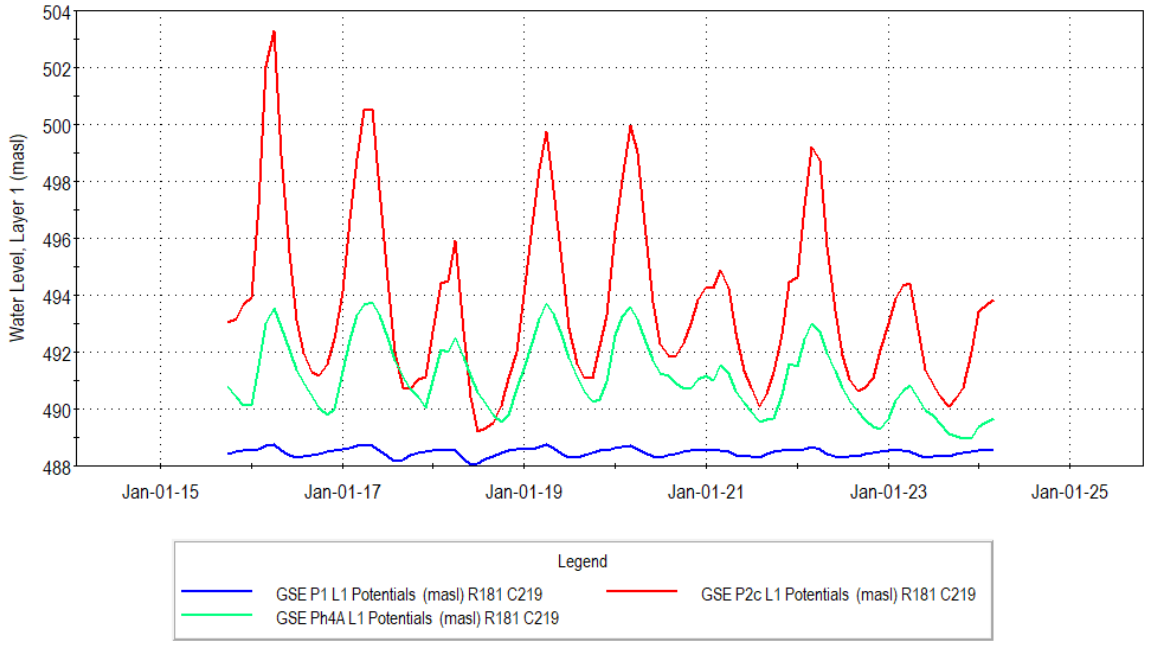


Figure 6.2: Water levels predicted at the southern infiltration trench in all scenarios.

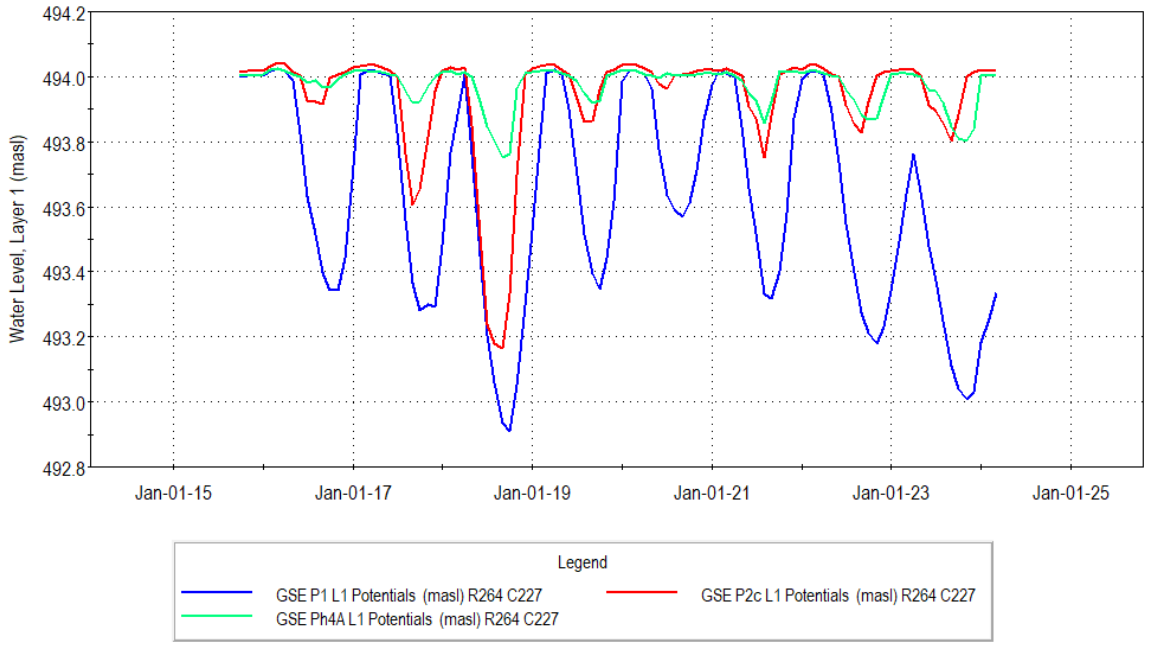


Figure 6.3: Water levels predicted at the central infiltration trench in all scenarios.

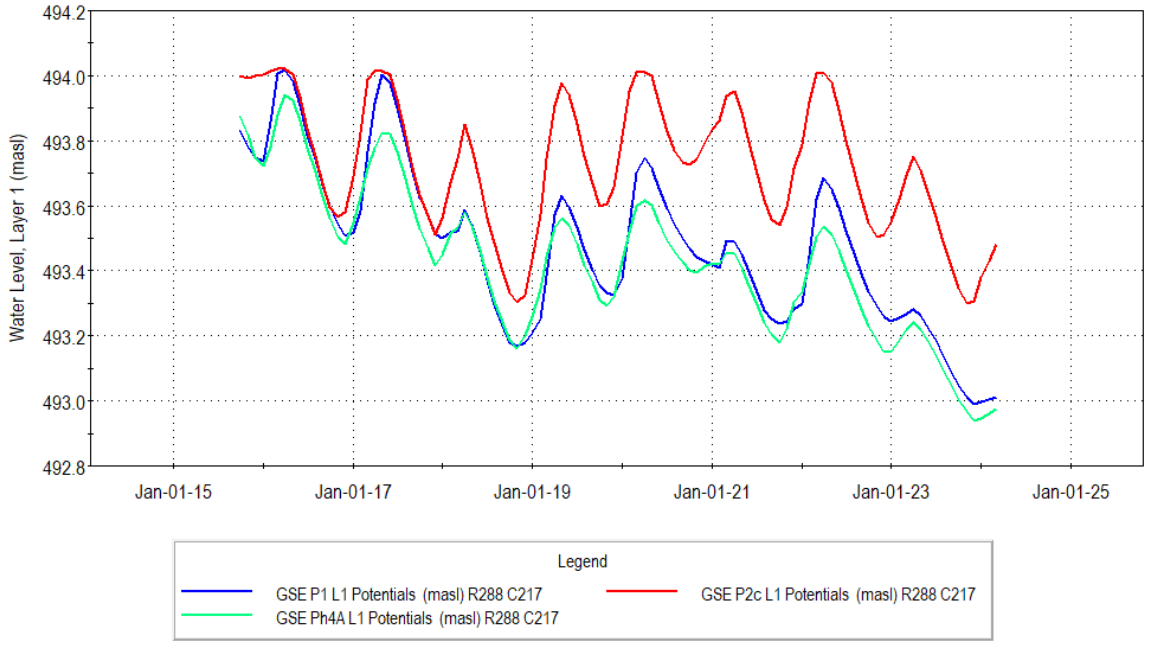


Figure 6.4: Water levels predicted at the southern infiltration trench in all scenarios.

6.2 *Constructed Wetland Water Levels*

As noted in Section 3.8.1, during rehabilitation the constructed wetland (located west of the NAT-18), will be surrounded by a graded terrain such that runoff converges toward the wetland. The graded terrain will be underlain by a thin layer of silty sand or silty loam so as to generate sufficient runoff and interflow to the wetland without any need for active long-term pumping or wetland management. The groundwater mounding and impacts on the NAT-19 water budget are discussed in Section 3.8.

At closure, the wetland will be constructed to overflow, at 495 masl, into the adjacent NAT-18 feature to the immediate east, should water levels in the wetland rise above that elevation.

The predicted water level in the constructed wetland after rehab is shown in Figure 6.5. The bottom of the wetland is at 492 masl and simulations indicate that a near permanent pool will be maintained.

Water levels in the constructed wetland will fluctuate, and simulations indicate that occasional overflows (above 495 masl) may occur towards NAT-18, of the order of 0.2 to 1.4 L/s. The timing of this estimated flux after closure is shown in Figure 6.5 (green line, right-axis).

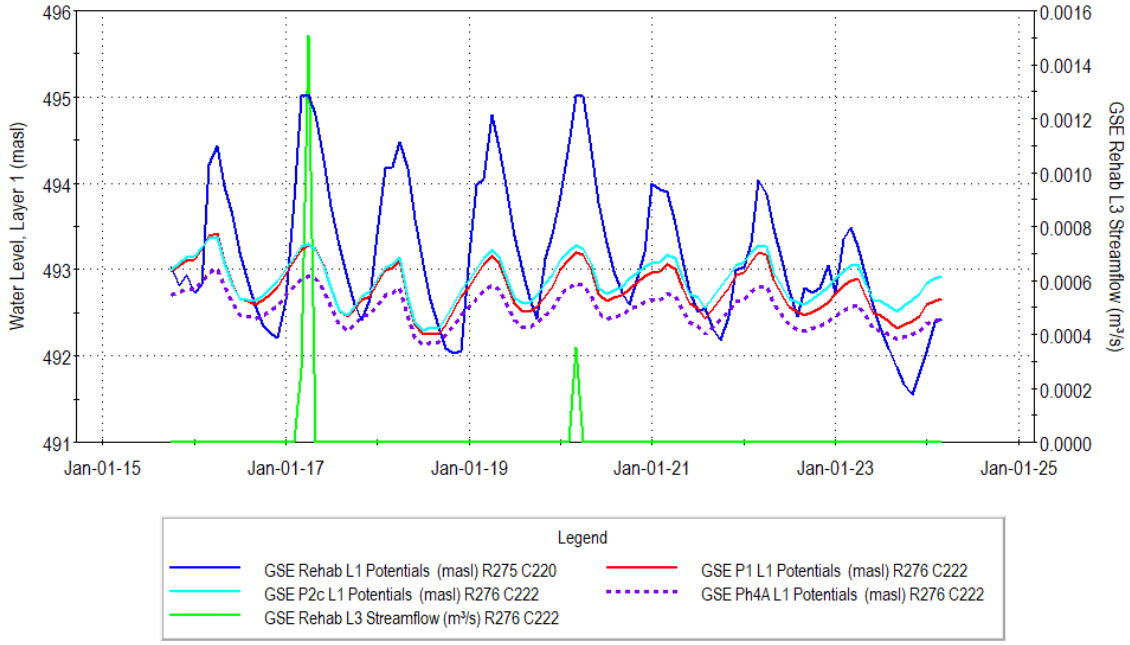


Figure 6.5: Water levels and flows (after closure) at the constructed wetland.

7 Summary and Conclusions

This Level 2 ARA Impact Assessment presents a detailed comparative evaluation of the effects of the proposed development of the Strada Pit/Quarry. The predicted effects of the development have been systematically evaluated across a range of seasonal and inter-annual (wet and dry year) climate conditions. The predicted effects on groundwater levels are minimal when compared to the extensive available drawdown in the bedrock aquifers. The streams and wetlands may see small changes in flows and levels, but the majority of these changes are likely below what is measurable in the field.

The final rehabilitation plan will preserve the general water level patterns and ensure that the final lake will not overflow and create surface water impacts.

At the subwatershed scale, the proposed pit/quarry will not change the overall surface water and groundwater flow system. There will be no cross-watershed impacts, groundwater recharge rates will be preserved, and groundwater and surface water in and around the quarry will continue to flow toward the Pine River Valley. The quality and quantity of groundwater needed for the natural environment and wells will be protected, and no municipal wellhead protection areas will be impacted. The evaluated rehabilitation option preserves the surface water and groundwater system. A comprehensive monitoring and response plan has been developed. The additional available groundwater resources have been quantified, and a well mitigation program has been proposed.

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8 References

Armstrong, D.K. and Carter, T.R. 2010. The Subsurface Paleozoic Stratigraphy of Southern Ontario. Ontario Geological Survey Special Volume 7

Earthfx Incorporated, 2022, Updated wellhead protection area delineation, vulnerability scoring, and threats assessment for the Town of Shelburne, Ontario. Prepared for: S. Burnett and Associates, June, 2022. 309 p.

Earthfx Incorporated, 2024. Proposed Strada Aggregates Shelburne Pit/Quarry Model Development and Calibration Report (Application Appendix D). October 2024, 148 p.

Gwyn, Q.H.J. 1972. Quaternary Geology of the Dundalk area Southern Ontario. Ontario Department of Mines and Northern Affairs. Preliminary Map P.727 Geological Series Scale 1:50,000

Natural Resource Solutions Inc. (NRSI), 2024. Strada Pit/Quarry Natural Environment Assessment, Prepared for Strada Aggregates Inc. Project No.2473A, 597 p.

9 Water Budget Details

The water budgets for the primary wetlands of interest (NAT-18 and NAT-19) are presented and discussed in detail in the main body of this report. This section includes water budget details for select additional wetlands.

9.1 *Baseline*

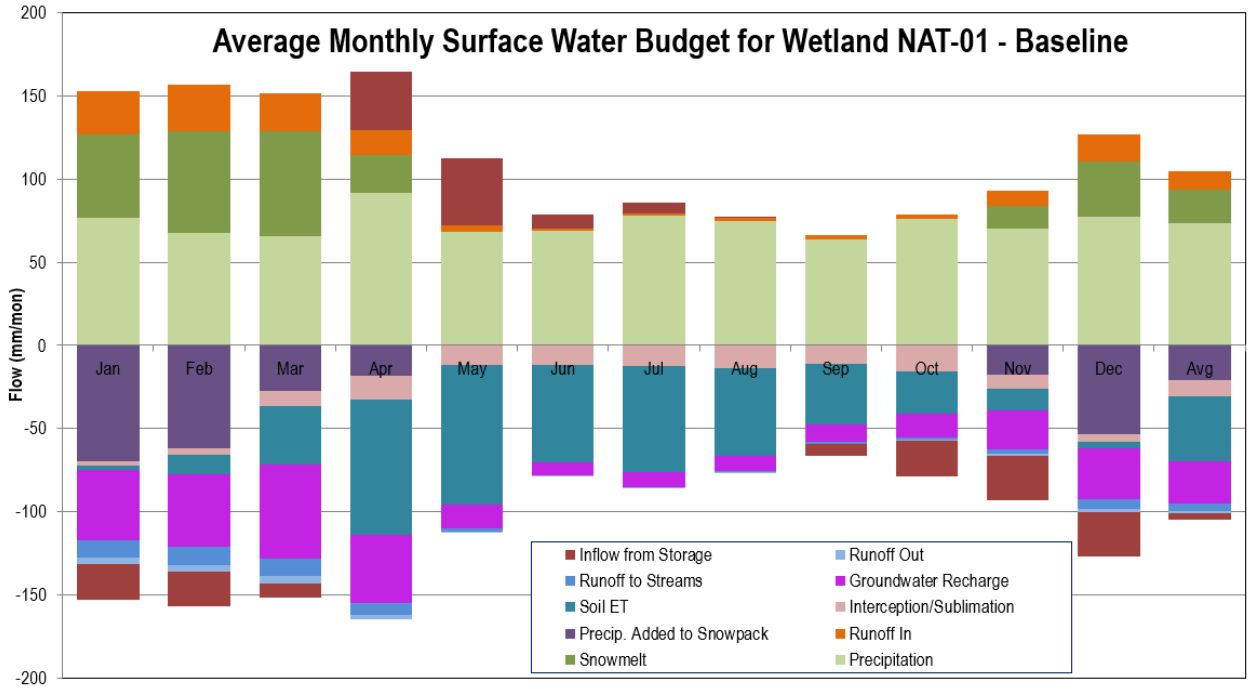


Table 1a – Monthly Surface Water Budget under Baseline Conditions (in mm/month) – Wetland NAT-01.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	76.56	67.29	65.88	91.50	67.99	69.09	78.19	74.90	63.93	76.07	70.01	77.42	73.24
Snowmelt	49.93	61.44	62.98	23.01	0.12	0.00	0.00	0.00	0.00	0.00	14.07	33.02	20.38
Runoff In	26.29	28.00	22.85	14.75	4.12	1.08	1.01	1.54	2.56	2.72	8.66	16.60	10.85
Precip. added to Snowpack	-69.52	-61.54	-27.31	-18.57	-0.12	0.00	0.00	0.00	0.00	0.00	-17.40	-53.05	-20.63
Interception/Sublimation	-2.57	-3.99	-9.15	-13.83	-11.52	-11.96	-12.60	-13.61	-11.32	-15.33	-8.92	-4.70	-9.96
Soil ET	-2.87	-11.98	-35.13	-81.73	-84.27	-58.61	-63.41	-52.74	-36.24	-25.66	-12.57	-3.79	-39.08
Groundwater Recharge	-42.09	-43.30	-56.31	-40.99	-14.14	-7.30	-9.11	-9.36	-10.14	-14.64	-23.68	-31.10	-25.18
Runoff to Streams	-10.66	-11.33	-10.76	-6.81	-1.52	-0.32	-0.36	-0.63	-1.26	-1.00	-2.73	-5.55	-4.41
Runoff Out	-3.79	-4.00	-4.24	-2.80	-0.74	-0.24	-0.28	-0.35	-0.51	-0.50	-1.28	-2.25	-1.75
Inflow from Storage	-21.27	-20.59	-8.80	35.47	40.09	8.26	6.56	0.26	-7.03	-21.65	-26.16	-26.61	-3.46

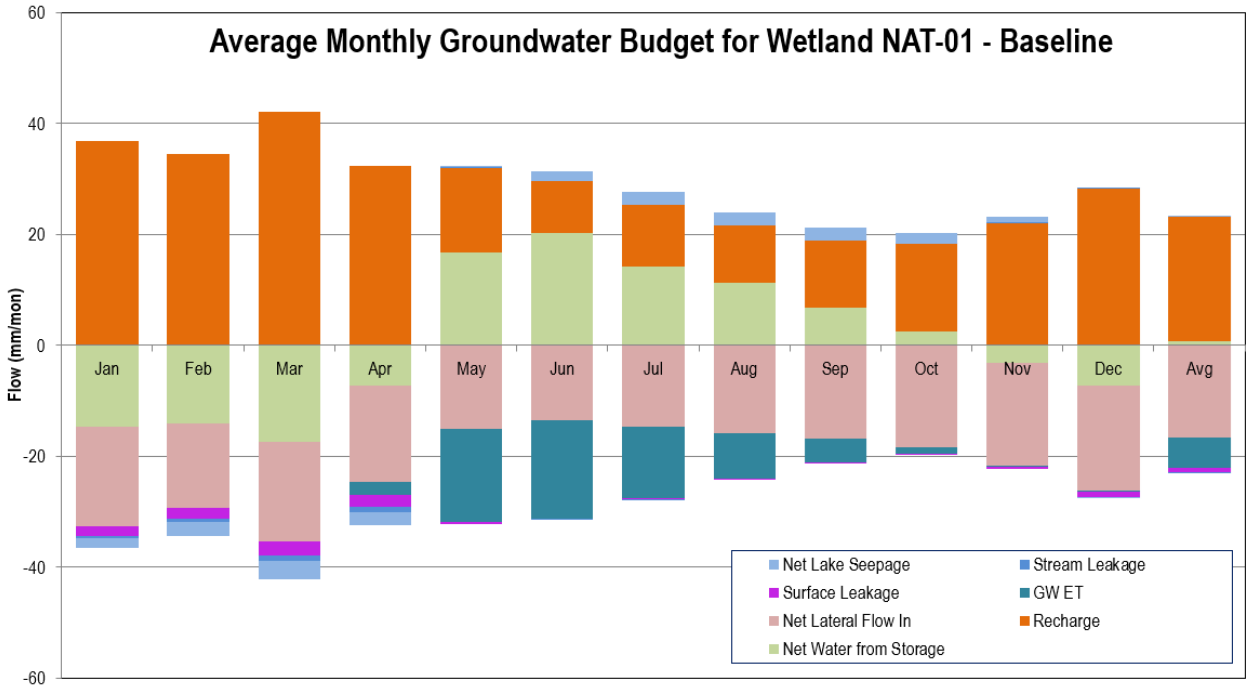


Table 1b – Monthly Groundwater Budget under Baseline Conditions (in mm/month) – Wetland NAT-01.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-14.61	-14.09	-17.32	-7.26	16.83	20.20	14.15	11.32	6.91	2.49	-3.11	-7.25	0.69
Recharge	36.88	34.58	42.21	32.38	15.16	9.40	11.28	10.27	11.91	15.75	22.04	28.25	22.51
Net Lateral Flow In	-18.02	-15.14	-18.03	-17.42	-15.08	-13.43	-14.63	-15.85	-16.71	-18.34	-18.56	-19.00	-16.68
GW ET	0.00	-0.01	-0.06	-2.36	-16.70	-17.71	-12.92	-8.08	-4.31	-1.20	-0.13	0.00	-5.29
Surface Leakage	-1.70	-2.01	-2.54	-2.14	-0.49	-0.18	-0.18	-0.18	-0.18	-0.21	-0.45	-1.05	-0.94
Stream Leakage	-0.31	-0.62	-0.95	-0.83	0.11	-0.04	-0.03	0.02	0.19	0.09	0.22	0.06	-0.17
Net Lake Seepage	-1.75	-2.55	-3.28	-2.44	0.14	1.74	2.32	2.47	2.18	1.92	0.96	-0.15	0.13

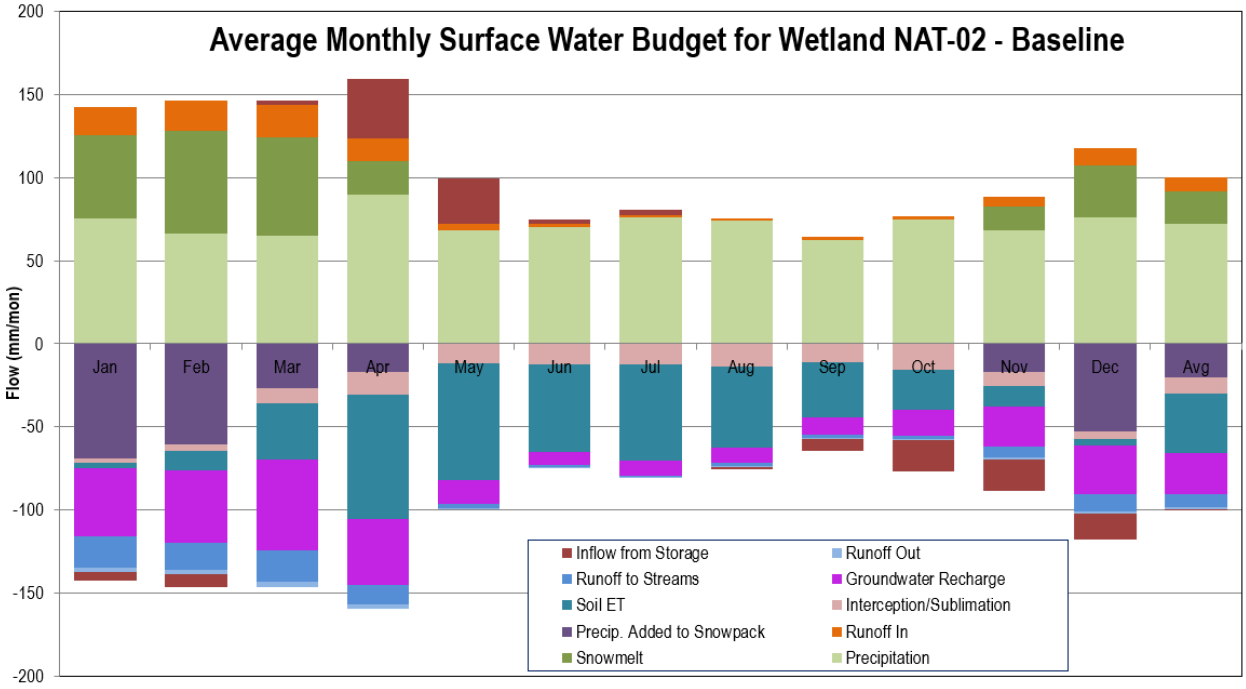


Table 2a – Monthly Surface Water Budget under Baseline Conditions (in mm/month) – Wetland NAT-02.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	75.14	66.03	64.85	90.01	68.18	70.44	76.23	73.87	62.18	74.47	68.21	75.79	72.12
Snowmelt	50.18	61.72	59.06	19.79	0.00	0.00	0.00	0.00	0.00	0.00	14.59	31.73	19.76
Runoff In	17.29	18.73	19.92	13.57	4.19	1.56	1.07	1.42	2.00	1.99	5.82	9.92	8.12
Precip. added to Snowpack	-69.20	-60.51	-26.68	-16.70	0.00	0.00	0.00	0.00	0.00	-0.01	-16.78	-52.65	-20.21
Interception/Sublimation	-2.20	-3.59	-9.01	-13.99	-11.65	-12.16	-12.47	-13.41	-11.13	-15.48	-8.86	-4.40	-9.86
Soil ET	-3.19	-12.28	-34.22	-74.73	-70.59	-53.16	-57.77	-48.81	-33.35	-24.30	-12.05	-4.00	-35.70
Groundwater Recharge	-41.48	-43.37	-54.61	-39.67	-13.74	-7.59	-8.95	-9.66	-10.20	-15.22	-23.88	-29.57	-24.83
Runoff to Streams	-18.47	-16.33	-18.70	-11.76	-2.86	-0.98	-0.90	-1.45	-2.19	-2.23	-6.74	-10.13	-7.73
Runoff Out	-2.63	-2.77	-3.22	-2.33	-0.89	-0.57	-0.56	-0.60	-0.60	-0.64	-1.13	-1.66	-1.47
Inflow from Storage	-5.43	-7.61	2.61	35.81	27.37	2.46	3.35	-1.36	-6.71	-18.59	-19.18	-15.02	-0.19

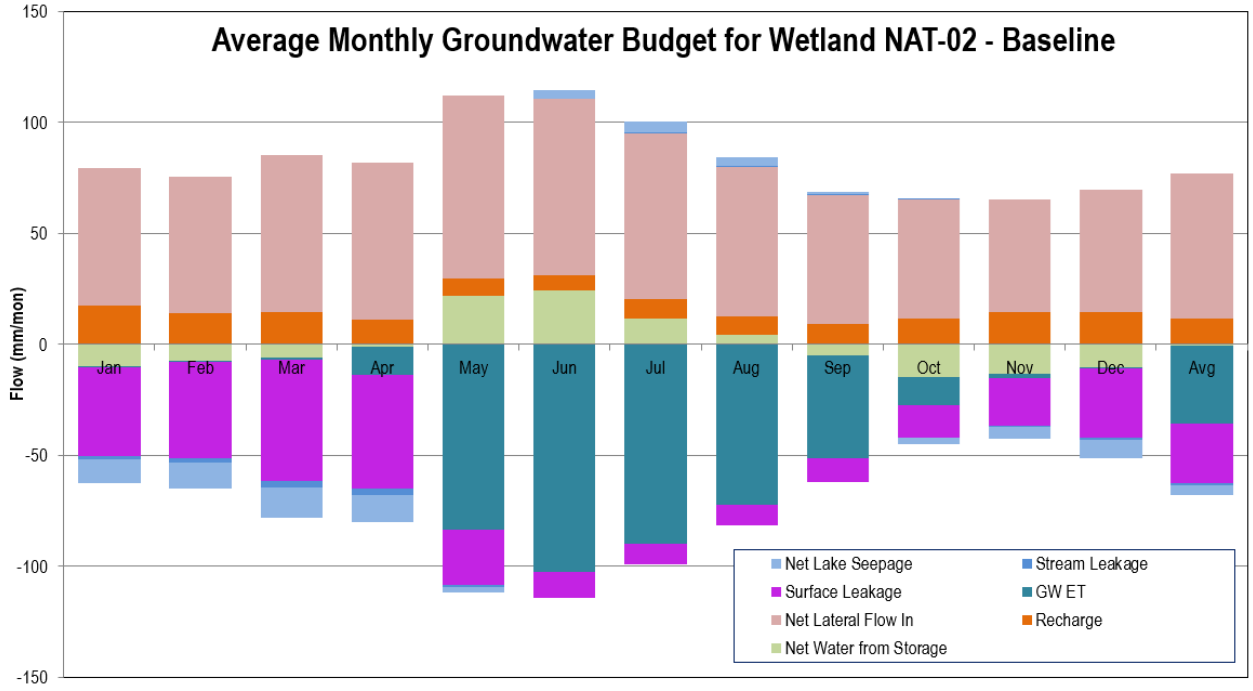


Table 2b – Monthly Groundwater Budget under Baseline Conditions (in mm/month) – Wetland NAT-02.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-9.94	-7.45	-5.76	-0.97	22.02	24.22	11.82	4.27	-4.93	-14.54	-13.42	-10.44	-0.43
Recharge	17.31	13.90	14.75	11.42	7.94	7.05	8.74	8.18	9.25	11.89	14.65	14.66	11.64
Net Lateral Flow In	61.94	61.56	70.32	70.55	82.10	79.35	74.62	67.43	58.08	53.49	50.83	55.13	65.45
GW ET	-0.18	-0.19	-1.09	-12.64	-83.59	-102.41	-89.66	-72.30	-46.49	-12.91	-1.96	-0.20	-35.30
Surface Leakage	-40.03	-43.57	-54.40	-51.36	-24.72	-11.83	-9.52	-9.27	-10.41	-14.75	-21.41	-31.53	-26.90
Stream Leakage	-1.63	-2.17	-2.93	-2.84	-0.72	0.29	0.37	0.57	0.33	0.17	-0.20	-0.90	-0.80
Net Lake Seepage	-10.85	-11.61	-13.68	-12.18	-2.67	3.67	4.66	3.82	1.18	-2.58	-5.55	-8.23	-4.50

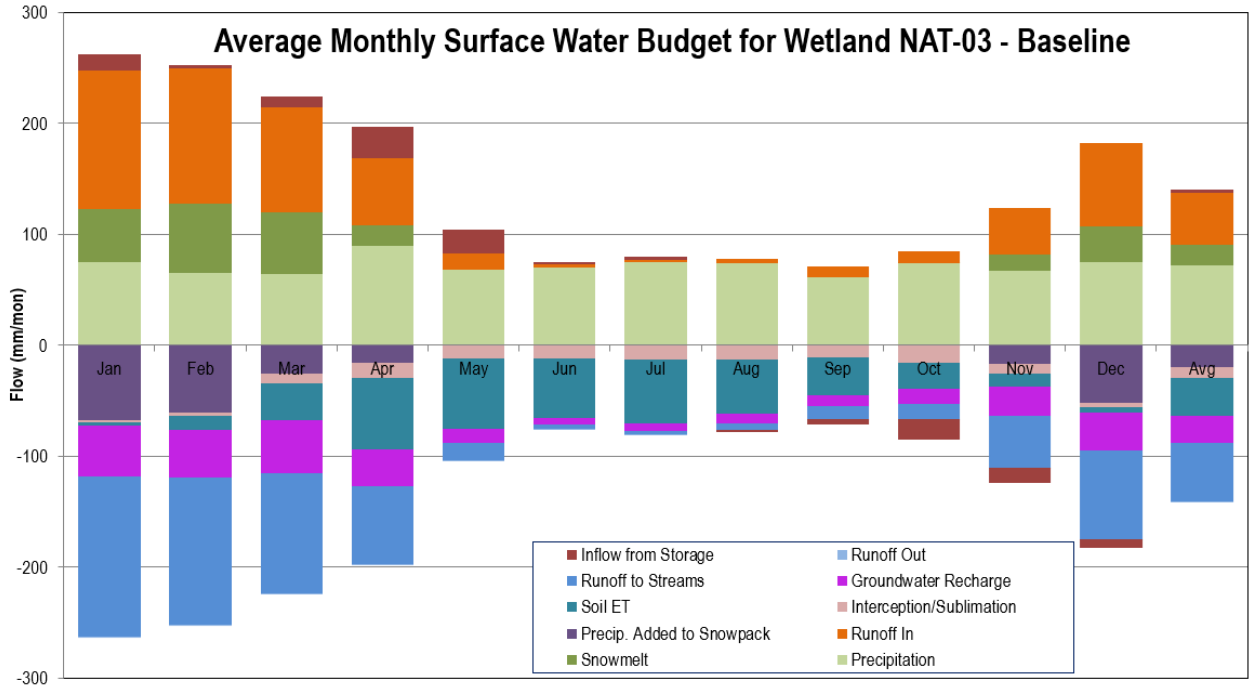


Table 3a – Monthly Surface Water Budget under Baseline Conditions (in mm/month) – Wetland NAT-03.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	74.66	65.43	64.44	89.68	68.61	70.57	75.15	73.73	61.69	73.90	67.57	75.24	71.72
Snowmelt	47.92	62.01	55.70	18.16	0.00	0.00	0.00	0.00	0.00	0.01	14.51	31.61	19.16
Runoff In	125.38	121.86	94.07	60.85	14.50	2.97	2.12	4.34	9.88	11.24	41.66	75.55	47.04
Precip. added to Snowpack	-67.02	-60.47	-25.60	-16.06	0.00	0.00	0.00	0.00	0.00	-0.01	-16.57	-51.78	-19.79
Interception/Sublimation	-1.91	-3.12	-8.58	-13.71	-11.49	-11.92	-12.28	-13.17	-10.93	-15.37	-8.74	-4.19	-9.62
Soil ET	-3.48	-12.63	-32.71	-63.57	-63.97	-53.11	-57.76	-48.79	-34.07	-23.56	-11.99	-4.18	-34.15
Groundwater Recharge	-45.31	-42.82	-48.71	-33.31	-11.91	-6.44	-7.37	-8.41	-9.40	-14.15	-26.21	-34.65	-24.06
Runoff to Streams	-144.59	-132.92	-107.86	-70.01	-16.47	-3.51	-2.90	-5.85	-12.10	-13.49	-46.88	-79.94	-53.04
Runoff Out	-0.43	-0.40	-0.51	-0.35	-0.09	-0.03	-0.03	-0.04	-0.06	-0.06	-0.20	-0.33	-0.21
Inflow from Storage	14.78	3.05	9.76	28.32	20.82	1.47	3.06	-1.80	-5.00	-18.51	-13.15	-7.33	2.96

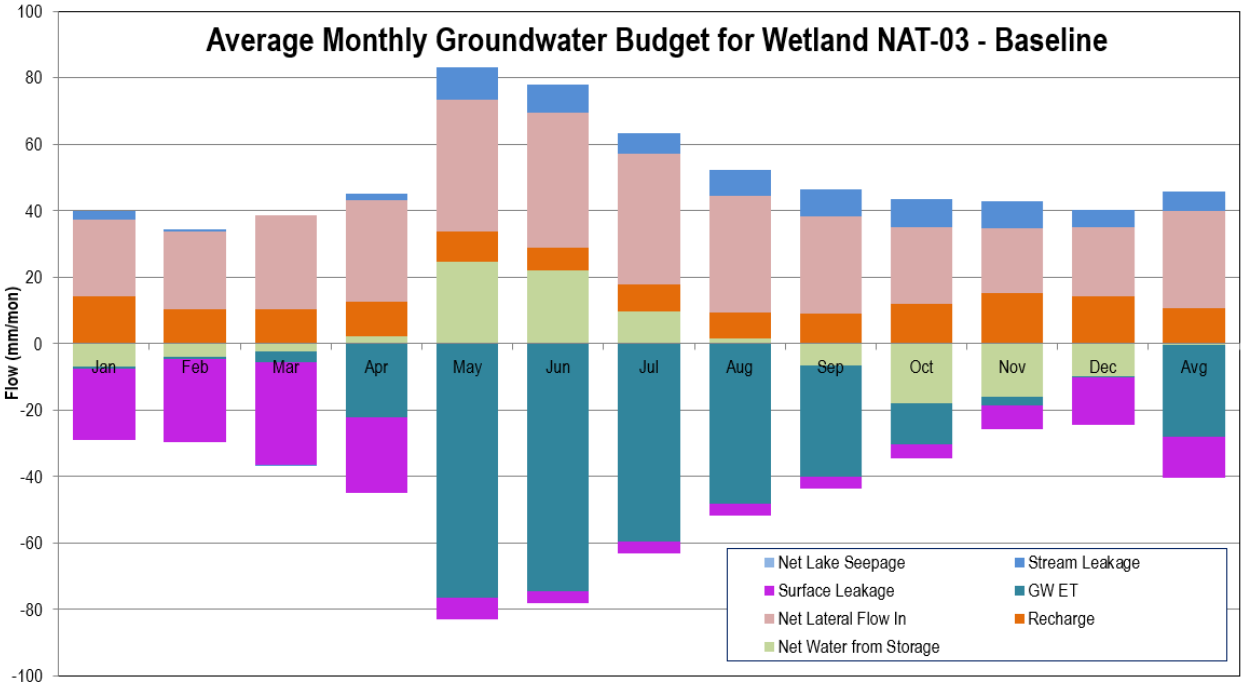


Table 3b – Monthly Groundwater Budget under Baseline Conditions (in mm/month) – Wetland NAT-03.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-6.93	-3.91	-2.29	2.16	24.69	22.00	9.84	1.46	-6.37	-17.86	-15.85	-9.61	-0.22
Recharge	14.13	10.34	10.35	10.40	9.24	6.95	7.92	7.92	8.97	11.87	15.31	14.42	10.65
Net Lateral Flow In	23.16	23.30	28.38	30.62	39.66	40.53	39.33	35.27	29.45	23.32	19.41	20.57	29.42
GW ET	-0.53	-0.63	-3.21	-22.21	-76.39	-74.31	-59.62	-48.27	-33.69	-12.26	-2.58	-0.58	-27.86
Surface Leakage	-21.43	-25.15	-31.00	-22.67	-6.69	-3.64	-3.48	-3.49	-3.65	-4.44	-7.35	-14.07	-12.26
Stream Leakage	2.77	0.80	-0.06	2.05	9.67	8.62	6.18	7.56	8.18	8.30	8.31	5.29	5.64
Net Lake Seepage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

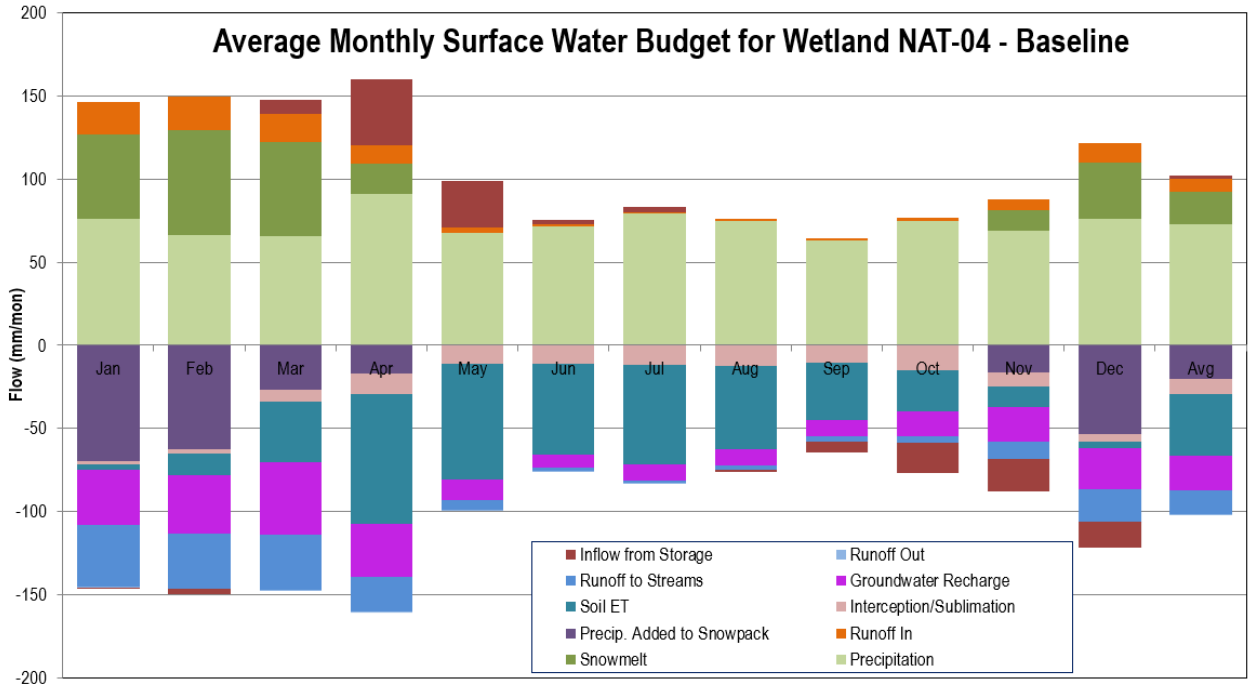


Table 4a – Monthly Surface Water Budget under Baseline Conditions (in mm/month) – Wetland NAT-04.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	75.88	66.60	65.32	90.72	67.38	71.74	79.00	74.79	62.71	74.78	68.62	76.26	72.82
Snowmelt	50.92	62.52	57.11	18.58	0.09	0.00	0.00	0.00	0.00	0.00	12.94	33.46	19.64
Runoff In	19.24	20.27	16.37	10.92	3.28	1.09	0.92	1.20	1.80	1.96	6.01	11.98	7.92
Precip. added to Snowpack	-69.72	-62.18	-26.40	-16.74	-0.09	0.00	0.00	0.00	0.00	-0.01	-16.18	-53.68	-20.42
Interception/Sublimation	-1.74	-2.57	-7.74	-12.78	-10.83	-11.18	-11.71	-12.55	-10.58	-14.68	-8.47	-3.91	-9.06
Soil ET	-3.65	-13.31	-35.97	-78.03	-69.64	-54.29	-59.81	-50.17	-34.07	-25.15	-12.54	-4.52	-36.76
Groundwater Recharge	-33.04	-35.14	-43.56	-31.54	-12.29	-7.86	-9.60	-9.73	-9.94	-14.97	-20.57	-24.46	-21.06
Runoff to Streams	-37.19	-33.05	-33.58	-20.87	-5.82	-1.93	-1.68	-2.28	-3.53	-3.79	-10.47	-19.14	-14.45
Runoff Out	-0.20	-0.22	-0.19	-0.18	-0.12	-0.12	-0.13	-0.12	-0.10	-0.11	-0.12	-0.14	-0.15
Inflow from Storage	-0.50	-2.91	8.66	39.92	28.04	2.55	3.02	-1.13	-6.30	-18.04	-19.21	-15.84	1.52

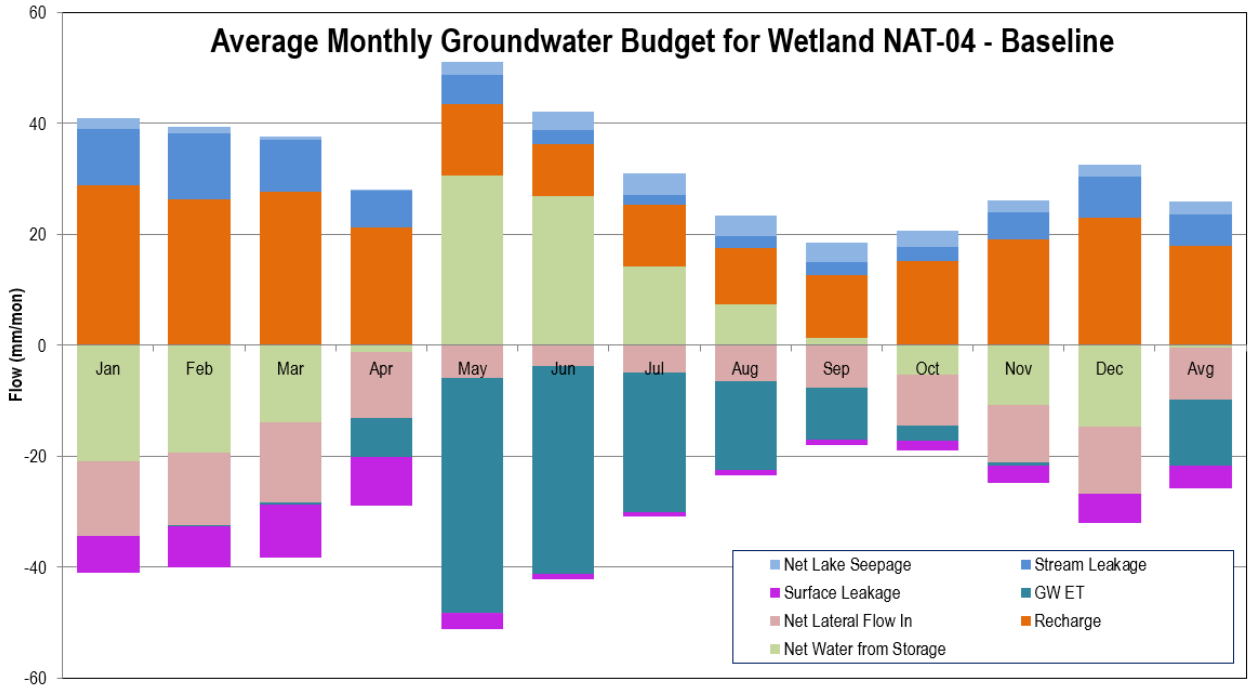


Table 4b – Monthly Groundwater Budget under Baseline Conditions (in mm/month) – Wetland NAT-04.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-20.89	-19.28	-13.94	-1.16	30.67	26.91	14.25	7.49	1.40	-5.25	-10.76	-14.69	-0.44
Recharge	28.92	26.23	27.77	21.26	12.78	9.41	11.01	10.02	11.30	15.28	19.19	22.92	18.01
Net Lateral Flow In	-13.36	-13.21	-14.41	-11.99	-5.80	-3.73	-4.94	-6.42	-7.58	-9.21	-10.37	-12.03	-9.42
GW ET	-0.06	-0.06	-0.38	-6.93	-42.47	-37.41	-25.10	-16.07	-9.43	-2.76	-0.47	-0.06	-11.77
Surface Leakage	-6.74	-7.45	-9.58	-8.77	-2.76	-1.02	-0.87	-0.88	-0.97	-1.71	-3.24	-5.16	-4.10
Stream Leakage	10.18	11.94	9.35	6.55	5.37	2.41	1.83	2.15	2.35	2.37	4.71	7.51	5.56
Net Lake Seepage	1.77	1.17	0.60	0.31	2.20	3.43	3.88	3.82	3.39	2.92	2.27	2.09	2.32

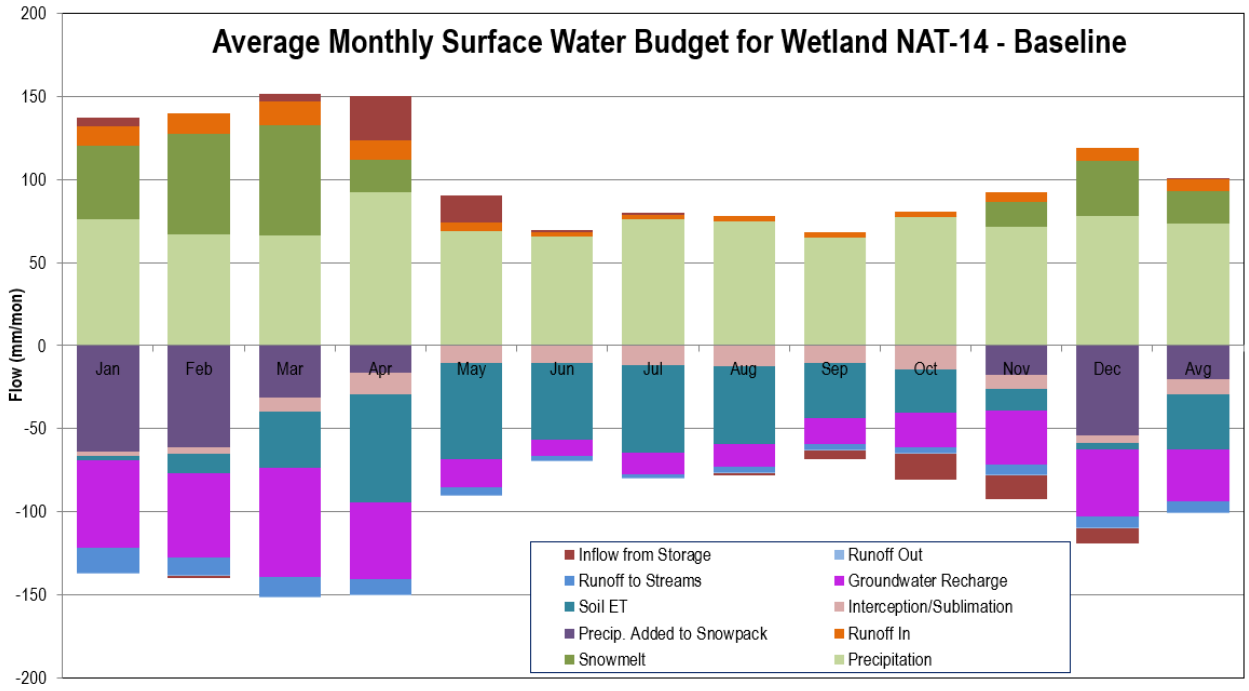


Table 5a – Monthly Surface Water Budget under Baseline Conditions (in mm/month) – Wetland NAT-14.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	75.92	66.77	66.36	92.13	69.05	65.58	75.80	75.01	65.16	77.60	71.24	77.90	73.21
Snowmelt	44.56	60.89	66.27	19.98	0.00	0.00	0.00	0.00	0.00	0.00	15.40	33.30	20.03
Runoff In	11.36	12.19	14.08	11.66	5.01	2.67	2.61	3.07	3.03	3.16	5.45	7.62	6.83
Precip. added to Snowpack	-63.63	-61.10	-31.19	-16.56	0.00	0.00	0.00	0.00	0.00	0.00	-17.58	-53.69	-20.31
Interception/Sublimation	-2.67	-3.86	-8.35	-12.62	-10.25	-10.46	-11.60	-12.50	-10.23	-14.30	-8.67	-4.65	-9.18
Soil ET	-2.82	-12.13	-34.26	-65.14	-57.89	-46.15	-53.07	-46.52	-33.52	-25.96	-12.57	-3.84	-32.82
Groundwater Recharge	-52.81	-50.15	-65.10	-46.35	-17.38	-9.91	-12.46	-14.10	-15.64	-20.75	-33.00	-40.49	-31.51
Runoff to Streams	-14.37	-10.68	-11.83	-8.89	-3.97	-2.27	-2.50	-3.17	-3.23	-3.30	-5.58	-6.87	-6.39
Runoff Out	-0.90	-0.95	-0.90	-0.84	-0.57	-0.49	-0.56	-0.56	-0.50	-0.56	-0.66	-0.71	-0.68
Inflow from Storage	5.35	-0.98	4.90	26.64	15.99	1.01	1.78	-1.23	-5.07	-15.90	-14.02	-8.57	0.83

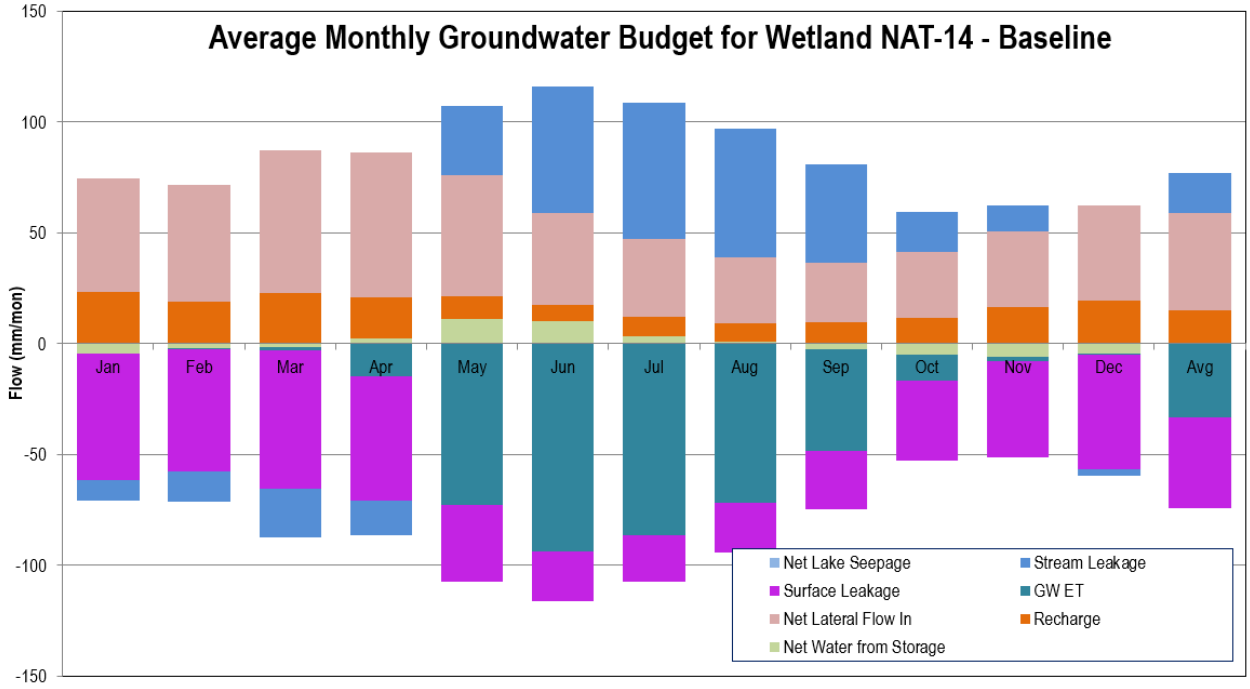


Table 5b – Monthly Groundwater Budget under Baseline Conditions (in mm/month) – Wetland NAT-14.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-4.26	-2.01	-1.41	2.18	11.29	10.17	3.25	0.76	-2.47	-4.96	-6.00	-4.65	0.16
Recharge	23.24	18.98	23.07	18.61	10.12	7.17	9.15	8.66	9.68	11.83	16.42	19.33	14.69
Net Lateral Flow In	51.17	52.78	63.98	65.35	54.81	41.69	34.89	29.46	26.86	29.37	34.37	42.92	43.97
GW ET	-0.24	-0.27	-1.41	-14.76	-72.83	-93.81	-86.31	-71.93	-45.68	-11.69	-1.73	-0.26	-33.41
Surface Leakage	-57.02	-55.26	-62.34	-56.21	-34.57	-22.20	-21.22	-22.18	-26.27	-36.12	-43.32	-51.67	-40.70
Stream Leakage	-9.16	-13.88	-22.12	-15.26	31.05	56.96	61.41	58.34	44.29	18.35	11.64	-3.08	18.21
Net Lake Seepage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

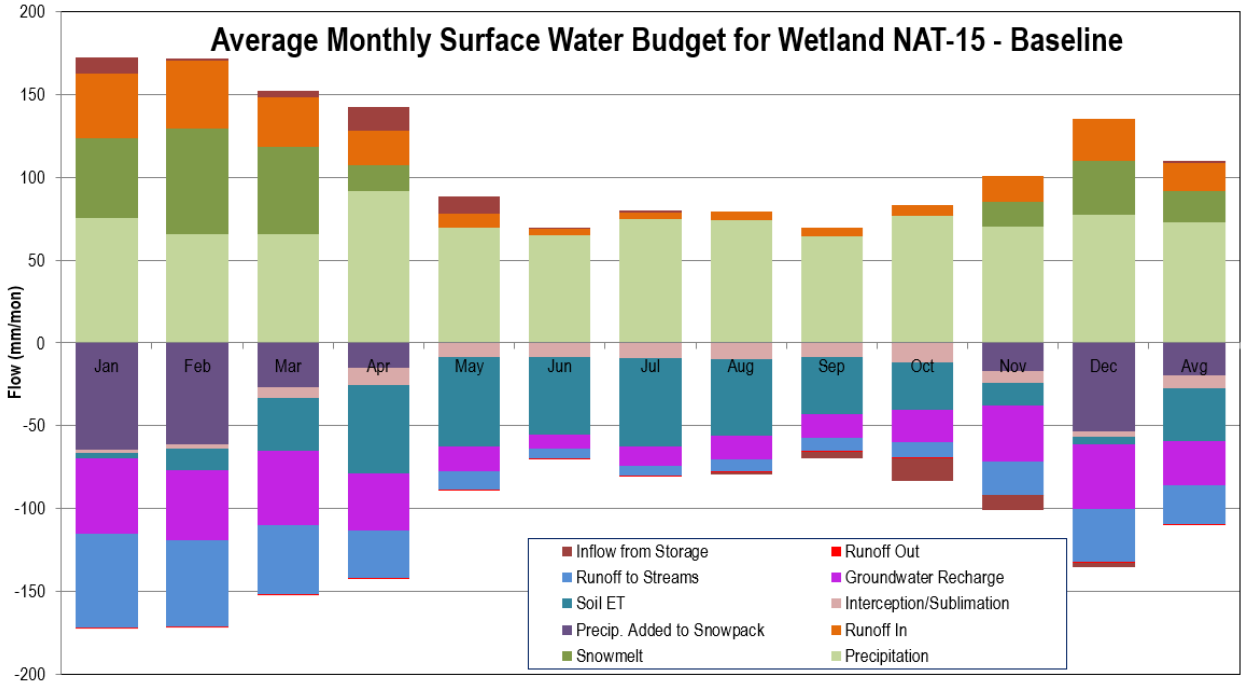


Table 6a – Monthly Surface Water Budget under Baseline Conditions (in mm/month) – Wetland NAT-15.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	75.13	65.93	65.60	91.46	69.58	65.04	74.79	74.34	64.15	76.79	70.33	77.17	72.53
Snowmelt	48.42	63.72	53.00	15.82	0.00	0.00	0.00	0.00	0.00	0.00	15.09	32.70	19.06
Runoff In	38.72	40.71	29.93	21.03	8.28	3.91	3.96	4.85	5.20	6.64	15.28	25.49	17.00
Precip. added to Snowpack	-64.53	-61.19	-26.60	-14.87	0.00	0.00	0.00	0.00	0.00	0.00	-16.90	-53.14	-19.77
Interception/Sublimation	-1.81	-2.42	-6.35	-10.23	-8.45	-8.56	-9.39	-10.10	-8.29	-11.96	-7.18	-3.63	-7.36
Soil ET	-3.52	-12.99	-32.07	-53.76	-53.70	-46.48	-52.94	-46.17	-34.65	-28.19	-13.96	-4.72	-31.93
Groundwater Recharge	-45.39	-42.54	-45.21	-34.59	-15.12	-8.96	-11.63	-14.10	-14.43	-19.50	-33.24	-38.62	-26.94
Runoff to Streams	-56.15	-51.62	-41.08	-28.37	-11.05	-5.59	-6.06	-7.32	-7.89	-9.47	-20.14	-31.75	-23.04
Runoff Out	-1.02	-1.03	-0.99	-0.69	-0.32	-0.15	-0.15	-0.21	-0.22	-0.22	-0.53	-0.80	-0.53
Inflow from Storage	10.14	1.43	3.77	14.19	10.77	0.80	1.43	-1.29	-3.88	-14.09	-8.74	-2.70	0.98

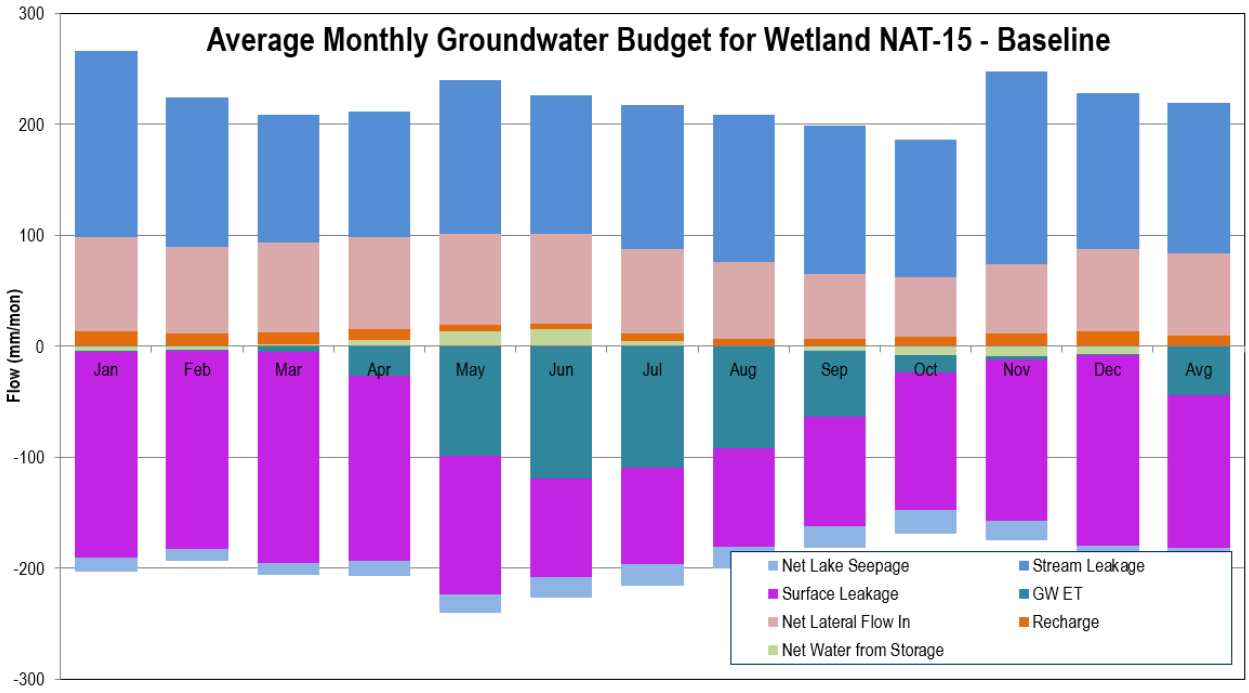


Table 6b – Monthly Groundwater Budget under Baseline Conditions (in mm/month) – Wetland NAT-15.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-4.20	-2.78	2.17	5.40	13.28	15.35	5.01	0.86	-4.30	-7.57	-9.02	-7.15	0.59
Recharge	13.93	11.57	10.68	10.62	6.41	4.98	6.76	6.20	6.95	8.47	11.92	13.41	9.32
Net Lateral Flow In	84.27	78.16	80.75	82.45	82.10	80.66	75.75	69.12	58.30	53.86	61.81	74.58	73.48
GW ET	-0.78	-1.09	-4.82	-26.02	-98.58	-118.7	-109.5	-91.99	-58.84	-15.58	-2.61	-0.82	-44.11
Surface Leakage	-185.4	-179.0	-190.2	-167.7	-124.4	-89.49	-86.93	-88.82	-99.24	-124.1	-145.0	-171.6	-137.7
Stream Leakage	168.4	134.6	115.2	112.7	137.7	125.6	129.9	132.7	133.5	124.0	174.3	140.5	135.7
Net Lake Seepage	-12.68	-10.47	-11.19	-13.07	-17.12	-18.36	-19.51	-19.17	-19.00	-21.45	-17.65	-14.85	-16.21

9.2 *Phase 1*

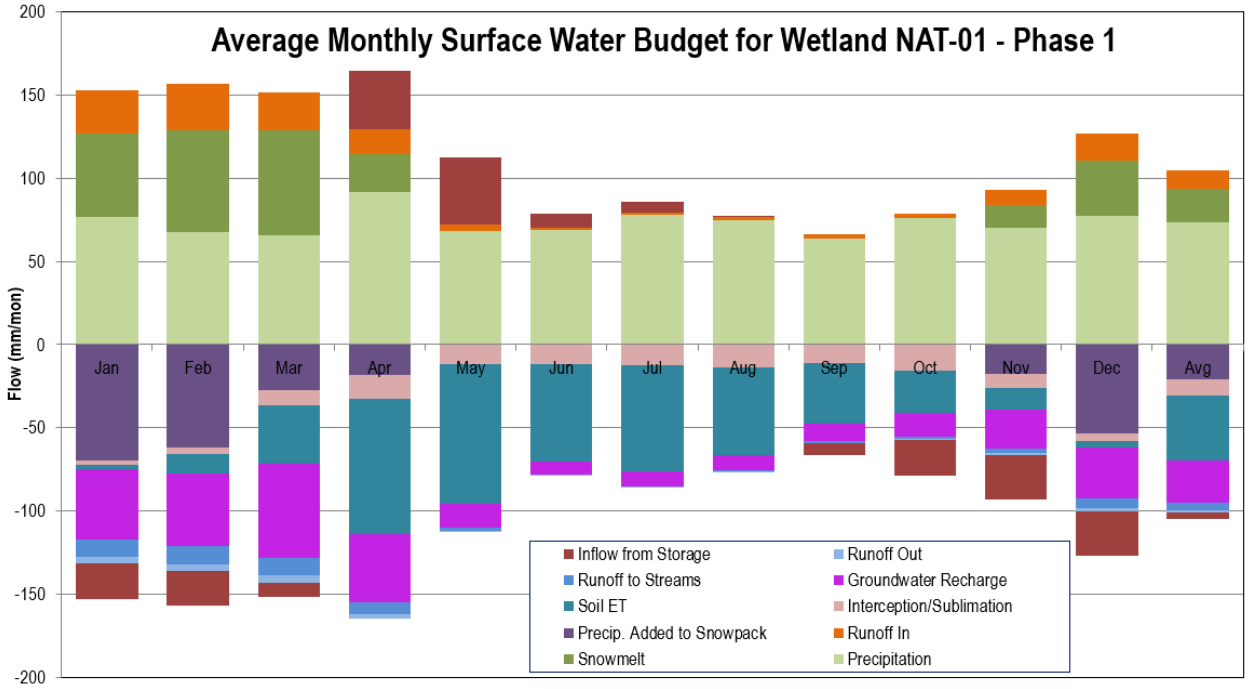


Table 7a – Monthly Surface Water Budget under Phase 1 Conditions (in mm/month) – Wetland NAT-01.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	76.56	67.29	65.88	91.50	67.99	69.09	78.19	74.90	63.93	76.07	70.01	77.42	73.24
Snowmelt	49.93	61.44	62.98	23.01	0.12	0.00	0.00	0.00	0.00	0.00	14.07	33.02	20.38
Runoff In	26.29	28.00	22.85	14.75	4.12	1.08	1.01	1.54	2.56	2.72	8.66	16.60	10.85
Precip. added to Snowpack	-69.52	-61.54	-27.31	-18.57	-0.12	0.00	0.00	0.00	0.00	0.00	-17.40	-53.05	-20.63
Interception/Sublimation	-2.57	-3.99	-9.15	-13.83	-11.52	-11.96	-12.60	-13.61	-11.32	-15.33	-8.92	-4.70	-9.96
Soil ET	-2.87	-11.98	-35.13	-81.73	-84.27	-58.61	-63.41	-52.74	-36.24	-25.66	-12.57	-3.79	-39.08
Groundwater Recharge	-42.09	-43.30	-56.31	-40.99	-14.14	-7.30	-9.11	-9.36	-10.14	-14.64	-23.68	-31.10	-25.18
Runoff to Streams	-10.66	-11.33	-10.76	-6.81	-1.52	-0.32	-0.36	-0.63	-1.26	-1.00	-2.73	-5.55	-4.41
Runoff Out	-3.79	-4.00	-4.24	-2.80	-0.74	-0.24	-0.28	-0.35	-0.51	-0.50	-1.28	-2.25	-1.75
Inflow from Storage	-21.27	-20.59	-8.80	35.47	40.09	8.26	6.56	0.26	-7.03	-21.65	-26.16	-26.61	-3.46

Table 7b – Difference in Monthly Surface Water Budget (Baseline - Phase 1) in mm/month – Wetland NAT-01.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precip. added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater Recharge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff to Streams	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

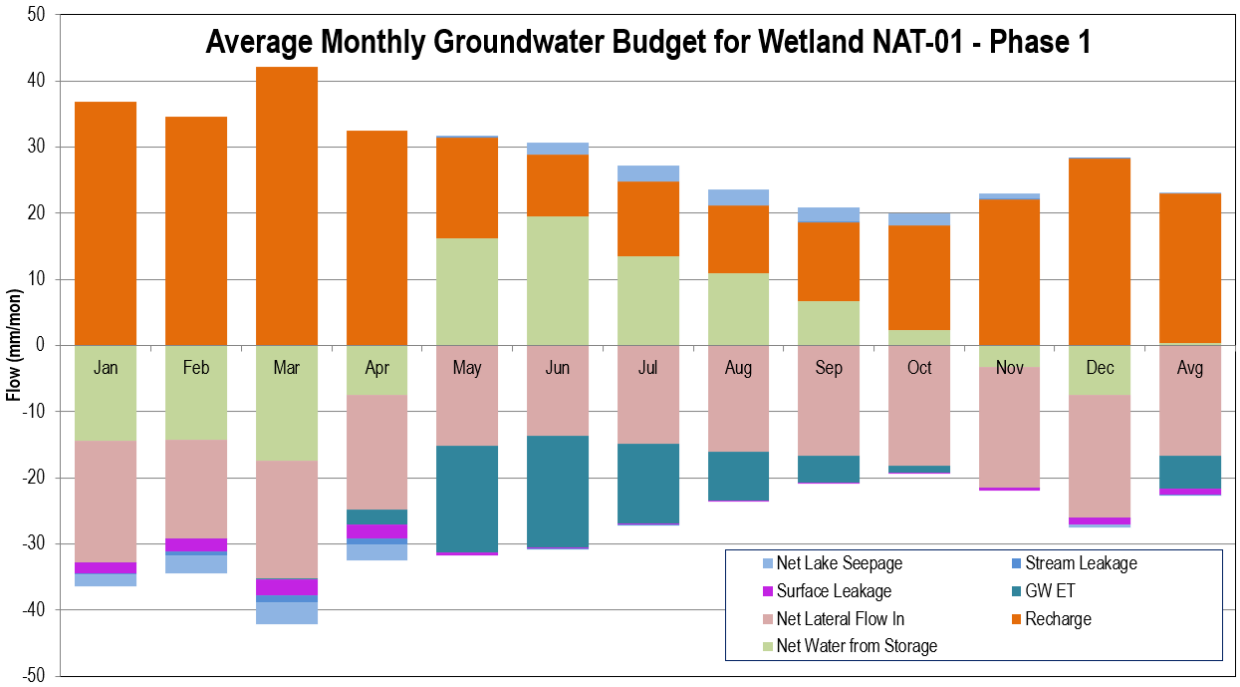


Table 7c – Monthly Groundwater Budget under Phase 1 Conditions (in mm/month) – Wetland NAT-01.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-14.39	-14.28	-17.49	-7.48	16.22	19.51	13.57	10.92	6.69	2.40	-3.25	-7.49	0.41
Recharge	36.93	34.55	42.22	32.53	15.22	9.41	11.28	10.26	11.90	15.75	22.04	28.30	22.53
Net Lateral Flow In	-18.44	-14.84	-17.75	-17.30	-15.14	-13.65	-14.88	-15.99	-16.64	-18.18	-18.18	-18.52	-16.63
GW ET	0.00	-0.01	-0.06	-2.29	-16.09	-16.81	-12.04	-7.44	-4.03	-1.03	-0.11	0.00	-4.99
Surface Leakage	-1.59	-2.02	-2.54	-2.13	-0.48	-0.19	-0.19	-0.19	-0.19	-0.22	-0.47	-1.06	-0.94
Stream Leakage	-0.24	-0.60	-0.96	-0.84	0.11	-0.04	-0.04	0.01	0.18	0.08	0.20	0.03	-0.18
Net Lake Seepage	-1.74	-2.68	-3.36	-2.48	0.16	1.76	2.29	2.39	2.08	1.70	0.72	-0.40	0.04

Table 7d – Difference in Monthly Groundwater Budget (Baseline - Phase 1) in mm/month – Wetland NAT-01.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	-0.27	0.10	0.05	0.00	-0.05	0.01	0.10	0.14	0.18	0.25	0.28	0.30
Recharge	-0.02	0.05	0.04	-0.04	-0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.00
Net Lateral Flow In	0.38	-0.33	-0.28	-0.11	-0.07	-0.02	-0.04	-0.13	-0.27	-0.43	-0.56	-0.60
GW ET	0.00	0.00	0.00	0.02	0.16	0.08	-0.03	-0.05	-0.01	-0.02	0.00	0.00
Surface Leakage	-0.03	0.04	0.06	0.05	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.04
Stream Leakage	-0.02	0.05	0.04	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.06
Net Lake Seepage	-0.03	0.11	0.05	0.00	-0.08	-0.09	-0.04	0.02	0.07	0.14	0.18	0.20

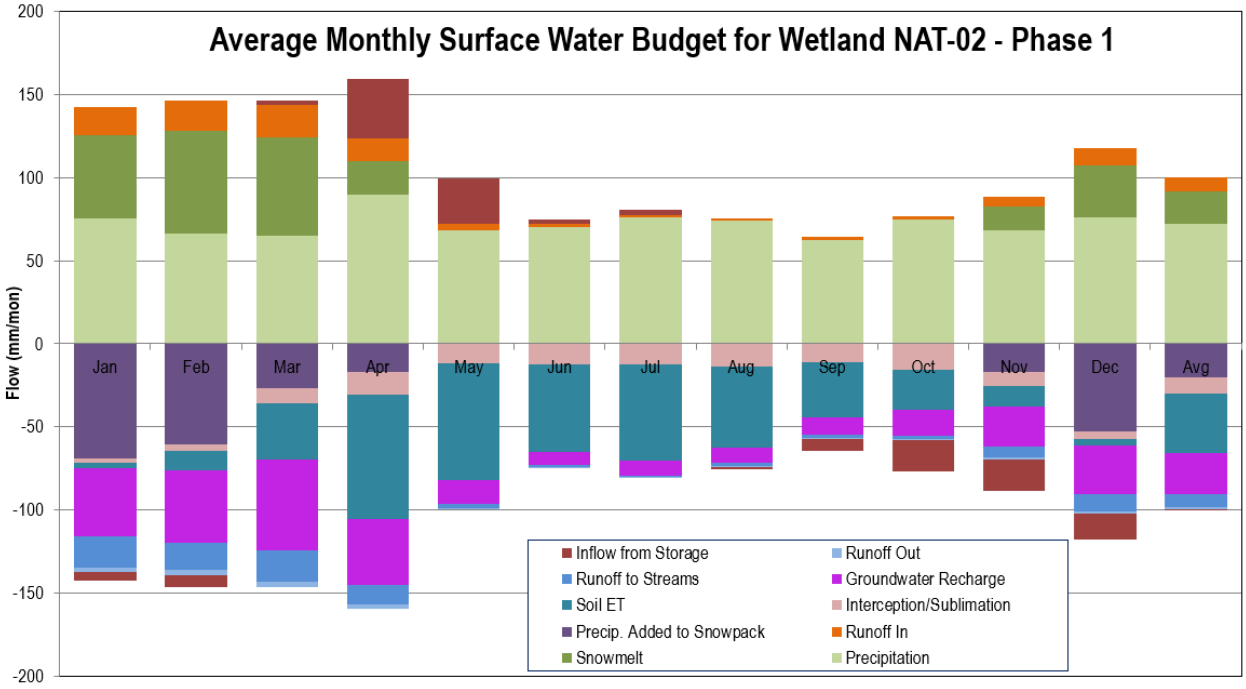


Table 8a – Monthly Surface Water Budget under Phase 1 Conditions (in mm/month) – Wetland NAT-02.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	75.14	66.03	64.85	90.01	68.18	70.44	76.23	73.87	62.18	74.47	68.21	75.79	72.12
Snowmelt	50.18	61.72	59.06	19.79	0.00	0.00	0.00	0.00	0.00	0.00	14.59	31.73	19.76
Runoff In	17.31	18.75	19.93	13.58	4.19	1.56	1.08	1.43	2.01	2.00	5.83	9.93	8.13
Precip. added to Snowpack	-69.20	-60.51	-26.68	-16.70	0.00	0.00	0.00	0.00	0.00	-0.01	-16.78	-52.65	-20.21
Interception/Sublimation	-2.20	-3.59	-9.01	-13.99	-11.65	-12.16	-12.47	-13.41	-11.13	-15.48	-8.86	-4.40	-9.86
Soil ET	-3.19	-12.28	-34.22	-74.73	-70.59	-53.16	-57.78	-48.81	-33.35	-24.30	-12.05	-4.00	-35.70
Groundwater Recharge	-41.51	-43.39	-54.62	-39.69	-13.74	-7.59	-8.95	-9.66	-10.20	-15.23	-23.89	-29.58	-24.84
Runoff to Streams	-18.48	-16.34	-18.70	-11.76	-2.86	-0.98	-0.90	-1.45	-2.19	-2.23	-6.74	-10.14	-7.73
Runoff Out	-2.63	-2.77	-3.22	-2.33	-0.89	-0.57	-0.56	-0.60	-0.60	-0.64	-1.13	-1.66	-1.47
Inflow from Storage	-5.42	-7.61	2.61	35.81	27.37	2.46	3.35	-1.36	-6.71	-18.59	-19.18	-15.03	-0.19

Table 8b – Difference in Monthly Surface Water Budget (Baseline - Phase 1) in mm/month – Wetland NAT-02.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	-0.02	-0.02	-0.01	-0.01	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.01	-0.02
Precip. added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater Recharge	0.03	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03
Runoff to Streams	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Runoff Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

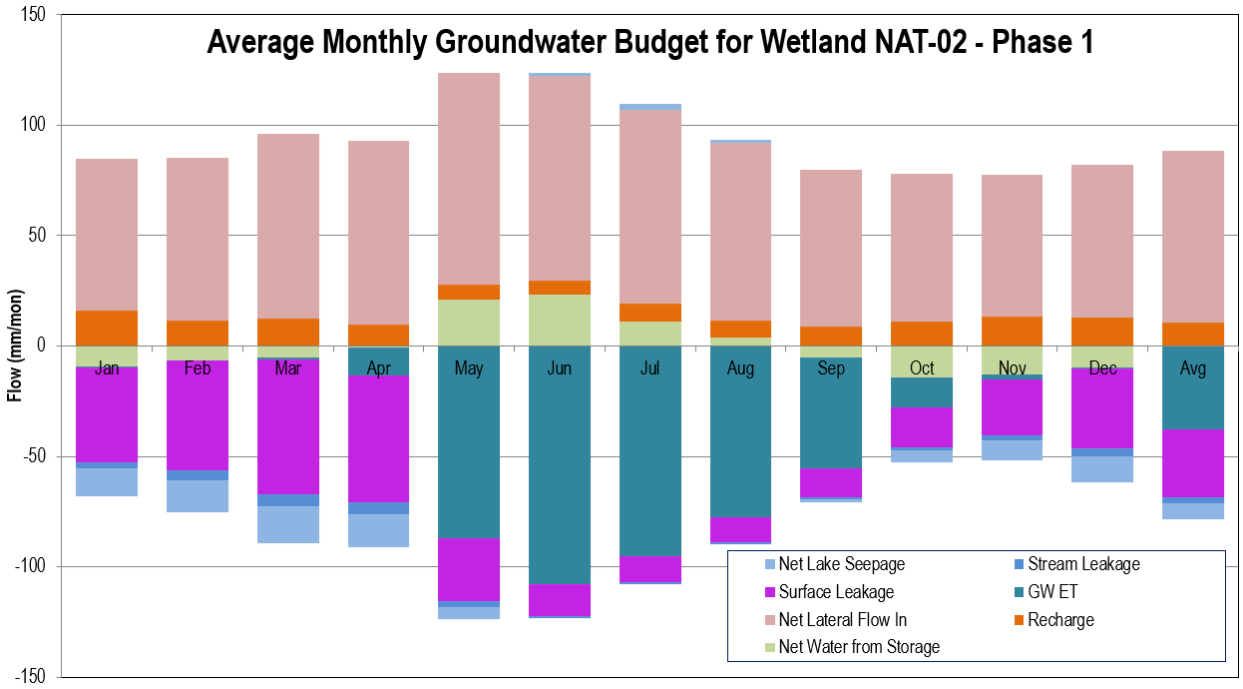


Table 8c – Monthly Groundwater Budget under Phase 1 Conditions (in mm/month) – Wetland NAT-02.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-9.39	-6.58	-5.03	-0.66	20.92	23.32	11.11	3.75	-5.38	-14.37	-13.04	-9.82	-0.43
Recharge	15.89	11.72	12.33	9.52	7.06	6.53	8.20	7.66	8.62	11.03	13.39	12.97	10.41
Net Lateral Flow In	68.81	73.59	83.64	83.47	95.96	92.45	87.64	80.52	71.07	66.99	63.97	69.09	78.10
GW ET	-0.18	-0.20	-1.11	-12.91	-86.96	-108.06	-95.41	-77.50	-50.00	-13.67	-2.06	-0.20	-37.35
Surface Leakage	-43.06	-49.42	-60.95	-57.29	-28.72	-14.32	-11.80	-11.51	-13.03	-17.72	-25.36	-36.44	-30.80
Stream Leakage	-2.82	-4.68	-5.57	-5.28	-2.66	-1.10	-0.91	-0.72	-1.05	-1.68	-2.48	-3.49	-2.70
Net Lake Seepage	-12.82	-14.50	-16.65	-15.08	-5.23	1.56	2.53	1.57	-1.21	-5.41	-8.69	-11.66	-7.13

Table 8d – Difference in Monthly Groundwater Budget (Baseline - Phase 1) in mm/month – Wetland NAT-02.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	-0.60	-0.92	-0.74	-0.33	1.09	0.90	0.71	0.52	0.46	-0.20	-0.37	-0.65
Recharge	1.47	2.25	2.47	1.96	0.89	0.53	0.53	0.52	0.63	0.86	1.27	1.72
Net Lateral Flow In	-7.00	-12.22	-13.43	-13.05	-13.98	-13.19	-13.10	-13.15	-13.03	-13.64	-13.33	-14.11
GW ET	0.00	0.01	0.02	0.27	3.40	5.70	5.81	5.26	3.56	0.79	0.10	0.01
Surface Leakage	3.12	5.90	6.65	6.02	4.05	2.51	2.29	2.25	2.63	3.00	4.00	5.00
Stream Leakage	1.21	2.54	2.66	2.46	1.96	1.39	1.30	1.28	1.37	1.88	2.30	2.62
Net Lake Seepage	2.02	2.91	3.00	2.91	2.56	2.11	2.13	2.25	2.39	2.85	3.16	3.47

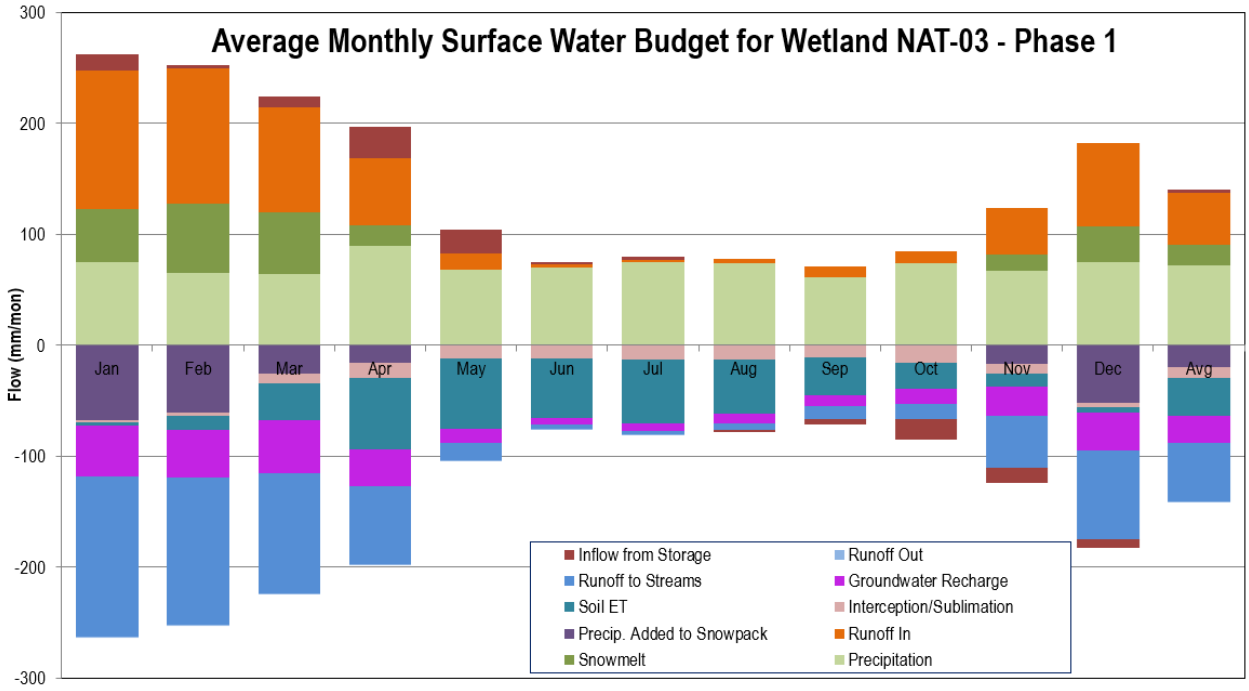


Table 9a – Monthly Surface Water Budget under Phase 1 Conditions (in mm/month) – Wetland NAT-03.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	74.66	65.43	64.44	89.68	68.61	70.57	75.15	73.73	61.69	73.90	67.57	75.24	71.72
Snowmelt	47.92	62.01	55.70	18.16	0.00	0.00	0.00	0.00	0.00	0.01	14.51	31.61	19.16
Runoff In	125.4	121.9	94.07	60.85	14.50	2.97	2.12	4.34	9.88	11.24	41.66	75.55	47.04
Precip. added to Snowpack	-67.02	-60.47	-25.60	-16.06	0.00	0.00	0.00	0.00	0.00	-0.01	-16.57	-51.78	-19.79
Interception/Sublimation	-1.91	-3.12	-8.58	-13.71	-11.49	-11.92	-12.28	-13.17	-10.93	-15.37	-8.74	-4.19	-9.62
Soil ET	-3.48	-12.63	-32.71	-63.57	-63.97	-53.11	-57.76	-48.79	-34.07	-23.56	-11.99	-4.18	-34.15
Groundwater Recharge	-45.31	-42.82	-48.71	-33.31	-11.91	-6.44	-7.37	-8.41	-9.40	-14.15	-26.21	-34.65	-24.06
Runoff to Streams	-144.6	-132.9	-107.9	-70.01	-16.47	-3.51	-2.90	-5.85	-12.10	-13.49	-46.88	-79.94	-53.04
Runoff Out	-0.43	-0.40	-0.51	-0.35	-0.09	-0.03	-0.03	-0.04	-0.06	-0.06	-0.20	-0.33	-0.21
Inflow from Storage	14.78	3.05	9.76	28.32	20.82	1.47	3.06	-1.80	-5.00	-18.51	-13.15	-7.33	2.96

Table 9b – Difference in Monthly Surface Water Budget (Baseline - Phase 1) in mm/month – Wetland NAT-03.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precip. added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater Recharge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff to Streams	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

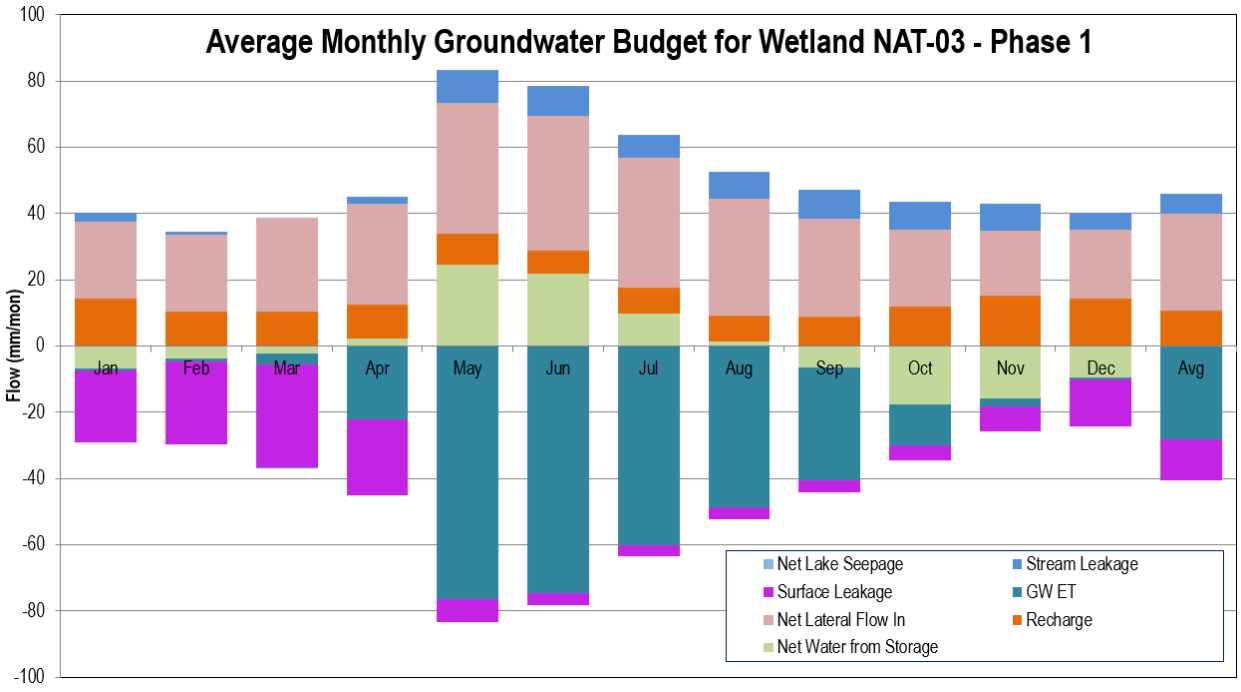


Table 9c – Monthly Groundwater Budget under Phase 1 Conditions (in mm/month) – Wetland NAT-03.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-6.93	-3.90	-2.29	2.11	24.62	21.89	9.71	1.33	-6.46	-17.72	-15.75	-9.59	-0.25
Recharge	14.20	10.29	10.32	10.26	9.16	6.94	7.91	7.88	8.94	11.82	15.27	14.39	10.62
Net Lateral Flow In	23.20	23.43	28.56	30.70	39.73	40.55	39.32	35.22	29.44	23.32	19.46	20.65	29.46
GW ET	-0.53	-0.63	-3.22	-22.22	-76.54	-74.61	-60.02	-48.74	-34.05	-12.29	-2.58	-0.58	-28.00
Surface Leakage	-21.51	-25.27	-31.09	-22.79	-6.75	-3.69	-3.53	-3.55	-3.70	-4.48	-7.43	-14.17	-12.33
Stream Leakage	2.79	0.86	-0.04	2.10	9.83	9.03	6.76	8.18	8.69	8.31	8.29	5.28	5.84
Net Lake Seepage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 9d – Difference in Monthly Groundwater Budget (Baseline - Phase 1) in mm/month – Wetland NAT-03.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	-0.05	-0.03	-0.01	0.03	0.06	0.10	0.12	0.10	0.09	-0.14	-0.13	-0.07
Recharge	0.05	0.08	0.04	0.05	-0.03	0.00	0.01	0.04	0.03	0.05	0.07	0.06
Net Lateral Flow In	-0.15	-0.22	-0.27	-0.17	-0.17	-0.09	-0.05	-0.04	-0.02	-0.12	-0.17	-0.20
GW ET	0.00	0.00	0.00	0.02	0.19	0.35	0.47	0.50	0.39	0.08	0.01	0.00
Surface Leakage	0.11	0.18	0.19	0.17	0.07	0.05	0.05	0.05	0.05	0.05	0.08	0.12
Stream Leakage	0.02	0.00	0.02	-0.02	-0.15	-0.41	-0.58	-0.63	-0.51	0.02	0.05	0.43
Net Lake Seepage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

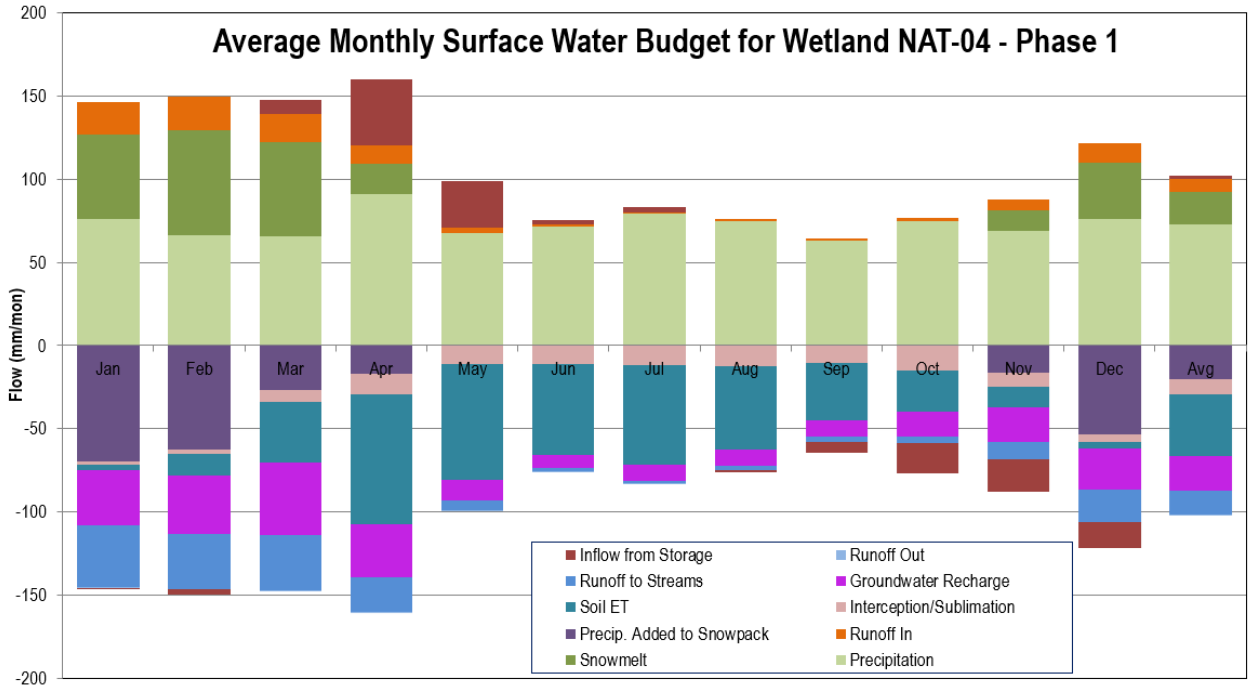


Table 10a – Monthly Surface Water Budget under Phase 1 Conditions (in mm/month) – Wetland NAT-04.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	75.88	66.60	65.32	90.72	67.38	71.74	79.00	74.79	62.71	74.78	68.62	76.26	72.82
Snowmelt	50.92	62.52	57.11	18.58	0.09	0.00	0.00	0.00	0.00	0.00	12.94	33.46	19.64
Runoff In	19.24	20.27	16.37	10.92	3.28	1.09	0.92	1.20	1.80	1.96	6.01	11.98	7.92
Precip. added to Snowpack	-69.72	-62.18	-26.40	-16.74	-0.09	0.00	0.00	0.00	0.00	-0.01	-16.18	-53.68	-20.42
Interception/Sublimation	-1.74	-2.57	-7.74	-12.78	-10.83	-11.18	-11.71	-12.55	-10.58	-14.68	-8.47	-3.91	-9.06
Soil ET	-3.65	-13.31	-35.97	-78.03	-69.64	-54.29	-59.81	-50.17	-34.07	-25.15	-12.54	-4.52	-36.76
Groundwater Recharge	-33.04	-35.14	-43.56	-31.54	-12.29	-7.86	-9.60	-9.73	-9.94	-14.97	-20.57	-24.46	-21.06
Runoff to Streams	-37.19	-33.05	-33.58	-20.87	-5.82	-1.93	-1.68	-2.28	-3.53	-3.79	-10.47	-19.14	-14.45
Runoff Out	-0.20	-0.22	-0.19	-0.18	-0.12	-0.12	-0.13	-0.12	-0.10	-0.11	-0.12	-0.14	-0.15
Inflow from Storage	-0.50	-2.91	8.66	39.92	28.04	2.55	3.02	-1.13	-6.30	-18.04	-19.21	-15.84	1.52

Table 10b – Difference in Monthly Surface Water Budget (Baseline - Phase 1) in mm/month – Wetland NAT-04.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precip. added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater Recharge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff to Streams	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

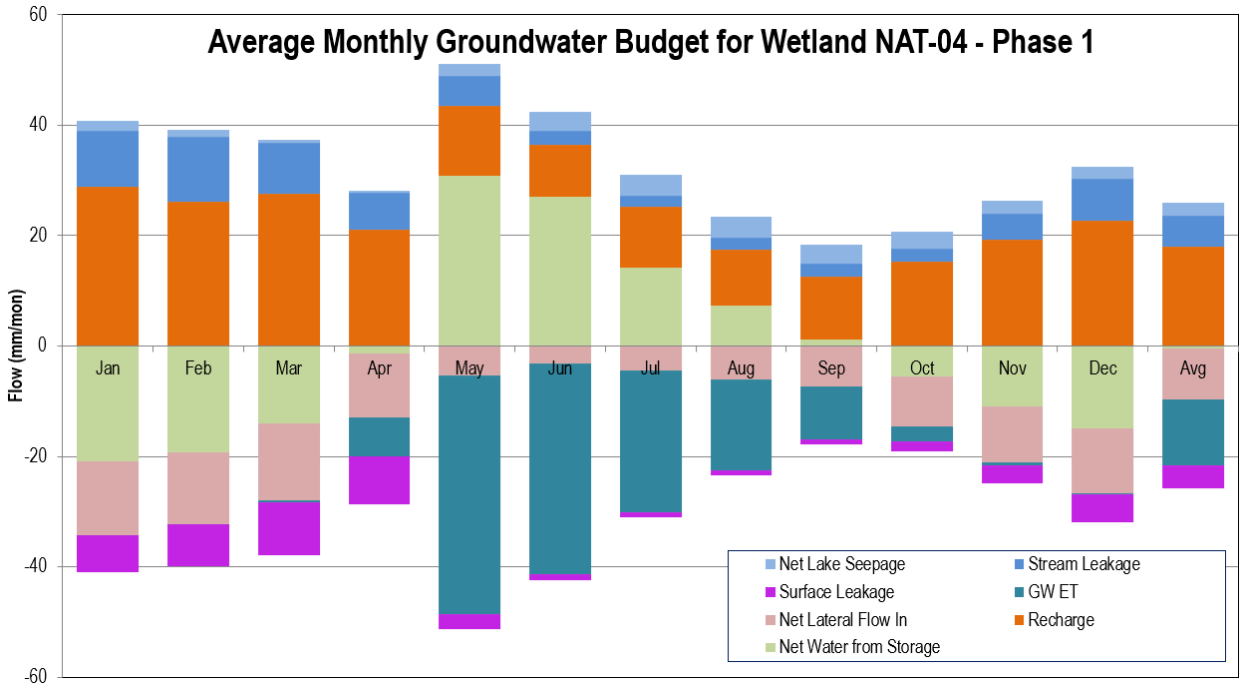


Table 10c – Monthly Groundwater Budget under Phase 1 Conditions (in mm/month) – Wetland NAT-04.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-20.88	-19.32	-13.95	-1.30	30.81	27.08	14.25	7.40	1.26	-5.49	-10.94	-14.94	-0.50
Recharge	28.93	26.13	27.56	21.16	12.68	9.41	11.00	10.01	11.29	15.27	19.25	22.78	17.96
Net Lateral Flow In	-13.37	-12.94	-14.04	-11.61	-5.33	-3.26	-4.51	-6.06	-7.24	-9.01	-10.15	-11.81	-9.11
GW ET	-0.06	-0.06	-0.39	-7.03	-43.21	-38.17	-25.64	-16.45	-9.68	-2.79	-0.47	-0.06	-12.00
Surface Leakage	-6.69	-7.49	-9.62	-8.81	-2.76	-1.02	-0.88	-0.90	-0.98	-1.71	-3.25	-5.15	-4.11
Stream Leakage	10.11	11.85	9.26	6.61	5.50	2.53	1.95	2.27	2.42	2.43	4.70	7.61	5.60
Net Lake Seepage	1.77	1.17	0.61	0.30	2.20	3.43	3.89	3.83	3.40	2.94	2.29	2.10	2.33

Table 10d – Difference in Monthly Groundwater Budget (Baseline - Phase 1) in mm/month – Wetland NAT-04.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	-0.04	-0.05	-0.18	0.03	-0.18	-0.22	-0.05	0.08	0.15	0.31	0.26	0.30
Recharge	0.01	0.20	0.29	0.20	0.07	0.01	0.01	0.01	0.01	0.01	-0.07	0.27
Net Lateral Flow In	-0.09	-0.37	-0.50	-0.51	-0.60	-0.58	-0.53	-0.44	-0.39	-0.32	-0.32	-0.29
GW ET	0.00	0.00	0.01	0.12	0.88	0.92	0.68	0.49	0.31	0.08	0.01	0.00
Surface Leakage	0.00	0.09	0.09	0.10	0.02	0.01	0.02	0.01	0.01	0.01	0.02	0.04
Stream Leakage	0.11	0.13	0.15	-0.02	-0.16	-0.14	-0.11	-0.14	-0.08	-0.11	0.00	-0.11
Net Lake Seepage	0.01	0.02	0.01	0.03	0.01	0.00	-0.01	-0.01	-0.01	-0.01	0.01	0.02

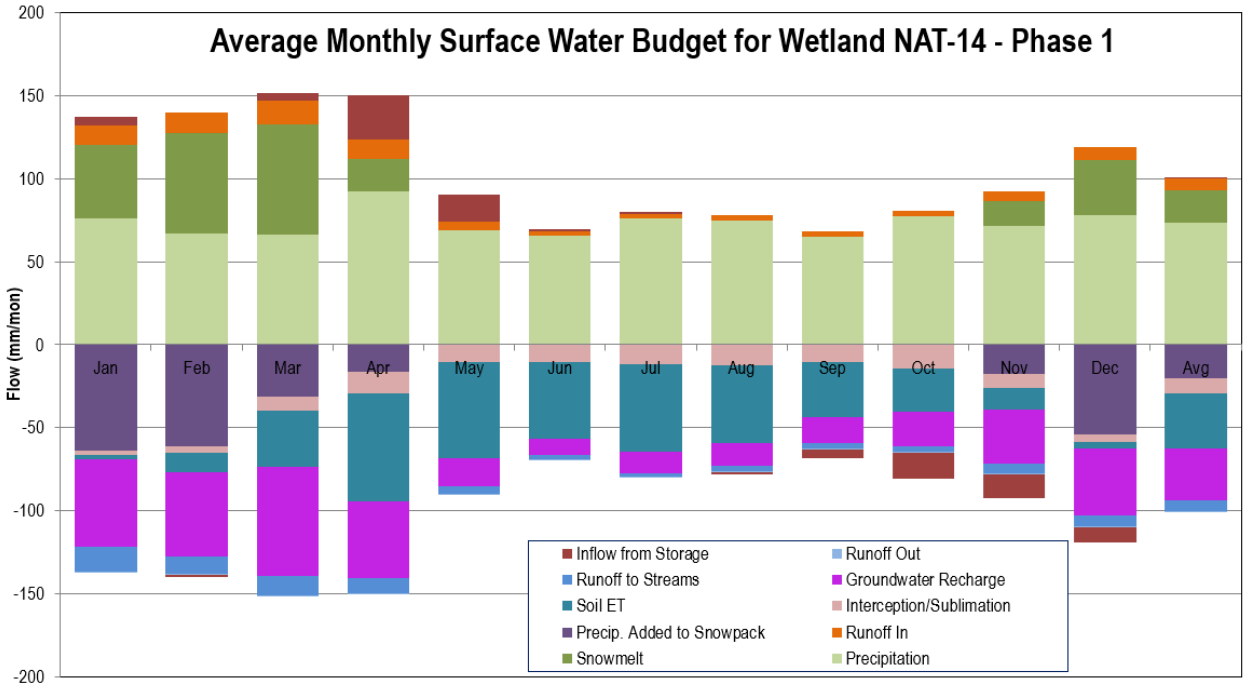


Table 11a – Monthly Surface Water Budget under Phase 1 Conditions (in mm/month) – Wetland NAT-14.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	75.92	66.77	66.36	92.13	69.05	65.58	75.80	75.01	65.16	77.60	71.24	77.90	73.21
Snowmelt	44.56	60.89	66.27	19.98	0.00	0.00	0.00	0.00	0.00	0.00	15.40	33.30	20.03
Runoff In	11.36	12.19	14.08	11.66	5.01	2.67	2.61	3.07	3.03	3.16	5.45	7.62	6.83
Precip. added to Snowpack	-63.63	-61.10	-31.19	-16.56	0.00	0.00	0.00	0.00	0.00	0.00	-17.58	-53.69	-20.31
Interception/Sublimation	-2.67	-3.86	-8.35	-12.62	-10.25	-10.46	-11.60	-12.50	-10.23	-14.30	-8.67	-4.65	-9.18
Soil ET	-2.82	-12.13	-34.26	-65.14	-57.89	-46.15	-53.07	-46.52	-33.52	-25.96	-12.57	-3.84	-32.82
Groundwater Recharge	-52.81	-50.15	-65.10	-46.35	-17.38	-9.91	-12.46	-14.10	-15.64	-20.75	-33.00	-40.49	-31.51
Runoff to Streams	-14.37	-10.68	-11.83	-8.89	-3.97	-2.27	-2.50	-3.17	-3.23	-3.30	-5.58	-6.87	-6.39
Runoff Out	-0.90	-0.95	-0.90	-0.84	-0.57	-0.49	-0.56	-0.56	-0.50	-0.56	-0.66	-0.71	-0.68
Inflow from Storage	5.35	-0.98	4.90	26.64	15.99	1.01	1.78	-1.23	-5.07	-15.90	-14.02	-8.57	0.83

Table 11b – Difference in Monthly Surface Water Budget (Baseline - Phase 1) in mm/month – Wetland NAT-14.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precip. added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater Recharge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff to Streams	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

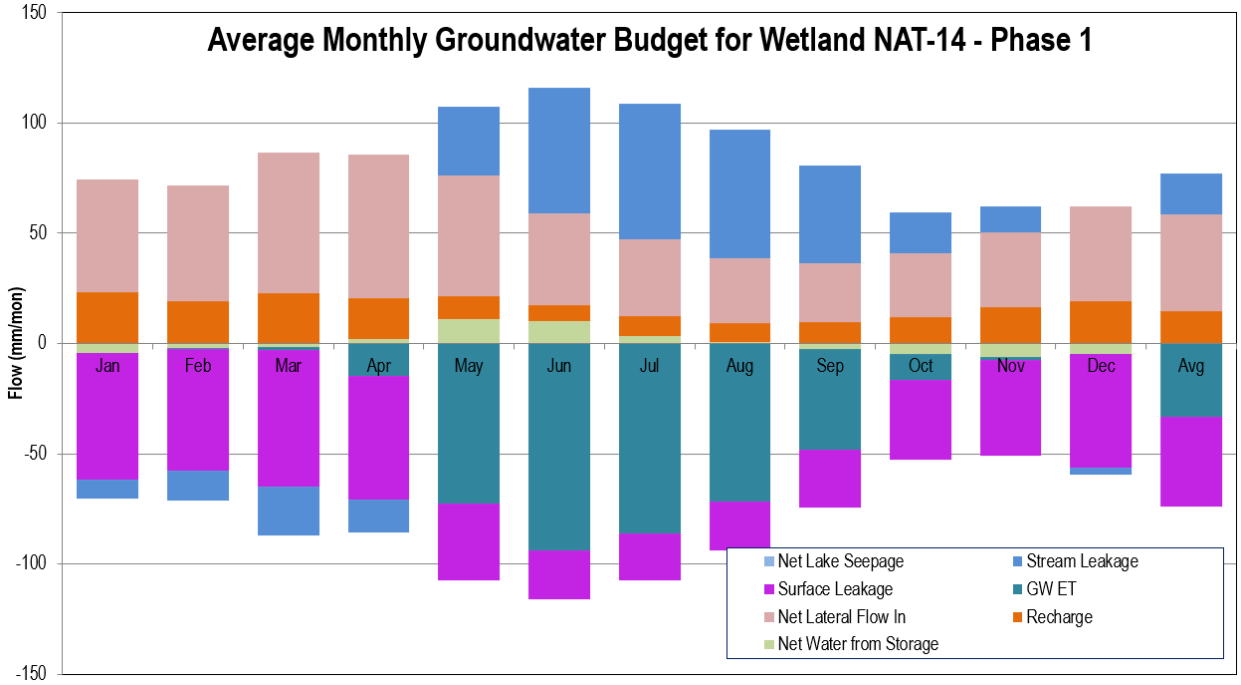


Table 11c – Monthly Groundwater Budget under Phase 1 Conditions (in mm/month) – Wetland NAT-14.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-4.24	-2.05	-1.43	2.17	11.30	10.19	3.27	0.78	-2.46	-4.95	-5.97	-4.70	0.16
Recharge	23.19	19.01	23.06	18.59	10.22	7.17	9.16	8.66	9.69	11.86	16.44	19.38	14.70
Net Lateral Flow In	51.04	52.54	63.72	65.09	54.58	41.48	34.68	29.24	26.60	29.08	34.00	42.62	43.72
GW ET	-0.24	-0.27	-1.41	-14.75	-72.80	-93.76	-86.24	-71.86	-45.63	-11.68	-1.72	-0.26	-33.39
Surface Leakage	-57.17	-55.17	-62.28	-56.16	-34.54	-22.16	-21.18	-22.12	-26.22	-35.99	-43.02	-51.51	-40.63
Stream Leakage	-8.68	-13.70	-21.90	-15.04	31.25	57.05	61.54	58.40	44.29	18.44	11.64	-3.00	18.36
Net Lake Seepage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 11d – Difference in Monthly Groundwater Budget (Baseline - Phase 1) in mm/month – Wetland NAT-14.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	-0.04	0.02	0.01	0.00	-0.01	-0.02	-0.02	-0.02	-0.01	-0.01	-0.01	0.04
Recharge	0.06	-0.01	-0.08	0.01	-0.08	0.01	-0.01	0.00	-0.01	-0.02	-0.01	-0.02
Net Lateral Flow In	0.08	0.22	0.25	0.24	0.22	0.20	0.20	0.21	0.23	0.24	0.29	0.26
GW ET	0.00	0.00	0.00	0.00	-0.03	-0.05	-0.06	-0.06	-0.04	-0.01	0.00	0.00
Surface Leakage	0.27	-0.06	-0.04	-0.05	-0.03	-0.02	-0.03	-0.06	-0.04	-0.11	-0.12	-0.08
Stream Leakage	-0.51	-0.17	-0.21	-0.32	-0.19	-0.11	-0.05	-0.07	-0.02	-0.08	-0.03	-0.12
Net Lake Seepage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

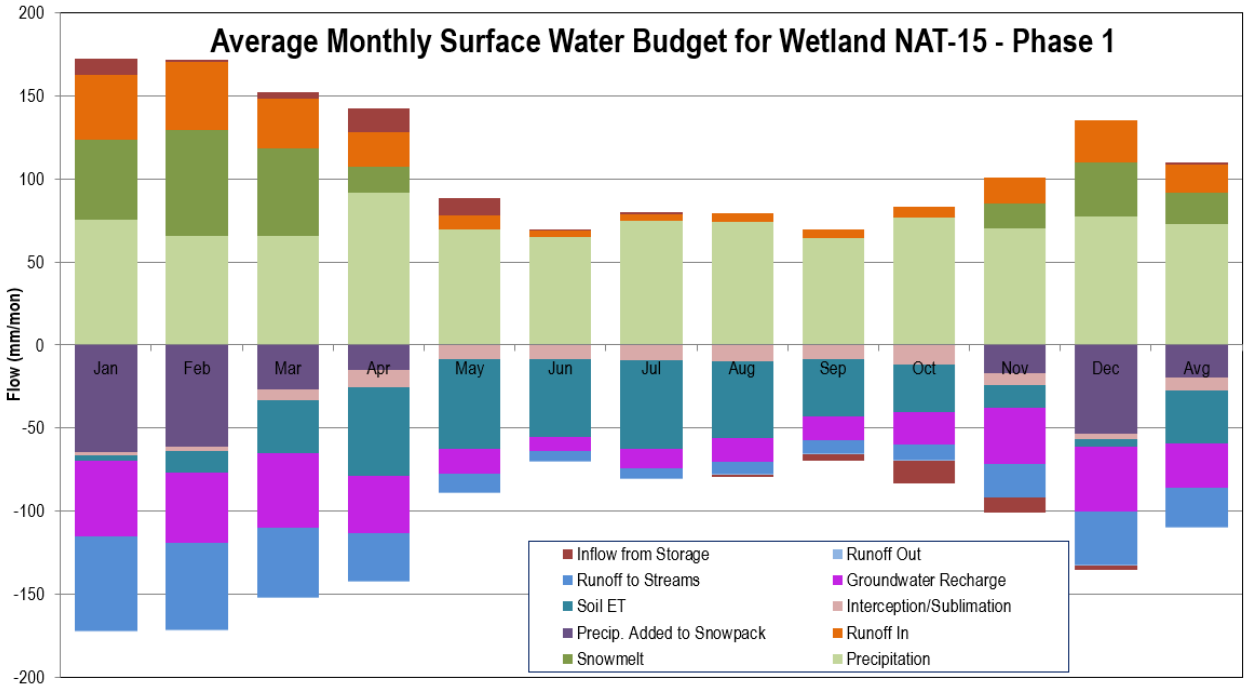


Table 12a – Monthly Surface Water Budget under Phase 1 Conditions (in mm/month) – Wetland NAT-15.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	75.13	65.93	65.60	91.46	69.58	65.04	74.79	74.34	64.15	76.79	70.33	77.17	72.53
Snowmelt	48.42	63.72	53.00	15.82	0.00	0.00	0.00	0.00	0.00	0.00	15.09	32.70	19.06
Runoff In	38.72	40.71	29.93	21.03	8.28	3.91	3.96	4.85	5.20	6.64	15.28	25.49	17.00
Precip. added to Snowpack	-64.53	-61.19	-26.60	-14.87	0.00	0.00	0.00	0.00	0.00	0.00	-16.90	-53.14	-19.77
Interception/Sublimation	-1.81	-2.42	-6.35	-10.23	-8.45	-8.56	-9.39	-10.10	-8.29	-11.96	-7.18	-3.63	-7.36
Soil ET	-3.52	-12.99	-32.07	-53.76	-53.70	-46.48	-52.94	-46.17	-34.65	-28.19	-13.96	-4.72	-31.93
Groundwater Recharge	-45.39	-42.54	-45.21	-34.59	-15.12	-8.96	-11.63	-14.10	-14.43	-19.50	-33.24	-38.62	-26.94
Runoff to Streams	-56.15	-51.62	-41.08	-28.37	-11.05	-5.59	-6.06	-7.32	-7.89	-9.47	-20.14	-31.75	-23.04
Runoff Out	-1.02	-1.03	-0.99	-0.69	-0.32	-0.15	-0.15	-0.21	-0.22	-0.22	-0.53	-0.80	-0.53
Inflow from Storage	10.14	1.43	3.77	14.19	10.77	0.80	1.43	-1.29	-3.88	-14.09	-8.74	-2.70	0.98

Table 12b – Difference in Monthly Surface Water Budget (Baseline - Phase 1) in mm/month – Wetland NAT-15.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precip. added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater Recharge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff to Streams	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

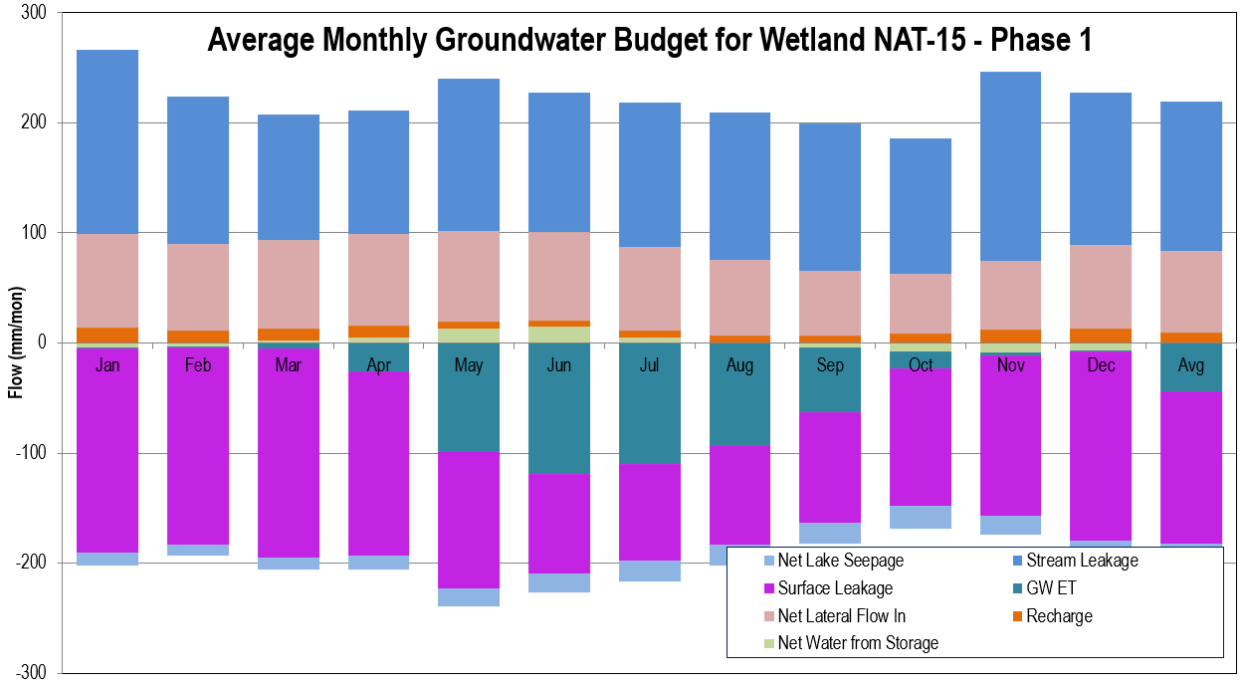


Table 12c – Monthly Groundwater Budget under Phase 1 Conditions (in mm/month) – Wetland NAT-15.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-4.14	-2.77	2.13	5.38	13.22	15.27	4.91	0.62	-4.17	-7.43	-8.95	-7.12	0.58
Recharge	13.90	11.53	10.66	10.56	6.35	4.96	6.73	6.11	6.92	8.43	11.85	13.29	9.27
Net Lateral Flow In	84.76	78.48	81.22	82.96	82.64	80.96	75.79	68.53	58.51	54.17	62.45	75.45	73.83
GW ET	-0.76	-1.04	-4.61	-25.40	-98.26	-118.9	-109.7	-92.38	-58.96	-15.52	-2.58	-0.79	-44.07
Surface Leakage	-185.7	-179.3	-190.7	-168.0	-124.9	-90.29	-87.98	-90.59	-100.4	-124.9	-145.5	-172.0	-138.4
Stream Leakage	167.4	133.9	113.5	112.2	137.7	126.2	130.9	133.8	133.7	123.5	172.4	138.8	135.3
Net Lake Seepage	-11.90	-10.08	-10.73	-12.58	-16.38	-17.91	-19.28	-18.88	-18.42	-20.74	-16.76	-14.11	-15.65

Table 12d – Difference in Monthly Groundwater Budget (Baseline - Phase 1) in mm/month – Wetland NAT-15.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	-0.05	-0.03	0.04	0.01	0.06	0.12	0.11	0.19	-0.13	-0.15	-0.06	-0.03
Recharge	-0.01	0.03	0.00	0.02	0.00	0.00	0.01	0.04	0.00	0.00	0.01	0.02
Net Lateral Flow In	-0.50	-0.34	-0.50	-0.63	-0.57	-0.30	-0.03	0.09	-0.22	-0.37	-0.70	-0.90
GW ET	0.00	0.00	0.00	0.01	0.09	0.27	0.37	0.45	0.21	0.02	0.00	0.00
Surface Leakage	0.35	0.29	0.52	0.34	0.48	0.84	1.09	1.68	1.11	0.69	0.49	0.45
Stream Leakage	0.63	0.71	2.26	0.36	0.70	-0.65	-1.18	-1.32	-0.35	0.39	0.24	0.33
Net Lake Seepage	-0.79	-0.38	-0.49	-0.57	-0.77	-0.47	-0.26	-0.41	-0.65	-0.79	-0.95	-0.80

9.3 *Phase 2*

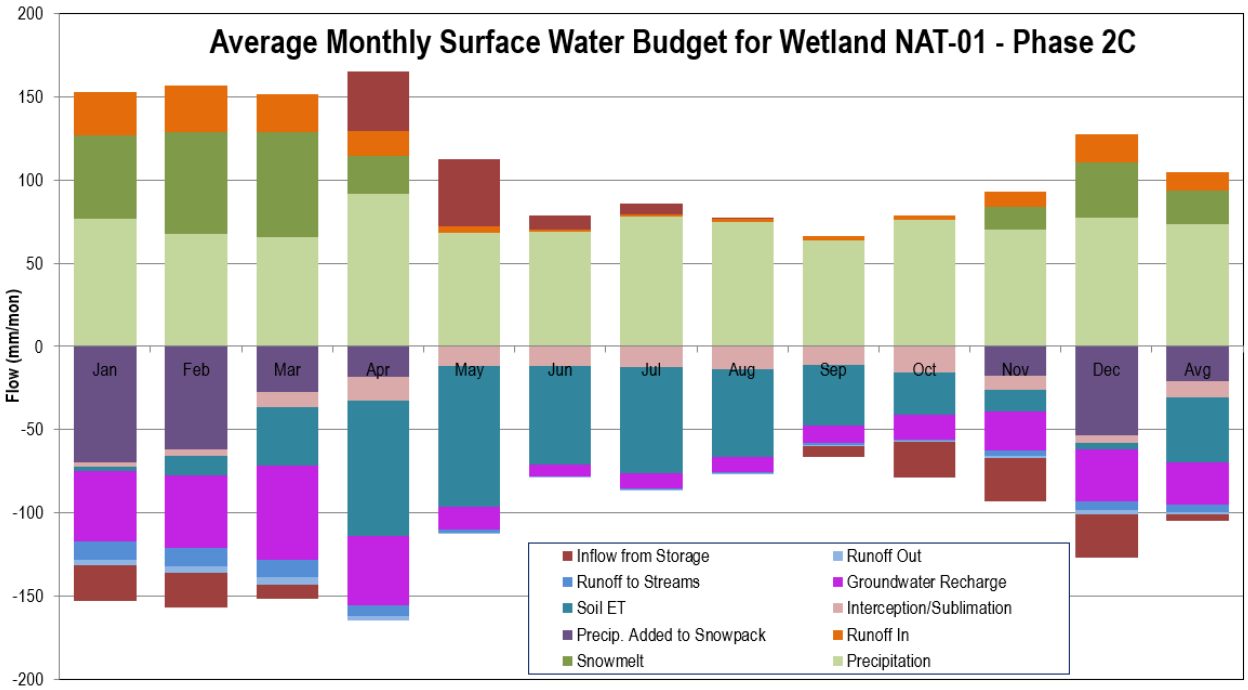


Table 13a – Monthly Surface Water Budget under Phase 2C Conditions (in mm/month) – Wetland NAT-01.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	76.56	67.29	65.88	91.50	67.99	69.09	78.19	74.90	63.93	76.07	70.01	77.42	73.24
Snowmelt	49.93	61.44	62.98	23.01	0.12	0.00	0.00	0.00	0.00	0.00	14.07	33.02	20.38
Runoff In	26.29	28.00	22.85	14.75	4.12	1.08	1.01	1.54	2.56	2.72	8.66	16.60	10.85
Precip. added to Snowpack	-69.52	-61.54	-27.31	-18.57	-0.12	0.00	0.00	0.00	0.00	0.00	-17.40	-53.05	-20.63
Interception/Sublimation	-2.57	-3.99	-9.15	-13.83	-11.52	-11.96	-12.60	-13.61	-11.32	-15.33	-8.92	-4.70	-9.96
Soil ET	-2.87	-11.98	-35.13	-81.73	-84.27	-58.61	-63.41	-52.74	-36.24	-25.66	-12.57	-3.79	-39.08
Groundwater Recharge	-42.09	-43.30	-56.31	-40.99	-14.14	-7.30	-9.11	-9.36	-10.14	-14.64	-23.68	-31.10	-25.18
Runoff to Streams	-10.66	-11.33	-10.76	-6.81	-1.52	-0.32	-0.36	-0.63	-1.26	-1.00	-2.73	-5.55	-4.41
Runoff Out	-3.79	-4.00	-4.24	-2.80	-0.74	-0.24	-0.28	-0.35	-0.51	-0.50	-1.28	-2.25	-1.75
Inflow from Storage	-21.27	-20.59	-8.80	35.47	40.09	8.26	6.56	0.26	-7.03	-21.65	-26.16	-26.61	-3.46

Table 13b – Difference in Monthly Surface Water Budget (Baseline - Phase 2C) in mm/month – Wetland NAT-01.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precip. added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater Recharge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff to Streams	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

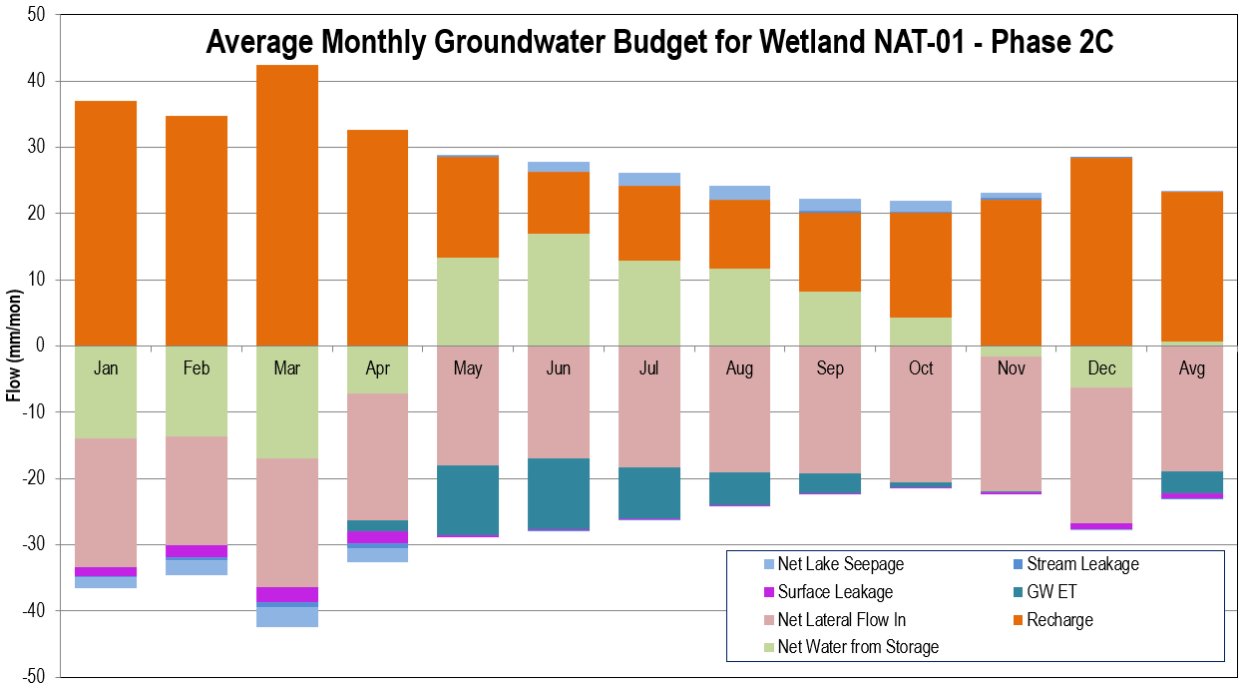


Table 13c – Monthly Groundwater Budget under Phase 2C Conditions (in mm/month) – Wetland NAT-01.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-14.03	-13.72	-16.98	-7.23	13.48	17.02	12.82	11.57	8.05	4.19	-1.74	-6.27	0.60
Recharge	37.01	34.69	42.45	32.66	15.28	9.47	11.29	10.31	11.93	15.77	22.09	28.38	22.61
Net Lateral Flow In	-19.17	-16.28	-19.31	-18.89	-17.70	-16.69	-17.96	-18.79	-19.02	-20.34	-20.12	-20.35	-18.72
GW ET	0.00	-0.01	-0.05	-1.76	-11.00	-11.19	-8.09	-5.19	-2.99	-0.79	-0.09	0.00	-3.43
Surface Leakage	-1.47	-1.82	-2.28	-1.89	-0.41	-0.15	-0.15	-0.15	-0.15	-0.17	-0.39	-0.90	-0.83
Stream Leakage	-0.15	-0.43	-0.78	-0.69	0.17	-0.01	-0.01	0.04	0.22	0.13	0.27	0.17	-0.09
Net Lake Seepage	-1.66	-2.34	-3.02	-2.21	0.15	1.58	2.08	2.20	1.92	1.62	0.74	-0.25	0.07

Table 13d – Difference in Monthly Groundwater Budget (Baseline - Phase 2C) in mm/month – Wetland NAT-01.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	-0.62	-0.47	-0.47	-0.24	2.69	2.51	0.84	-0.51	-1.18	-1.53	-1.23	-0.92
Recharge	-0.10	-0.09	-0.18	-0.17	-0.06	-0.06	-0.01	-0.04	-0.02	-0.02	-0.04	-0.08
Net Lateral Flow In	1.12	1.12	1.28	1.47	2.49	3.01	3.03	2.66	2.11	1.74	1.38	1.23
GW ET	0.00	0.00	-0.01	-0.52	-4.93	-5.55	-3.99	-2.30	-1.05	-0.27	-0.02	0.00
Surface Leakage	-0.16	-0.16	-0.20	-0.19	-0.06	-0.03	-0.03	-0.03	-0.03	-0.03	-0.06	-0.12
Stream Leakage	-0.12	-0.13	-0.13	-0.11	-0.05	-0.02	-0.02	-0.02	-0.03	-0.03	-0.05	-0.09
Net Lake Seepage	-0.11	-0.24	-0.29	-0.27	-0.07	0.09	0.17	0.21	0.22	0.22	0.15	0.04

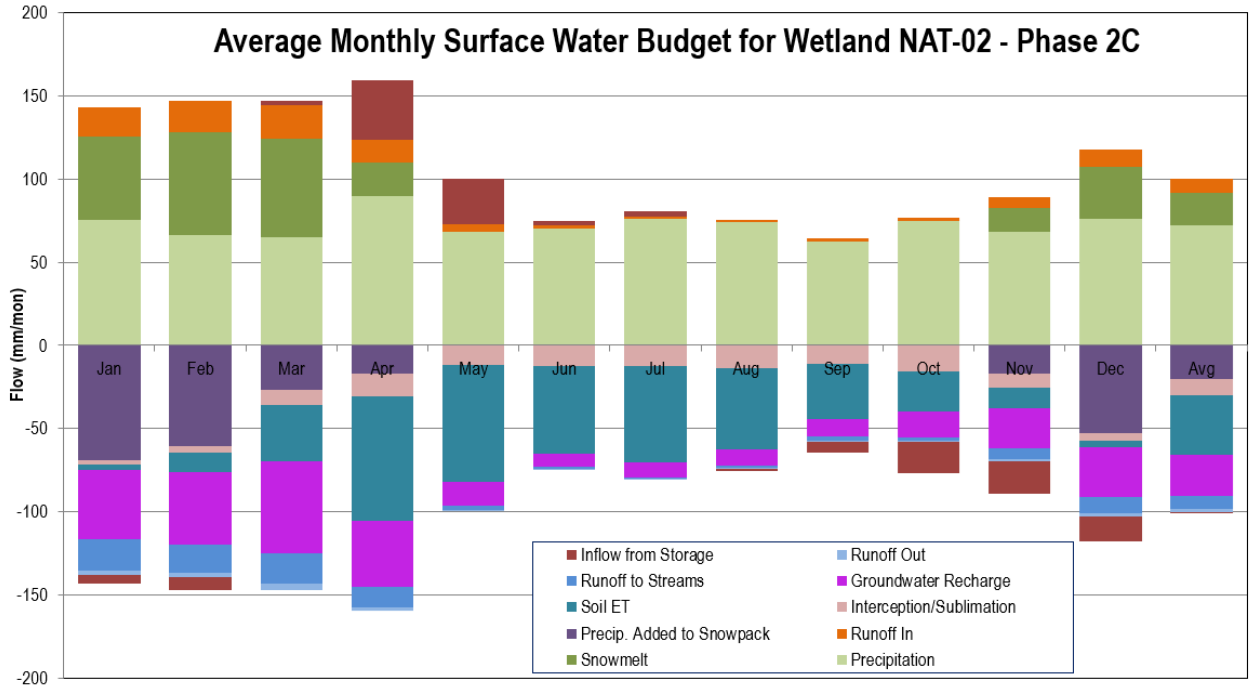


Table 14a – Monthly Surface Water Budget under Phase 2C Conditions (in mm/month) – Wetland NAT-02.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	75.14	66.03	64.85	90.01	68.18	70.44	76.23	73.87	62.18	74.47	68.21	75.79	72.12
Snowmelt	50.18	61.72	59.06	19.79	0.00	0.00	0.00	0.00	0.00	0.00	14.59	31.73	19.76
Runoff In	17.83	19.35	20.26	13.99	4.35	1.68	1.25	1.68	2.29	2.15	6.02	10.15	8.42
Precip. added to Snowpack	-69.20	-60.51	-26.68	-16.70	0.00	0.00	0.00	0.00	0.00	-0.01	-16.78	-52.65	-20.21
Interception/Sublimation	-2.20	-3.59	-9.01	-13.99	-11.65	-12.16	-12.47	-13.41	-11.13	-15.48	-8.86	-4.40	-9.86
Soil ET	-3.19	-12.28	-34.22	-74.73	-70.61	-53.19	-57.82	-48.85	-33.39	-24.30	-12.05	-4.00	-35.72
Groundwater Recharge	-41.82	-43.66	-54.80	-39.90	-13.82	-7.62	-9.00	-9.74	-10.28	-15.29	-24.05	-29.76	-24.98
Runoff to Streams	-18.73	-16.66	-18.85	-11.95	-2.93	-1.03	-0.98	-1.58	-2.37	-2.26	-6.77	-10.20	-7.86
Runoff Out	-2.63	-2.77	-3.22	-2.33	-0.89	-0.57	-0.56	-0.60	-0.60	-0.64	-1.13	-1.66	-1.47
Inflow from Storage	-5.37	-7.62	2.61	35.82	27.37	2.45	3.35	-1.37	-6.70	-18.65	-19.17	-15.01	-0.19

Table 14b – Difference in Monthly Surface Water Budget (Baseline - Phase 2C) in mm/month – Wetland NAT-02.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	-0.54	-0.63	-0.34	-0.41	-0.17	-0.13	-0.18	-0.26	-0.29	-0.16	-0.21	-0.23
Precip. added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.00	0.00	0.02	0.04	0.05	0.04	0.04	0.01	0.00	0.00
Groundwater Recharge	0.34	0.29	0.19	0.22	0.08	0.04	0.06	0.08	0.08	0.07	0.18	0.19
Runoff to Streams	0.26	0.33	0.15	0.20	0.07	0.05	0.08	0.13	0.19	0.04	0.04	0.07
Runoff Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

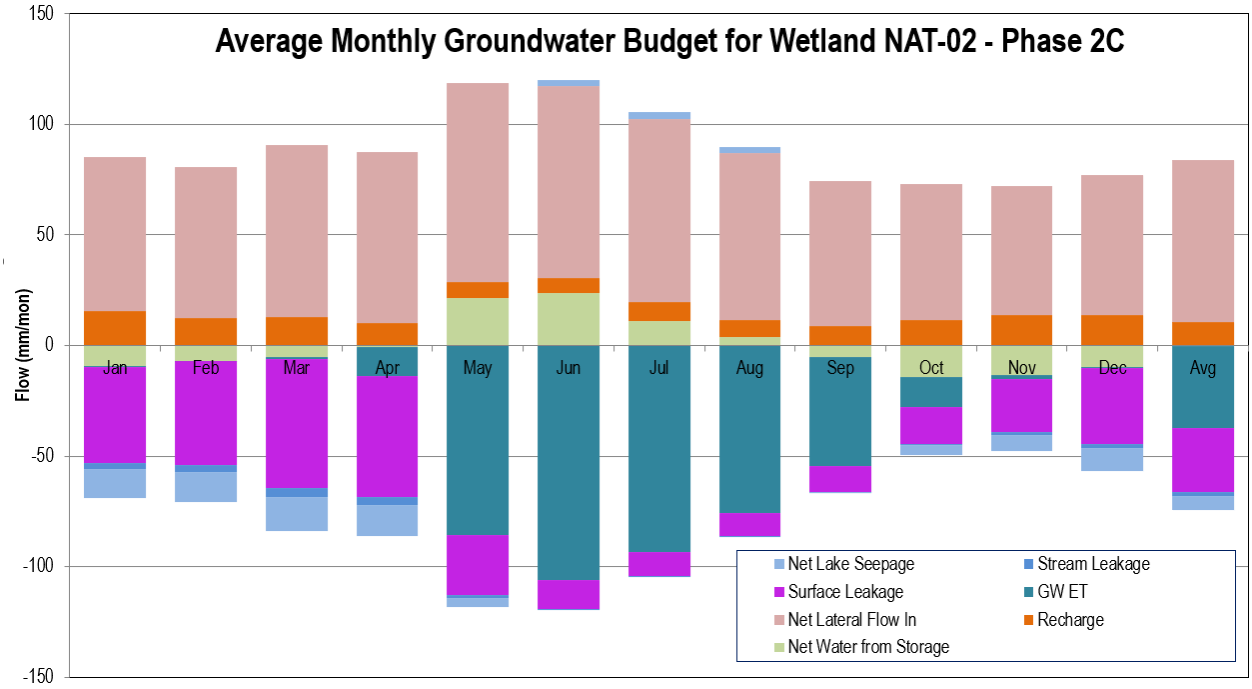


Table 14c – Monthly Groundwater Budget under Phase 2C Conditions (in mm/month) – Wetland NAT-02.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-9.38	-6.81	-5.22	-0.78	21.34	23.62	11.30	3.84	-5.38	-14.43	-13.21	-9.90	-0.42
Recharge	15.73	12.40	13.04	10.06	7.40	6.77	8.46	7.90	8.90	11.40	13.94	13.63	10.80
Net Lateral Flow In	69.57	68.29	77.69	77.69	90.11	87.23	82.60	75.48	65.73	61.71	58.39	63.29	73.15
GW ET	-0.18	-0.20	-1.10	-12.83	-85.82	-106.14	-93.49	-75.83	-48.92	-13.45	-2.03	-0.20	-36.68
Surface Leakage	-43.47	-47.05	-58.30	-54.79	-27.01	-13.27	-10.83	-10.55	-12.00	-16.51	-23.79	-34.36	-29.33
Stream Leakage	-2.93	-3.28	-3.99	-3.80	-1.52	-0.31	-0.20	0.00	-0.20	-0.63	-1.26	-2.12	-1.69
Net Lake Seepage	-12.99	-13.40	-15.42	-13.87	-4.18	2.42	3.35	2.45	-0.30	-4.38	-7.63	-10.42	-6.20

Table 14d – Difference in Monthly Groundwater Budget (Baseline - Phase 2C) in mm/month – Wetland NAT-02.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	-0.61	-0.68	-0.55	-0.22	0.67	0.61	0.52	0.43	0.45	-0.14	-0.20	-0.57
Recharge	1.63	1.57	1.76	1.43	0.55	0.29	0.28	0.28	0.35	0.50	0.72	1.06
Net Lateral Flow In	-7.76	-6.93	-7.47	-7.27	-8.13	-7.97	-8.06	-8.10	-7.69	-8.37	-7.74	-8.32
GW ET	0.00	0.00	0.02	0.19	2.26	3.79	3.89	3.60	2.48	0.57	0.08	0.00
Surface Leakage	3.52	3.53	4.00	3.51	2.34	1.46	1.32	1.29	1.60	1.79	2.44	2.92
Stream Leakage	1.32	1.13	1.08	0.97	0.81	0.60	0.58	0.56	0.52	0.83	1.07	1.25
Net Lake Seepage	2.19	1.81	1.77	1.71	1.51	1.25	1.31	1.37	1.48	1.82	2.10	2.23

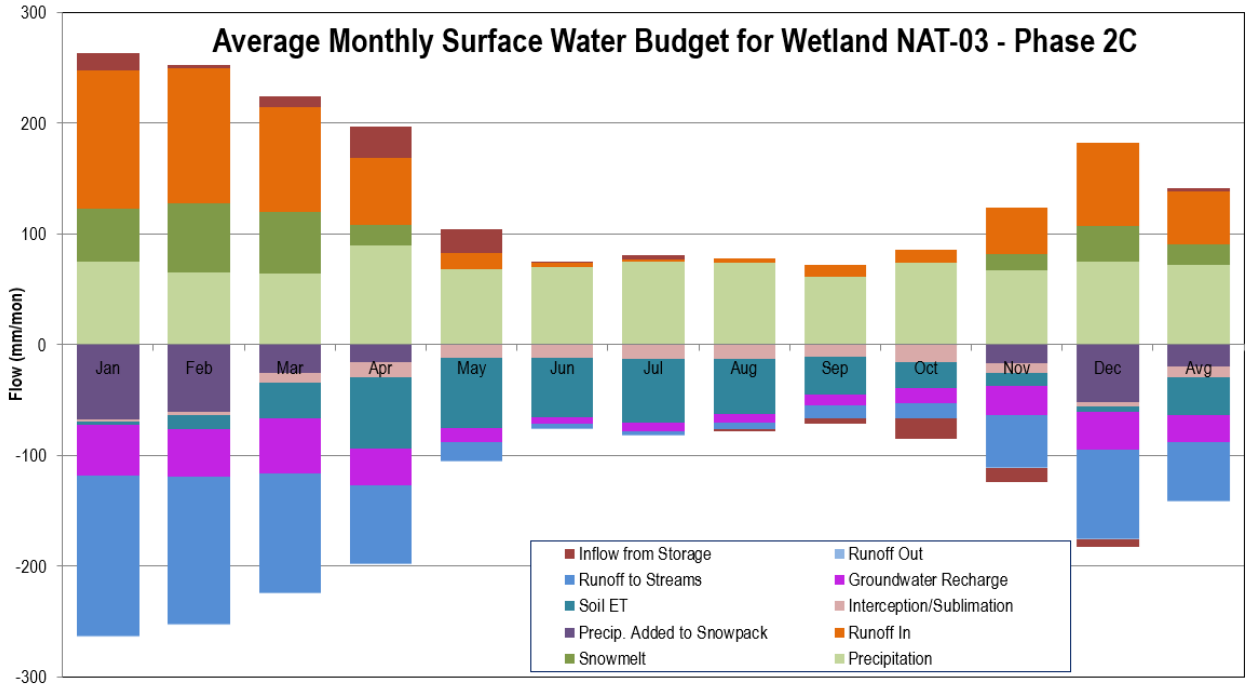


Table 15a – Monthly Surface Water Budget under Phase 2C Conditions (in mm/month) – Wetland NAT-03.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	74.66	65.43	64.44	89.68	68.61	70.57	75.15	73.73	61.69	73.90	67.57	75.24	71.72
Snowmelt	47.92	62.01	55.70	18.16	0.00	0.00	0.00	0.00	0.00	0.01	14.51	31.61	19.16
Runoff In	125.4	121.9	94.07	60.85	14.50	2.97	2.12	4.34	9.88	11.24	41.66	75.55	47.04
Precip. added to Snowpack	-67.02	-60.47	-25.60	-16.06	0.00	0.00	0.00	0.00	0.00	-0.01	-16.57	-51.78	-19.79
Interception/Sublimation	-1.91	-3.12	-8.58	-13.71	-11.49	-11.92	-12.28	-13.17	-10.93	-15.37	-8.74	-4.19	-9.62
Soil ET	-3.48	-12.63	-32.71	-63.57	-63.97	-53.11	-57.76	-48.79	-34.07	-23.56	-11.99	-4.18	-34.15
Groundwater Recharge	-45.31	-42.82	-48.71	-33.31	-11.91	-6.44	-7.37	-8.41	-9.40	-14.15	-26.21	-34.65	-24.06
Runoff to Streams	-144.6	-132.9	-107.9	-70.01	-16.47	-3.51	-2.90	-5.85	-12.10	-13.49	-46.88	-79.94	-53.04
Runoff Out	-0.43	-0.40	-0.51	-0.35	-0.09	-0.03	-0.03	-0.04	-0.06	-0.06	-0.20	-0.33	-0.21
Inflow from Storage	14.78	3.05	9.76	28.32	20.82	1.47	3.06	-1.80	-5.00	-18.51	-13.15	-7.33	2.96

Table 15b – Difference in Monthly Surface Water Budget (Baseline - Phase 2C) in mm/month – Wetland NAT-03.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precip. added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater Recharge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff to Streams	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

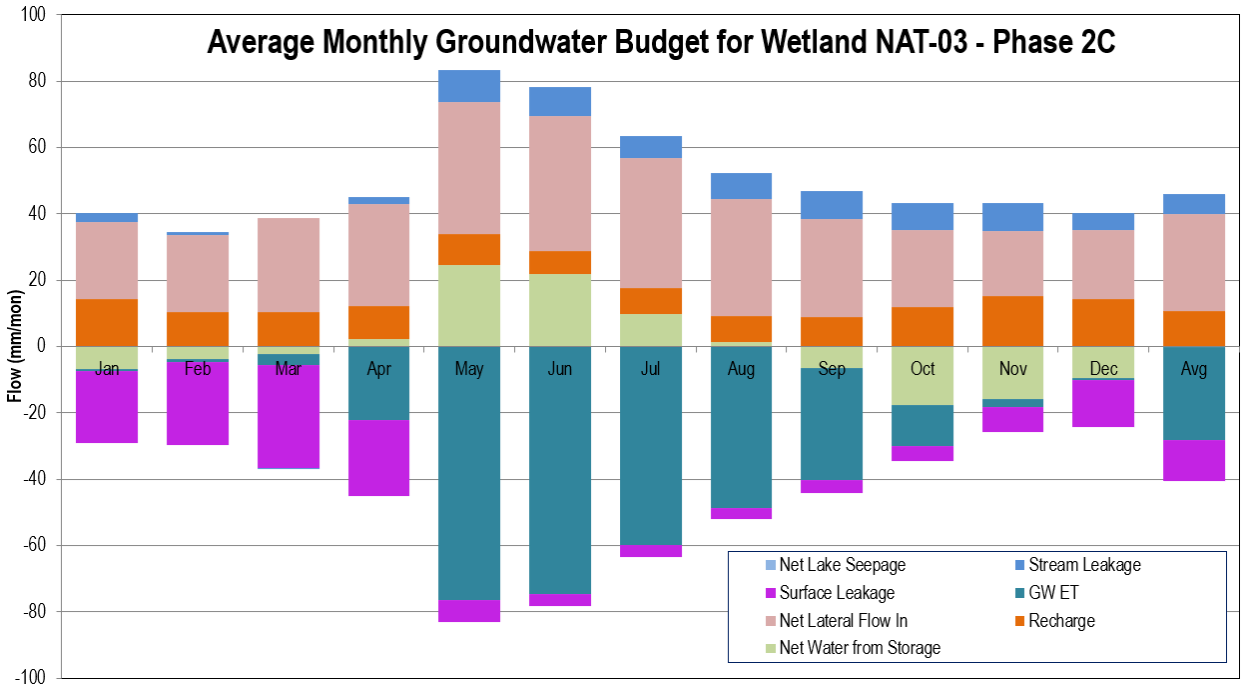


Table 15c – Monthly Groundwater Budget under Phase 2C Conditions (in mm/month) – Wetland NAT-03.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-6.93	-3.91	-2.30	2.12	24.64	21.92	9.74	1.36	-6.45	-17.74	-15.76	-9.62	-0.24
Recharge	14.20	10.32	10.33	10.21	9.33	6.94	7.91	7.89	8.94	11.84	15.27	14.40	10.63
Net Lateral Flow In	23.21	23.36	28.51	30.65	39.68	40.52	39.30	35.20	29.41	23.25	19.42	20.59	29.42
GW ET	-0.53	-0.63	-3.22	-22.21	-76.48	-74.50	-59.89	-48.57	-33.94	-12.28	-2.58	-0.58	-27.95
Surface Leakage	-21.51	-25.23	-31.05	-22.74	-6.73	-3.68	-3.52	-3.53	-3.69	-4.47	-7.40	-14.15	-12.31
Stream Leakage	2.80	0.86	-0.04	2.09	9.78	8.92	6.62	7.97	8.56	8.26	8.45	5.28	5.80
Net Lake Seepage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 15d – Difference in Monthly Groundwater Budget (Baseline - Phase 2C) in mm/month – Wetland NAT-03.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	-0.06	-0.03	-0.01	0.02	0.04	0.08	0.09	0.06	0.09	-0.12	-0.11	-0.05
Recharge	0.05	0.05	0.03	0.11	-0.21	0.00	0.01	0.03	0.02	0.03	0.06	0.06
Net Lateral Flow In	-0.16	-0.15	-0.21	-0.13	-0.12	-0.06	-0.02	-0.02	0.00	-0.06	-0.13	-0.14
GW ET	0.00	0.00	0.00	0.01	0.13	0.25	0.34	0.33	0.28	0.07	0.01	0.00
Surface Leakage	0.12	0.13	0.14	0.12	0.04	0.03	0.03	0.03	0.04	0.03	0.05	0.10
Stream Leakage	0.02	0.00	0.02	-0.01	-0.10	-0.30	-0.44	-0.42	-0.38	0.07	-0.12	0.43
Net Lake Seepage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

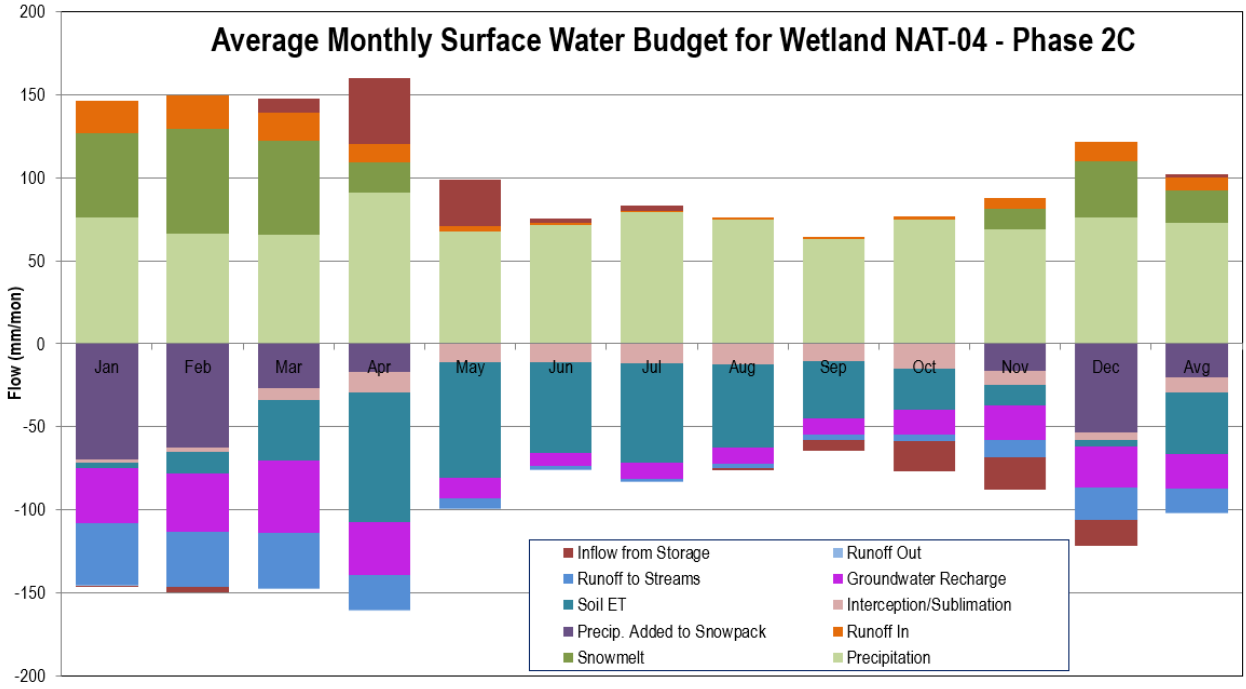


Table 16a – Monthly Surface Water Budget under Phase 2C Conditions (in mm/month) – Wetland NAT-04.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	75.88	66.60	65.32	90.72	67.38	71.74	79.00	74.79	62.71	74.78	68.62	76.26	72.82
Snowmelt	50.92	62.52	57.11	18.58	0.09	0.00	0.00	0.00	0.00	0.00	12.94	33.46	19.64
Runoff In	19.24	20.27	16.37	10.92	3.28	1.09	0.92	1.20	1.80	1.96	6.01	11.98	7.92
Precip. added to Snowpack	-69.72	-62.18	-26.40	-16.74	-0.09	0.00	0.00	0.00	0.00	-0.01	-16.18	-53.68	-20.42
Interception/Sublimation	-1.74	-2.57	-7.74	-12.78	-10.83	-11.18	-11.71	-12.55	-10.58	-14.68	-8.47	-3.91	-9.06
Soil ET	-3.65	-13.31	-35.97	-78.03	-69.64	-54.29	-59.81	-50.17	-34.07	-25.15	-12.54	-4.52	-36.76
Groundwater Recharge	-33.04	-35.14	-43.56	-31.54	-12.29	-7.86	-9.60	-9.73	-9.94	-14.97	-20.57	-24.46	-21.06
Runoff to Streams	-37.19	-33.05	-33.58	-20.87	-5.82	-1.93	-1.68	-2.28	-3.53	-3.79	-10.47	-19.14	-14.45
Runoff Out	-0.20	-0.22	-0.19	-0.18	-0.12	-0.12	-0.13	-0.12	-0.10	-0.11	-0.12	-0.14	-0.15
Inflow from Storage	-0.50	-2.91	8.66	39.92	28.04	2.55	3.02	-1.13	-6.30	-18.04	-19.21	-15.84	1.52

Table 16b – Difference in Monthly Surface Water Budget (Baseline - Phase 2C) in mm/month – Wetland NAT-04.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precip. added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater Recharge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff to Streams	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

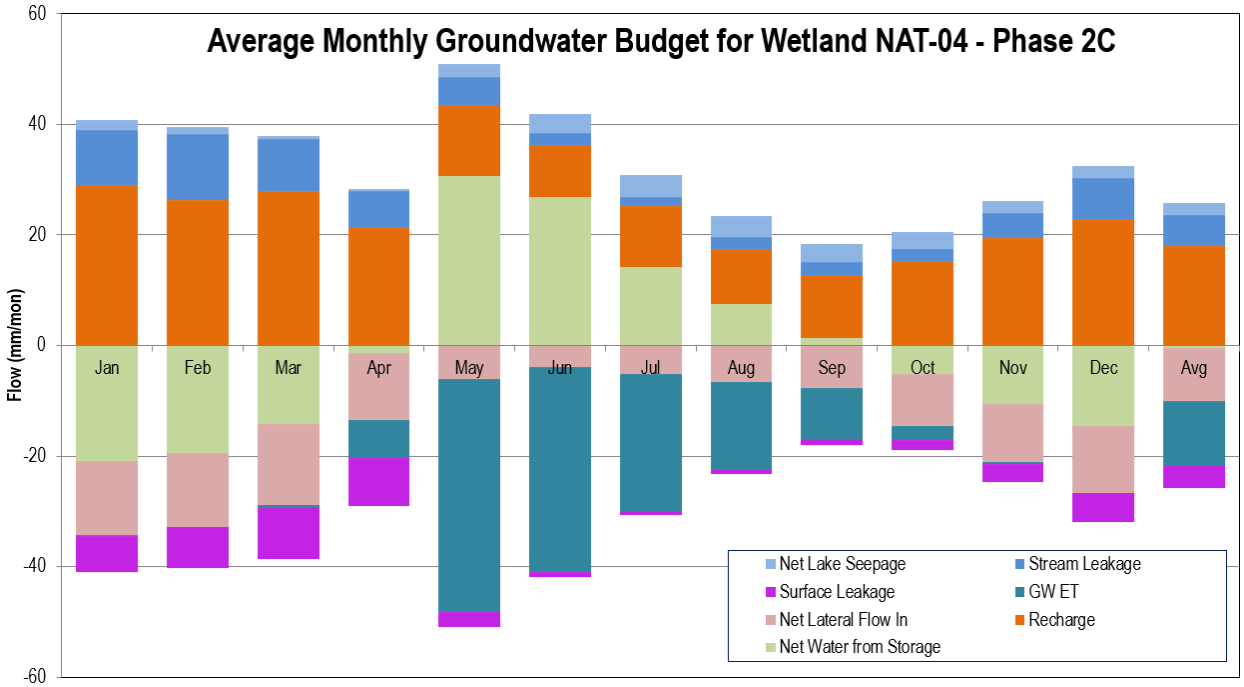


Table 16c – Monthly Groundwater Budget under Phase 2C Conditions (in mm/month) – Wetland NAT-04.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-20.86	-19.43	-14.22	-1.27	30.62	26.82	14.20	7.48	1.44	-5.12	-10.58	-14.59	-0.46
Recharge	28.97	26.37	27.91	21.42	12.81	9.42	11.01	10.02	11.30	15.28	19.37	22.93	18.07
Net Lateral Flow In	-13.47	-13.35	-14.61	-12.23	-6.06	-3.96	-5.14	-6.58	-7.70	-9.37	-10.49	-12.12	-9.59
GW ET	-0.06	-0.06	-0.38	-6.88	-42.10	-37.00	-24.75	-15.81	-9.29	-2.69	-0.45	-0.06	-11.63
Surface Leakage	-6.66	-7.37	-9.47	-8.66	-2.72	-1.00	-0.86	-0.88	-0.96	-1.69	-3.20	-5.08	-4.05
Stream Leakage	10.10	11.96	9.42	6.55	5.22	2.30	1.74	2.05	2.28	2.26	4.56	7.41	5.49
Net Lake Seepage	1.76	1.17	0.60	0.32	2.21	3.43	3.87	3.81	3.37	2.91	2.26	2.08	2.32

Table 16d – Difference in Monthly Groundwater Budget (Baseline - Phase 2C) in mm/month – Wetland NAT-04.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	-0.06	0.06	0.08	0.00	0.00	0.04	0.00	-0.01	-0.02	-0.07	-0.10	-0.06
Recharge	-0.02	-0.04	-0.06	-0.06	-0.06	0.00	0.00	0.00	0.00	0.00	-0.19	0.12
Net Lateral Flow In	0.01	0.04	0.07	0.10	0.14	0.13	0.11	0.08	0.07	0.04	0.02	0.02
GW ET	0.00	0.00	0.00	-0.03	-0.23	-0.25	-0.21	-0.15	-0.09	-0.02	0.00	0.00
Surface Leakage	-0.04	-0.03	-0.06	-0.04	-0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.03	-0.02
Stream Leakage	0.12	0.01	-0.02	0.04	0.12	0.09	0.10	0.08	0.05	0.07	0.14	0.09
Net Lake Seepage	0.02	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.03	0.04

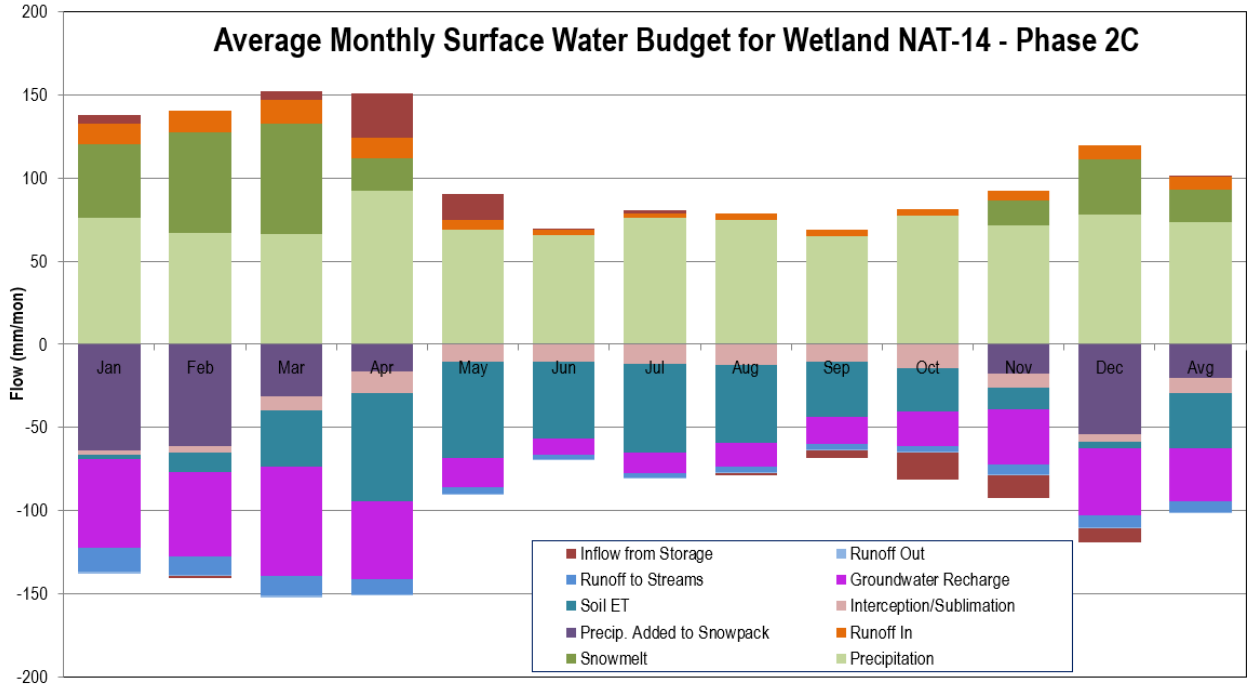


Table 17a – Monthly Surface Water Budget under Phase 2C Conditions (in mm/month) – Wetland NAT-14.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	75.92	66.77	66.36	92.13	69.05	65.58	75.80	75.01	65.16	77.60	71.24	77.90	73.21
Snowmelt	44.56	60.89	66.27	19.98	0.00	0.00	0.00	0.00	0.00	0.00	15.40	33.30	20.03
Runoff In	11.36	12.19	14.08	11.66	5.01	2.67	2.61	3.07	3.03	3.16	5.45	7.62	6.83
Precip. added to Snowpack	-63.63	-61.10	-31.19	-16.56	0.00	0.00	0.00	0.00	0.00	0.00	-17.58	-53.69	-20.31
Interception/Sublimation	-2.67	-3.86	-8.35	-12.62	-10.25	-10.46	-11.60	-12.50	-10.23	-14.30	-8.67	-4.65	-9.18
Soil ET	-2.82	-12.13	-34.26	-65.14	-57.89	-46.15	-53.07	-46.52	-33.52	-25.96	-12.57	-3.84	-32.82
Groundwater Recharge	-52.81	-50.15	-65.10	-46.35	-17.38	-9.91	-12.46	-14.10	-15.64	-20.75	-33.00	-40.49	-31.51
Runoff to Streams	-14.37	-10.68	-11.83	-8.89	-3.97	-2.27	-2.50	-3.17	-3.23	-3.30	-5.58	-6.87	-6.39
Runoff Out	-0.90	-0.95	-0.90	-0.84	-0.57	-0.49	-0.56	-0.56	-0.50	-0.56	-0.66	-0.71	-0.68
Inflow from Storage	5.35	-0.98	4.90	26.64	15.99	1.01	1.78	-1.23	-5.07	-15.90	-14.02	-8.57	0.83

Table 17b – Difference in Monthly Surface Water Budget (Baseline - Phase 2C) in mm/month – Wetland NAT-14.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precip. added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater Recharge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff to Streams	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

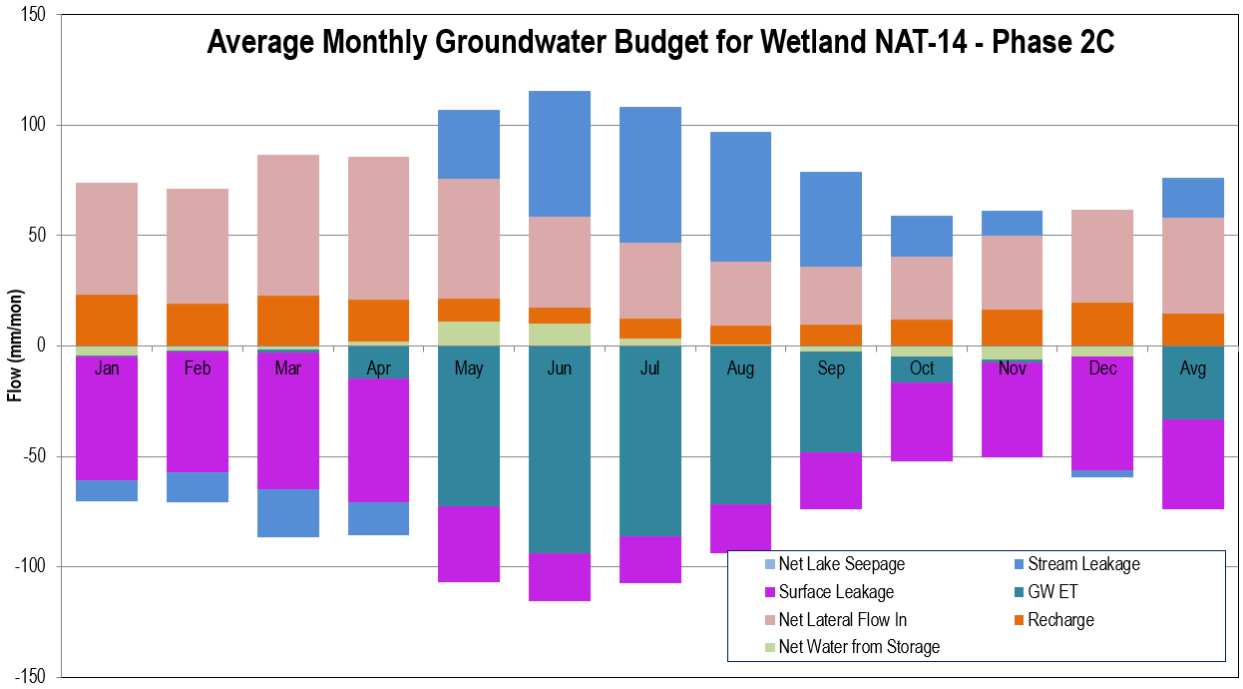


Table 17c – Monthly Groundwater Budget under Phase 2C Conditions (in mm/month) – Wetland NAT-14.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-4.33	-2.09	-1.44	2.18	11.29	10.15	3.22	0.82	-2.44	-4.93	-5.91	-4.66	0.16
Recharge	23.32	19.05	23.06	18.65	10.23	7.20	9.17	8.65	9.71	11.87	16.46	19.47	14.74
Net Lateral Flow In	50.55	52.21	63.44	64.87	54.31	41.12	34.21	28.78	26.03	28.60	33.56	42.14	43.32
GW ET	-0.24	-0.27	-1.41	-14.74	-72.73	-93.69	-86.20	-71.80	-45.58	-11.66	-1.72	-0.26	-33.36
Surface Leakage	-56.46	-54.92	-62.03	-55.95	-34.39	-22.08	-21.12	-22.04	-26.15	-35.87	-42.81	-51.19	-40.42
Stream Leakage	-9.22	-13.66	-21.93	-15.24	31.27	57.30	61.87	58.61	43.00	18.60	11.20	-3.29	18.21
Net Lake Seepage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 17d – Difference in Monthly Groundwater Budget (Baseline - Phase 2C) in mm/month – Wetland NAT-14.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	0.05	0.06	0.02	-0.01	0.00	0.02	0.02	-0.06	-0.02	-0.03	-0.06	0.00
Recharge	-0.07	-0.05	-0.07	-0.05	-0.09	-0.02	-0.02	0.01	-0.03	-0.04	-0.03	-0.12
Net Lateral Flow In	0.57	0.54	0.53	0.46	0.49	0.56	0.66	0.67	0.80	0.72	0.73	0.74
GW ET	0.00	0.00	0.00	-0.01	-0.09	-0.11	-0.10	-0.12	-0.09	-0.02	0.00	0.00
Surface Leakage	-0.44	-0.31	-0.29	-0.26	-0.18	-0.11	-0.09	-0.14	-0.12	-0.23	-0.33	-0.40
Stream Leakage	0.03	-0.22	-0.18	-0.13	-0.21	-0.36	-0.38	-0.28	1.27	-0.25	0.41	0.17
Net Lake Seepage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

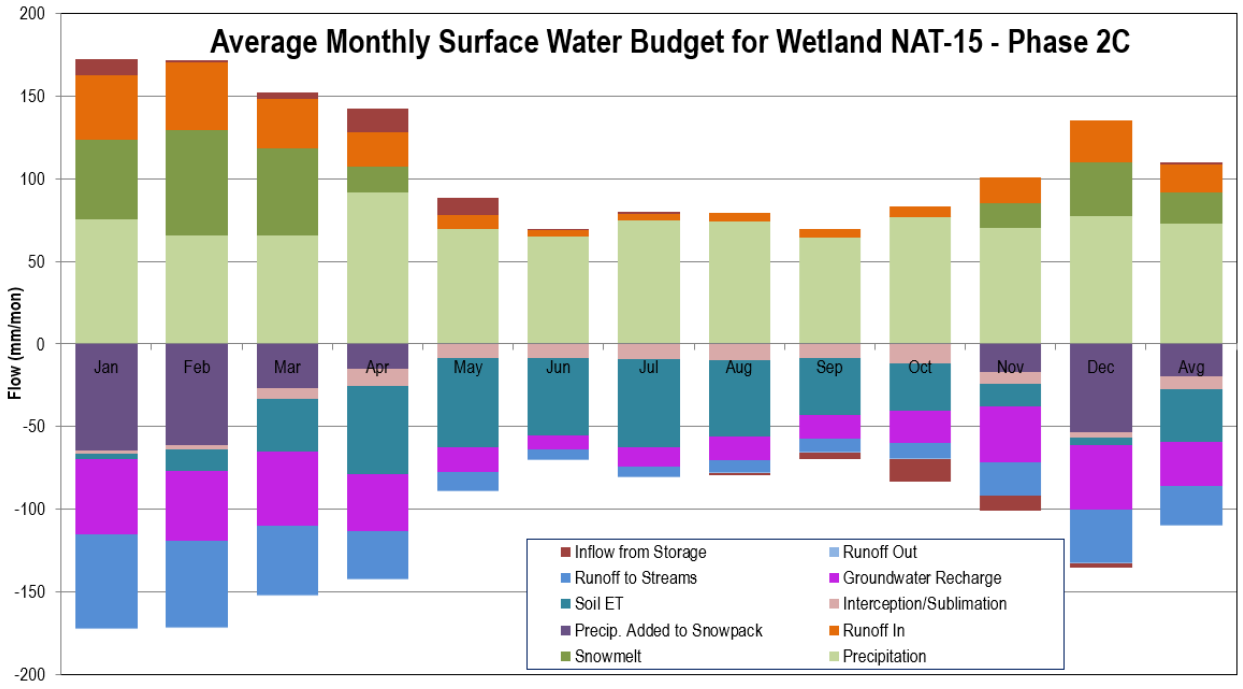


Table 18a – Monthly Surface Water Budget under Phase 2C Conditions (in mm/month) – Wetland NAT-15.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	75.13	65.93	65.60	91.46	69.58	65.04	74.79	74.34	64.15	76.79	70.33	77.17	72.53
Snowmelt	48.42	63.72	53.00	15.82	0.00	0.00	0.00	0.00	0.00	0.00	15.09	32.70	19.06
Runoff In	38.72	40.71	29.93	21.03	8.28	3.91	3.96	4.85	5.20	6.64	15.28	25.49	17.00
Precip. added to Snowpack	-64.53	-61.19	-26.60	-14.87	0.00	0.00	0.00	0.00	0.00	0.00	-16.90	-53.14	-19.77
Interception/Sublimation	-1.81	-2.42	-6.35	-10.23	-8.45	-8.56	-9.39	-10.10	-8.29	-11.96	-7.18	-3.63	-7.36
Soil ET	-3.52	-12.99	-32.07	-53.76	-53.70	-46.48	-52.94	-46.17	-34.65	-28.19	-13.96	-4.72	-31.93
Groundwater Recharge	-45.39	-42.54	-45.21	-34.59	-15.12	-8.96	-11.63	-14.10	-14.43	-19.50	-33.24	-38.62	-26.94
Runoff to Streams	-56.15	-51.62	-41.08	-28.37	-11.05	-5.59	-6.06	-7.32	-7.89	-9.47	-20.14	-31.75	-23.04
Runoff Out	-1.02	-1.03	-0.99	-0.69	-0.32	-0.15	-0.15	-0.21	-0.22	-0.22	-0.53	-0.80	-0.53
Inflow from Storage	10.14	1.43	3.77	14.19	10.77	0.80	1.43	-1.29	-3.88	-14.09	-8.74	-2.70	0.98

Table 18b – Difference in Monthly Surface Water Budget (Baseline - Phase 2C) in mm/month – Wetland NAT-15.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precip. added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater Recharge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff to Streams	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

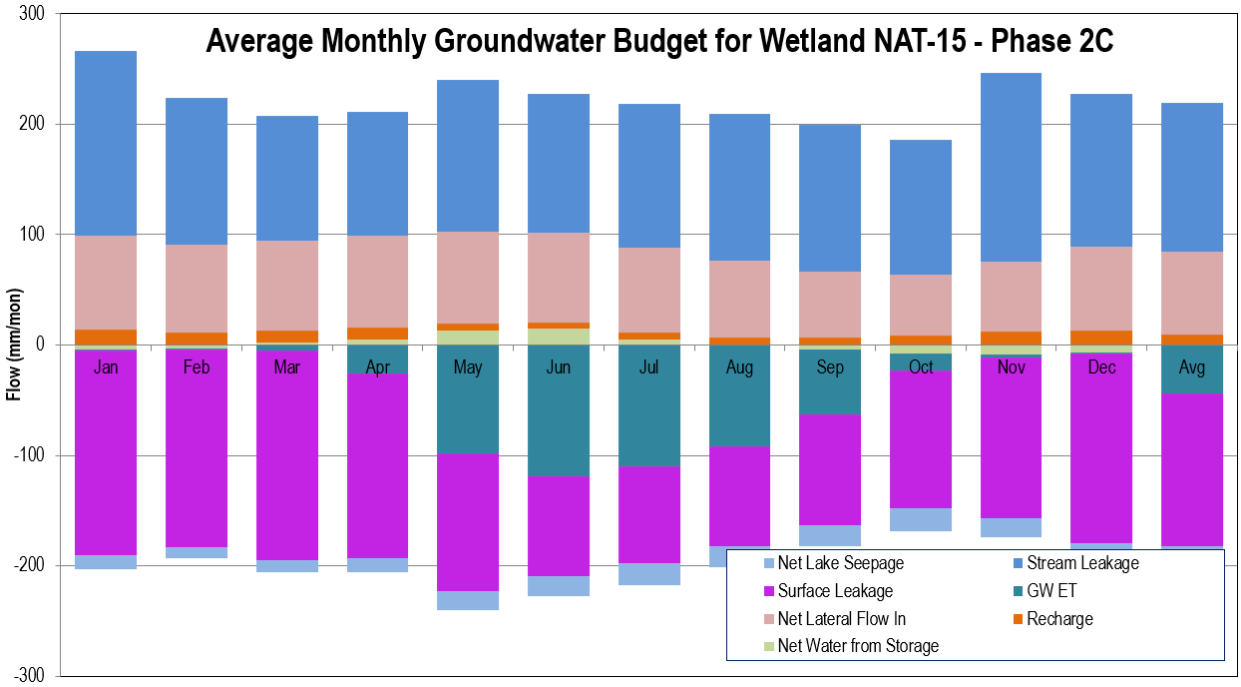


Table 18c – Monthly Groundwater Budget under Phase 2C Conditions (in mm/month) – Wetland NAT-15.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-4.17	-2.80	2.13	5.35	13.18	15.27	4.88	0.81	-4.28	-7.56	-8.96	-7.13	0.56
Recharge	13.88	11.55	10.66	10.55	6.35	4.96	6.74	6.15	6.92	8.42	11.84	13.29	9.28
Net Lateral Flow In	85.41	78.99	81.92	83.61	83.31	81.62	76.45	69.55	59.19	54.98	63.47	75.96	74.54
GW ET	-0.76	-1.04	-4.61	-25.41	-98.28	-118.9	-109.7	-92.17	-58.89	-15.53	-2.58	-0.79	-44.05
Surface Leakage	-185.7	-179.5	-190.7	-168.1	-125.0	-90.39	-88.11	-90.16	-100.2	-125.0	-145.6	-172.1	-138.4
Stream Leakage	167.3	133.8	113.0	111.9	137.1	125.6	130.3	132.8	133.1	122.8	171.5	138.0	134.8
Net Lake Seepage	-12.05	-10.21	-10.90	-12.74	-16.54	-18.09	-19.47	-19.04	-18.57	-20.94	-16.97	-14.27	-15.82

Table 18d – Difference in Monthly Groundwater Budget (Baseline - Phase 2C) in mm/month – Wetland NAT-15.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	-0.02	0.00	0.04	0.04	0.10	0.13	0.15	0.00	-0.01	-0.02	-0.05	-0.02
Recharge	0.01	0.02	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02
Net Lateral Flow In	-1.15	-0.86	-1.21	-1.29	-1.25	-0.95	-0.69	-0.92	-0.91	-1.18	-1.73	-1.40
GW ET	0.00	0.00	0.00	0.01	0.11	0.27	0.39	0.24	0.14	0.03	0.00	0.00
Surface Leakage	0.40	0.41	0.51	0.44	0.59	0.94	1.21	1.25	0.98	0.85	0.61	0.56
Stream Leakage	0.79	0.79	2.75	0.59	1.28	-0.08	-0.67	-0.31	0.23	1.02	1.16	1.14
Net Lake Seepage	-0.64	-0.25	-0.33	-0.42	-0.61	-0.29	-0.07	-0.25	-0.51	-0.59	-0.73	-0.64

9.4 *Phase 4*

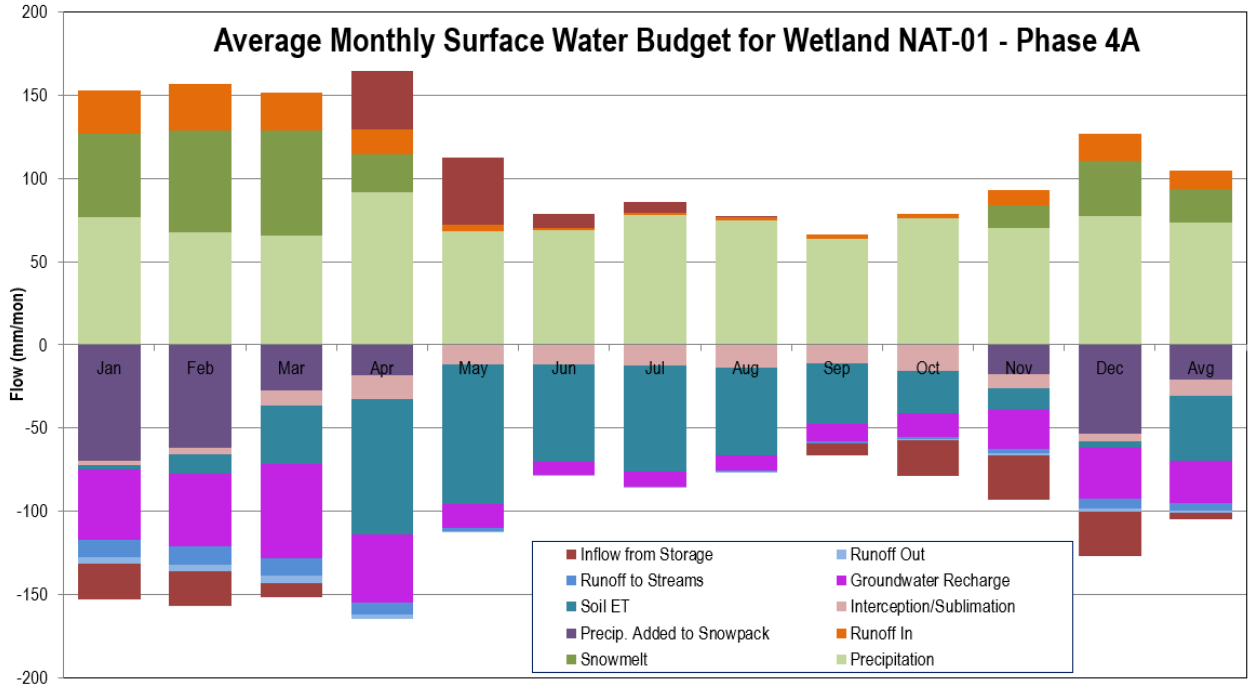


Table 19a – Monthly Surface Water Budget under Phase 4A Conditions (in mm/month) – Wetland NAT-01.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	76.56	67.29	65.88	91.50	67.99	69.09	78.19	74.90	63.93	76.07	70.01	77.42	73.24
Snowmelt	49.93	61.44	62.98	23.01	0.12	0.00	0.00	0.00	0.00	0.00	14.07	33.02	20.38
Runoff In	26.29	28.00	22.85	14.75	4.12	1.08	1.01	1.54	2.56	2.72	8.66	16.60	10.85
Precip. added to Snowpack	-69.52	-61.54	-27.31	-18.57	-0.12	0.00	0.00	0.00	0.00	0.00	-17.40	-53.05	-20.63
Interception/Sublimation	-2.57	-3.99	-9.15	-13.83	-11.52	-11.96	-12.60	-13.61	-11.32	-15.33	-8.92	-4.70	-9.96
Soil ET	-2.87	-11.98	-35.13	-81.73	-84.27	-58.61	-63.41	-52.74	-36.24	-25.66	-12.57	-3.79	-39.08
Groundwater Recharge	-42.09	-43.30	-56.31	-40.99	-14.14	-7.30	-9.11	-9.36	-10.14	-14.64	-23.68	-31.10	-25.18
Runoff to Streams	-10.66	-11.33	-10.76	-6.81	-1.52	-0.32	-0.36	-0.63	-1.26	-1.00	-2.73	-5.55	-4.41
Runoff Out	-3.79	-4.00	-4.24	-2.80	-0.74	-0.24	-0.28	-0.35	-0.51	-0.50	-1.28	-2.25	-1.75
Inflow from Storage	-21.27	-20.59	-8.80	35.47	40.09	8.26	6.56	0.26	-7.03	-21.65	-26.16	-26.61	-3.46

Table 19b – Difference in Monthly Surface Water Budget (Baseline - Phase 4A) in mm/month – Wetland NAT-01.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precip. added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater Recharge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff to Streams	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

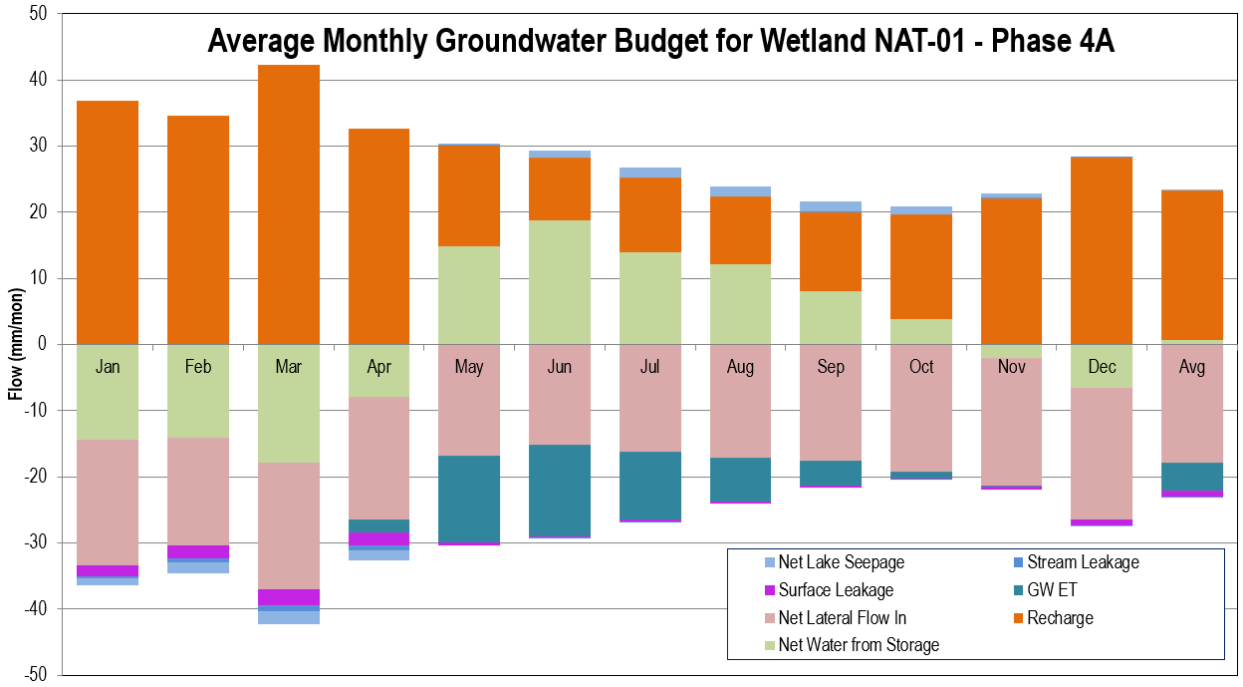


Table 19c – Monthly Groundwater Budget under Phase 4A Conditions (in mm/month) – Wetland NAT-01.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-14.35	-14.13	-17.87	-7.97	14.82	18.77	14.01	12.14	8.10	3.88	-2.01	-6.49	0.74
Recharge	36.90	34.61	42.36	32.61	15.28	9.46	11.28	10.27	11.91	15.75	22.05	28.30	22.56
Net Lateral Flow In	-19.06	-16.27	-19.09	-18.46	-16.75	-15.21	-16.21	-17.07	-17.59	-19.21	-19.36	-19.91	-17.85
GW ET	0.00	-0.01	-0.05	-1.98	-13.16	-13.86	-10.31	-6.75	-3.81	-1.01	-0.11	0.00	-4.25
Surface Leakage	-1.63	-1.95	-2.43	-2.00	-0.44	-0.18	-0.18	-0.18	-0.18	-0.20	-0.45	-1.03	-0.90
Stream Leakage	-0.26	-0.59	-0.88	-0.75	0.15	-0.04	-0.03	0.02	0.19	0.09	0.22	0.07	-0.15
Net Lake Seepage	-1.10	-1.60	-2.00	-1.46	0.11	1.08	1.43	1.53	1.37	1.19	0.59	-0.09	0.09

Table 19d – Difference in Monthly Groundwater Budget (Baseline - Phase 4A) in mm/month – Wetland NAT-01.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	-0.31	-0.06	0.42	0.49	1.35	0.76	-0.35	-1.08	-1.23	-1.23	-0.96	-0.70
Recharge	0.01	0.00	-0.09	-0.12	-0.07	-0.05	0.00	0.00	0.00	0.00	0.01	0.00
Net Lateral Flow In	1.00	1.11	1.06	1.05	1.54	1.53	1.28	0.95	0.69	0.61	0.62	0.79
GW ET	0.00	0.00	0.00	-0.30	-2.77	-2.87	-1.76	-0.74	-0.23	-0.04	0.00	0.00
Surface Leakage	0.00	-0.02	-0.06	-0.09	-0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Stream Leakage	0.00	0.03	-0.03	-0.06	-0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Net Lake Seepage	-0.67	-0.98	-1.31	-1.02	-0.03	0.59	0.82	0.88	0.78	0.65	0.30	-0.11

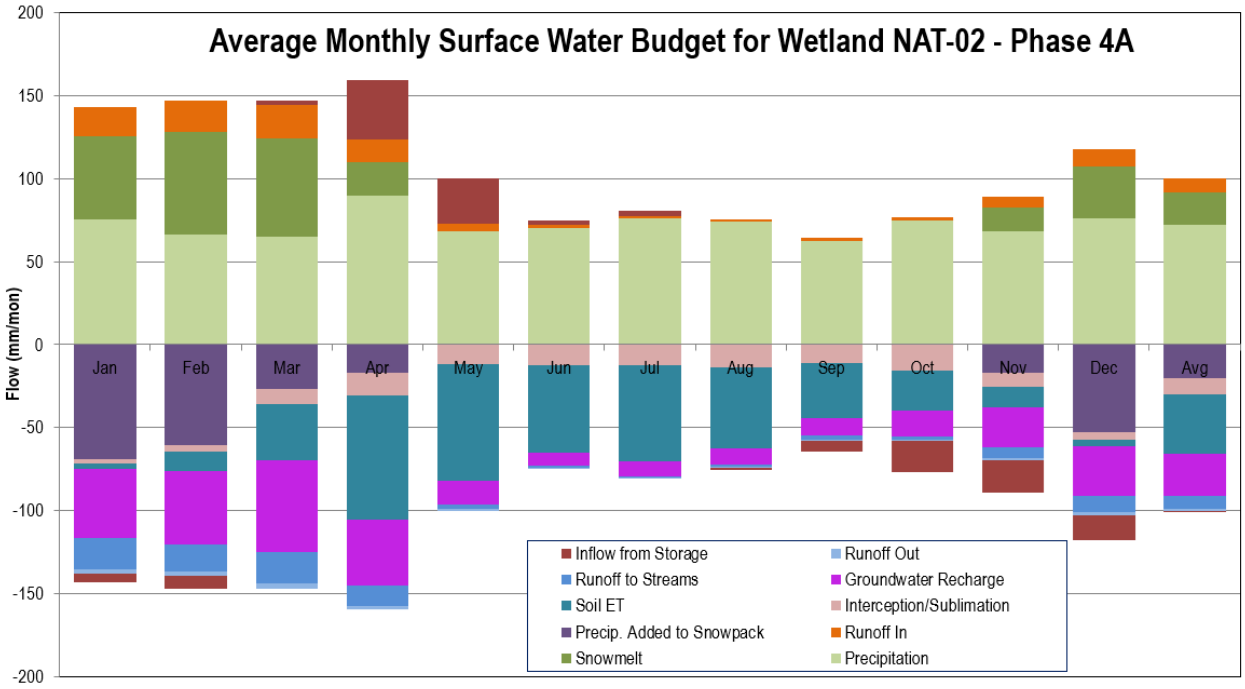


Table 20a – Monthly Surface Water Budget under Phase 4A Conditions (in mm/month) – Wetland NAT-02.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	75.14	66.03	64.85	90.01	68.18	70.44	76.23	73.87	62.18	74.47	68.21	75.79	72.12
Snowmelt	50.18	61.72	59.06	19.79	0.00	0.00	0.00	0.00	0.00	0.00	14.59	31.73	19.76
Runoff In	17.81	19.34	20.25	13.97	4.35	1.68	1.25	1.68	2.28	2.15	6.02	10.14	8.41
Precip. added to Snowpack	-69.20	-60.51	-26.68	-16.70	0.00	0.00	0.00	0.00	0.00	-0.01	-16.78	-52.65	-20.21
Interception/Sublimation	-2.20	-3.59	-9.01	-13.99	-11.65	-12.16	-12.47	-13.41	-11.13	-15.48	-8.86	-4.40	-9.86
Soil ET	-3.19	-12.28	-34.22	-74.73	-70.61	-53.19	-57.82	-48.85	-33.39	-24.30	-12.05	-4.00	-35.72
Groundwater Recharge	-41.81	-43.66	-54.80	-39.89	-13.82	-7.62	-9.00	-9.74	-10.28	-15.29	-24.05	-29.75	-24.98
Runoff to Streams	-18.72	-16.65	-18.84	-11.95	-2.93	-1.02	-0.98	-1.57	-2.37	-2.26	-6.77	-10.19	-7.86
Runoff Out	-2.63	-2.77	-3.22	-2.33	-0.89	-0.57	-0.56	-0.60	-0.60	-0.64	-1.13	-1.66	-1.47
Inflow from Storage	-5.37	-7.62	2.61	35.82	27.37	2.45	3.35	-1.37	-6.70	-18.65	-19.17	-15.01	-0.19

Table 20b – Difference in Monthly Surface Water Budget (Baseline - Phase 4A) in mm/month – Wetland NAT-02.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	-0.53	-0.61	-0.33	-0.40	-0.16	-0.13	-0.18	-0.26	-0.28	-0.16	-0.20	-0.23
Precip. added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.00	0.00	0.02	0.03	0.05	0.04	0.04	0.01	0.00	0.00
Groundwater Recharge	0.33	0.29	0.19	0.22	0.08	0.04	0.06	0.08	0.08	0.06	0.17	0.19
Runoff to Streams	0.25	0.33	0.14	0.19	0.07	0.04	0.08	0.13	0.18	0.03	0.04	0.07
Runoff Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

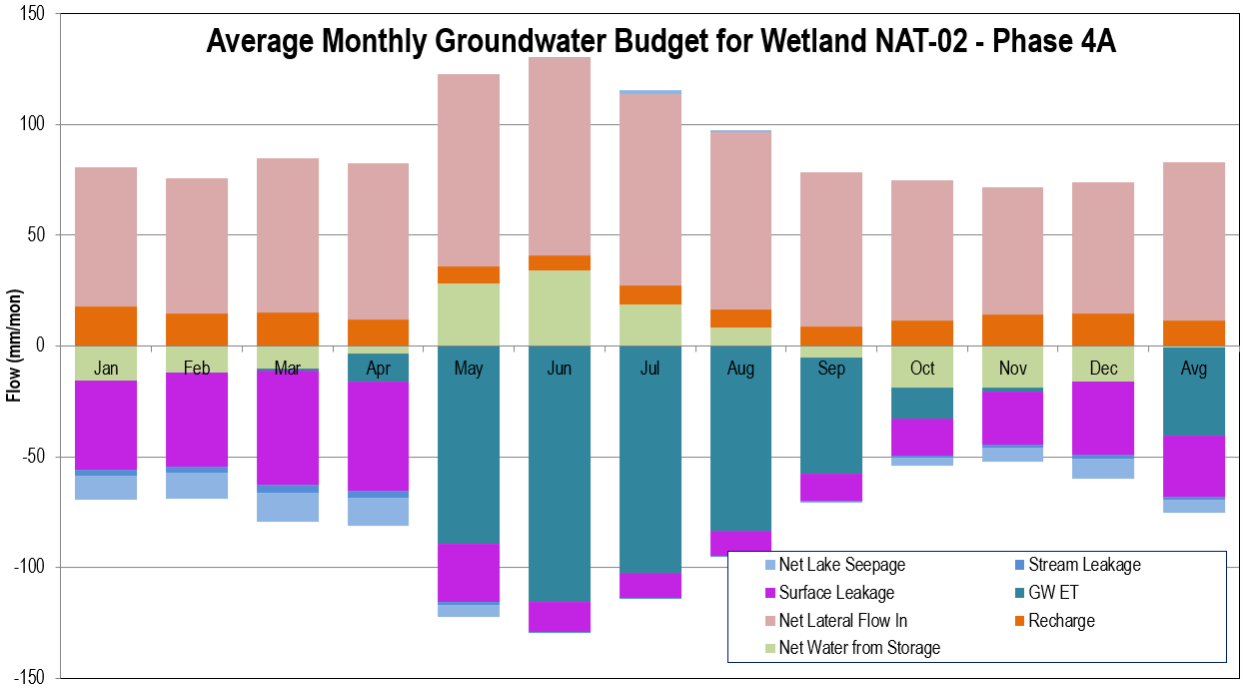


Table 20c – Monthly Groundwater Budget under Phase 4A Conditions (in mm/month) – Wetland NAT-02.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-15.42	-11.99	-10.01	-3.58	28.07	34.34	18.98	8.50	-5.09	-18.73	-18.68	-15.84	-0.79
Recharge	17.65	14.76	15.15	11.78	7.69	6.77	8.47	7.93	8.95	11.52	14.36	14.70	11.64
Net Lateral Flow In	62.87	61.08	69.84	70.92	87.03	88.74	86.55	79.95	69.48	63.49	57.43	59.46	71.40
GW ET	-0.18	-0.19	-1.07	-12.59	-89.38	-115.52	-102.63	-83.62	-52.50	-13.88	-2.03	-0.20	-39.48
Surface Leakage	-40.42	-42.42	-51.60	-49.19	-26.37	-13.85	-11.35	-11.10	-12.48	-17.10	-23.79	-33.16	-27.74
Stream Leakage	-2.55	-2.78	-3.38	-3.21	-1.34	-0.31	-0.20	0.00	-0.19	-0.67	-1.21	-1.91	-1.48
Net Lake Seepage	-11.01	-11.40	-13.45	-12.45	-5.42	0.10	1.39	1.09	-0.75	-3.87	-6.46	-8.89	-5.93

Table 20d – Difference in Monthly Groundwater Budget (Baseline - Phase 4A) in mm/month – Wetland NAT-02.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	5.43	4.49	4.24	2.58	-6.05	-10.12	-7.16	-4.23	0.17	4.17	5.27	5.37
Recharge	-0.29	-0.79	-0.35	-0.30	0.26	0.30	0.27	0.25	0.30	0.37	0.30	-0.02
Net Lateral Flow In	-1.06	0.28	0.38	-0.50	-5.04	-9.48	-12.01	-12.57	-11.44	-10.14	-6.79	-4.49
GW ET	0.00	0.00	-0.01	-0.05	5.83	13.16	13.03	11.39	6.05	1.01	0.08	0.00
Surface Leakage	0.48	-1.10	-2.70	-2.09	1.71	2.03	1.84	1.83	2.07	2.38	2.44	1.72
Stream Leakage	0.94	0.64	0.46	0.38	0.63	0.61	0.58	0.56	0.51	0.87	1.02	1.04
Net Lake Seepage	0.21	-0.19	-0.20	0.29	2.75	3.57	3.27	2.73	1.93	1.31	0.93	0.70

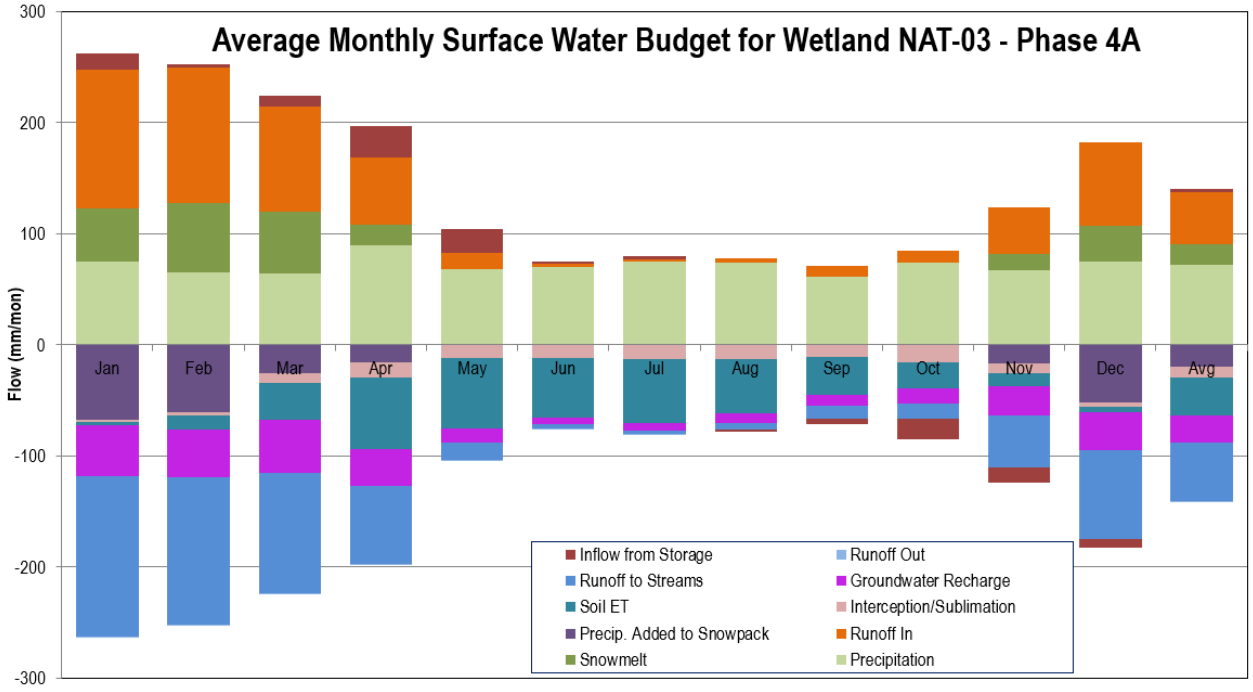


Table 21a – Monthly Surface Water Budget under Phase 4A Conditions (in mm/month) – Wetland NAT-03.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	74.66	65.43	64.44	89.68	68.61	70.57	75.15	73.73	61.69	73.90	67.57	75.24	71.72
Snowmelt	47.92	62.01	55.70	18.16	0.00	0.00	0.00	0.00	0.00	0.01	14.51	31.61	19.16
Runoff In	125.4	121.9	94.07	60.85	14.50	2.97	2.12	4.34	9.88	11.24	41.66	75.55	47.04
Precip. added to Snowpack	-67.02	-60.47	-25.60	-16.06	0.00	0.00	0.00	0.00	0.00	-0.01	-16.57	-51.78	-19.79
Interception/Sublimation	-1.91	-3.12	-8.58	-13.71	-11.49	-11.92	-12.28	-13.17	-10.93	-15.37	-8.74	-4.19	-9.62
Soil ET	-3.48	-12.63	-32.71	-63.57	-63.97	-53.11	-57.76	-48.79	-34.07	-23.56	-11.99	-4.18	-34.15
Groundwater Recharge	-45.31	-42.82	-48.71	-33.31	-11.91	-6.44	-7.37	-8.41	-9.40	-14.15	-26.21	-34.65	-24.06
Runoff to Streams	-144.6	-132.9	-107.9	-70.01	-16.47	-3.51	-2.90	-5.85	-12.10	-13.49	-46.88	-79.94	-53.04
Runoff Out	-0.43	-0.40	-0.51	-0.35	-0.09	-0.03	-0.03	-0.04	-0.06	-0.06	-0.20	-0.33	-0.21
Inflow from Storage	14.78	3.05	9.76	28.32	20.82	1.47	3.06	-1.80	-5.00	-18.51	-13.15	-7.33	2.96

Table 21b – Difference in Monthly Surface Water Budget (Baseline - Phase 4A) in mm/month – Wetland NAT-03.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precip. added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater Recharge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff to Streams	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

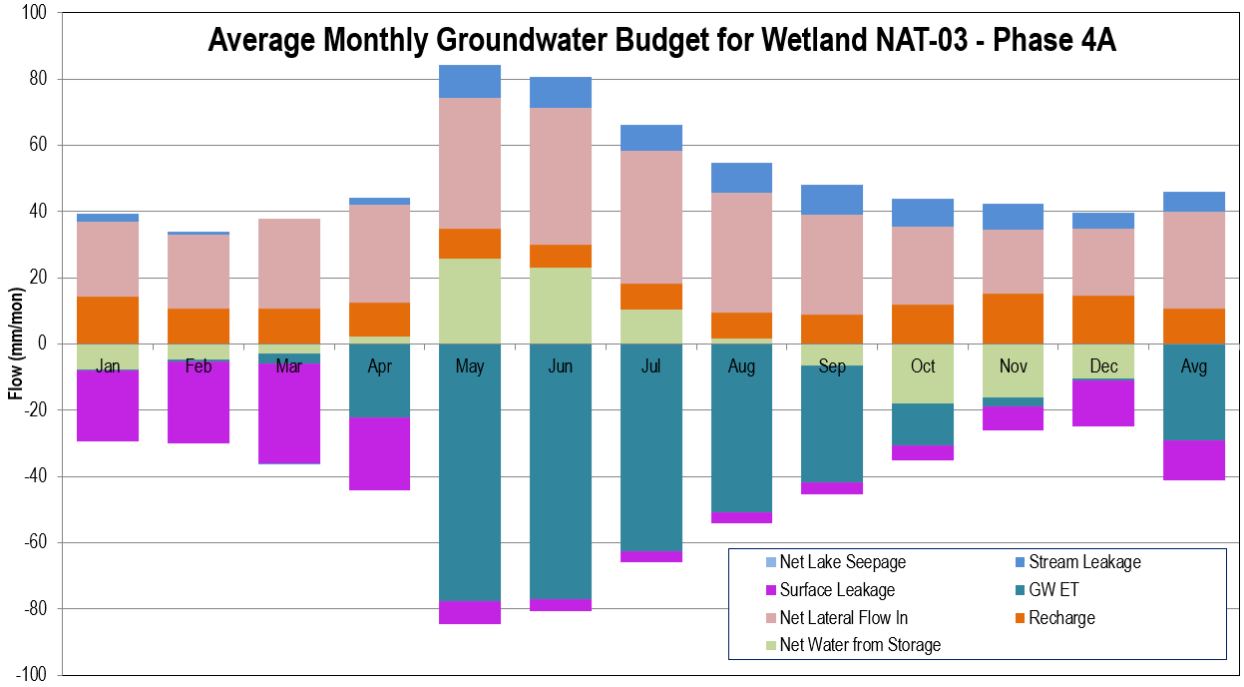


Table 21c – Monthly Groundwater Budget under Phase 4A Conditions (in mm/month) – Wetland NAT-03.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-7.57	-4.55	-2.81	2.12	25.65	23.05	10.29	1.60	-6.48	-18.09	-16.19	-10.29	-0.27
Recharge	14.38	10.79	10.85	10.53	9.15	6.96	7.94	7.90	8.95	11.81	15.25	14.49	10.75
Net Lateral Flow In	22.42	22.27	27.07	29.57	39.57	41.22	40.26	36.08	30.04	23.50	19.30	20.40	29.31
GW ET	-0.53	-0.63	-3.21	-22.15	-77.77	-77.00	-62.50	-50.81	-35.17	-12.50	-2.59	-0.58	-28.79
Surface Leakage	-21.16	-24.69	-30.10	-22.06	-6.69	-3.64	-3.45	-3.47	-3.66	-4.47	-7.36	-14.00	-12.06
Stream Leakage	2.70	0.81	-0.04	2.02	10.06	9.46	7.57	9.02	9.06	8.50	7.81	4.78	5.98
Net Lake Seepage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 21d – Difference in Monthly Groundwater Budget (Baseline - Phase 4A) in mm/month – Wetland NAT-03.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	0.59	0.61	0.51	0.02	-0.97	-1.05	-0.46	-0.17	0.11	0.23	0.31	0.63
Recharge	-0.13	-0.41	-0.49	-0.21	-0.02	-0.02	-0.01	0.03	0.01	0.06	0.08	-0.03
Net Lateral Flow In	0.62	0.94	1.23	0.95	-0.01	-0.76	-0.98	-0.90	-0.63	-0.30	0.00	0.05
GW ET	0.00	0.00	-0.01	-0.05	1.42	2.75	2.95	2.58	1.51	0.29	0.02	0.00
Surface Leakage	-0.24	-0.41	-0.80	-0.57	0.01	0.00	-0.03	-0.03	0.01	0.03	0.01	-0.05
Stream Leakage	0.12	0.05	0.02	0.05	-0.38	-0.84	-1.39	-1.47	-0.88	-0.18	0.52	0.94
Net Lake Seepage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

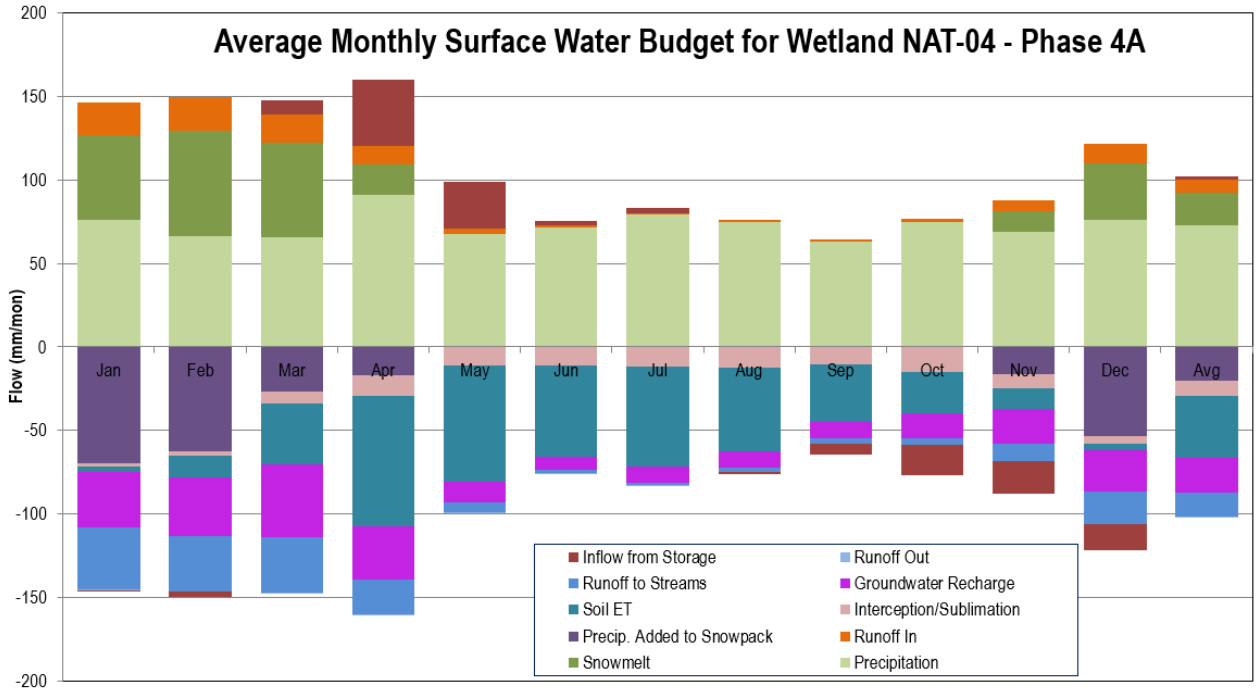


Table 22a – Monthly Surface Water Budget under Phase 4A Conditions (in mm/month) – Wetland NAT-04.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	75.88	66.60	65.32	90.72	67.38	71.74	79.00	74.79	62.71	74.78	68.62	76.26	72.82
Snowmelt	50.92	62.52	57.11	18.58	0.09	0.00	0.00	0.00	0.00	0.00	12.94	33.46	19.64
Runoff In	19.24	20.27	16.37	10.92	3.28	1.09	0.92	1.20	1.80	1.96	6.01	11.98	7.92
Precip. added to Snowpack	-69.72	-62.18	-26.40	-16.74	-0.09	0.00	0.00	0.00	0.00	-0.01	-16.18	-53.68	-20.42
Interception/Sublimation	-1.74	-2.57	-7.74	-12.78	-10.83	-11.18	-11.71	-12.55	-10.58	-14.68	-8.47	-3.91	-9.06
Soil ET	-3.65	-13.31	-35.97	-78.03	-69.64	-54.29	-59.81	-50.17	-34.07	-25.15	-12.54	-4.52	-36.76
Groundwater Recharge	-33.04	-35.14	-43.56	-31.54	-12.29	-7.86	-9.60	-9.73	-9.94	-14.97	-20.57	-24.46	-21.06
Runoff to Streams	-37.19	-33.05	-33.58	-20.87	-5.82	-1.93	-1.68	-2.28	-3.53	-3.79	-10.47	-19.14	-14.45
Runoff Out	-0.20	-0.22	-0.19	-0.18	-0.12	-0.12	-0.13	-0.12	-0.10	-0.11	-0.12	-0.14	-0.15
Inflow from Storage	-0.50	-2.91	8.66	39.92	28.04	2.55	3.02	-1.13	-6.30	-18.04	-19.21	-15.84	1.52

Table 22b – Difference in Monthly Surface Water Budget (Baseline - Phase 4A) in mm/month – Wetland NAT-04.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precip. added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater Recharge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff to Streams	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

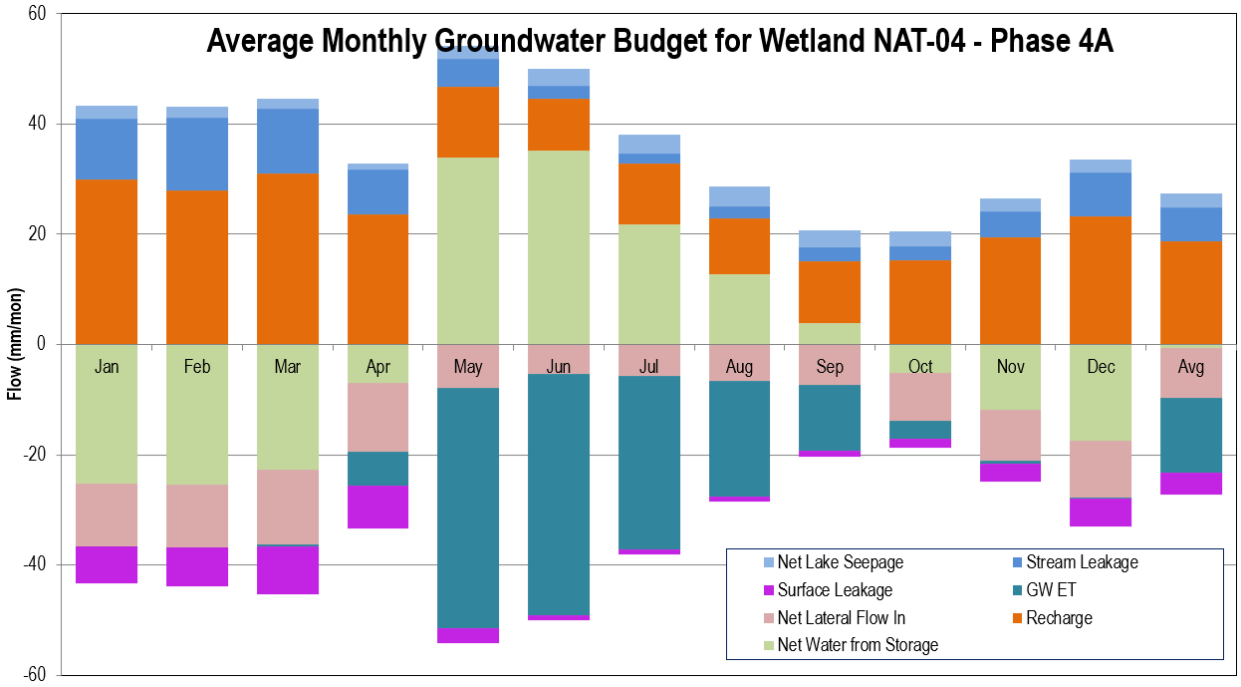


Table 22c – Monthly Groundwater Budget under Phase 4A Conditions (in mm/month) – Wetland NAT-04.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-25.29	-25.34	-22.79	-7.05	33.94	35.17	21.79	12.80	3.85	-5.08	-11.87	-17.41	-0.61
Recharge	29.97	28.02	31.08	23.70	12.92	9.42	11.01	10.02	11.30	15.27	19.36	23.22	18.78
Net Lateral Flow In	-11.34	-11.47	-13.47	-12.40	-7.82	-5.41	-5.76	-6.56	-7.36	-8.68	-9.24	-10.42	-9.16
GW ET	-0.06	-0.06	-0.35	-6.23	-43.73	-43.68	-31.51	-21.06	-11.96	-3.30	-0.51	-0.06	-13.54
Surface Leakage	-6.60	-7.06	-8.67	-7.79	-2.62	-0.99	-0.85	-0.86	-0.96	-1.72	-3.33	-5.18	-3.89
Stream Leakage	10.95	13.17	11.79	8.01	4.98	2.38	1.83	2.27	2.47	2.47	4.75	8.04	6.09
Net Lake Seepage	2.35	2.05	1.67	1.20	2.30	3.11	3.52	3.51	3.19	2.84	2.39	2.39	2.54

Table 22d – Difference in Monthly Groundwater Budget (Baseline - Phase 4A) in mm/month – Wetland NAT-04.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	4.36	5.97	8.66	5.77	-3.31	-8.30	-7.60	-5.32	-2.43	-0.10	1.19	2.76
Recharge	-1.03	-1.69	-3.24	-2.33	-0.17	0.00	0.00	0.00	0.00	0.01	-0.18	-0.17
Net Lateral Flow In	-2.12	-1.83	-1.07	0.27	1.90	1.57	0.72	0.06	-0.28	-0.65	-1.23	-1.69
GW ET	0.00	0.00	-0.03	-0.69	1.40	6.43	6.55	5.10	2.59	0.59	0.05	0.00
Surface Leakage	-0.09	-0.35	-0.86	-0.91	-0.12	-0.02	-0.02	-0.02	-0.01	0.01	0.10	0.07
Stream Leakage	-0.73	-1.19	-2.39	-1.42	0.35	0.01	0.00	-0.14	-0.13	-0.14	-0.05	-0.54
Net Lake Seepage	-0.57	-0.87	-1.06	-0.88	-0.09	0.33	0.36	0.30	0.20	0.09	-0.09	-0.27

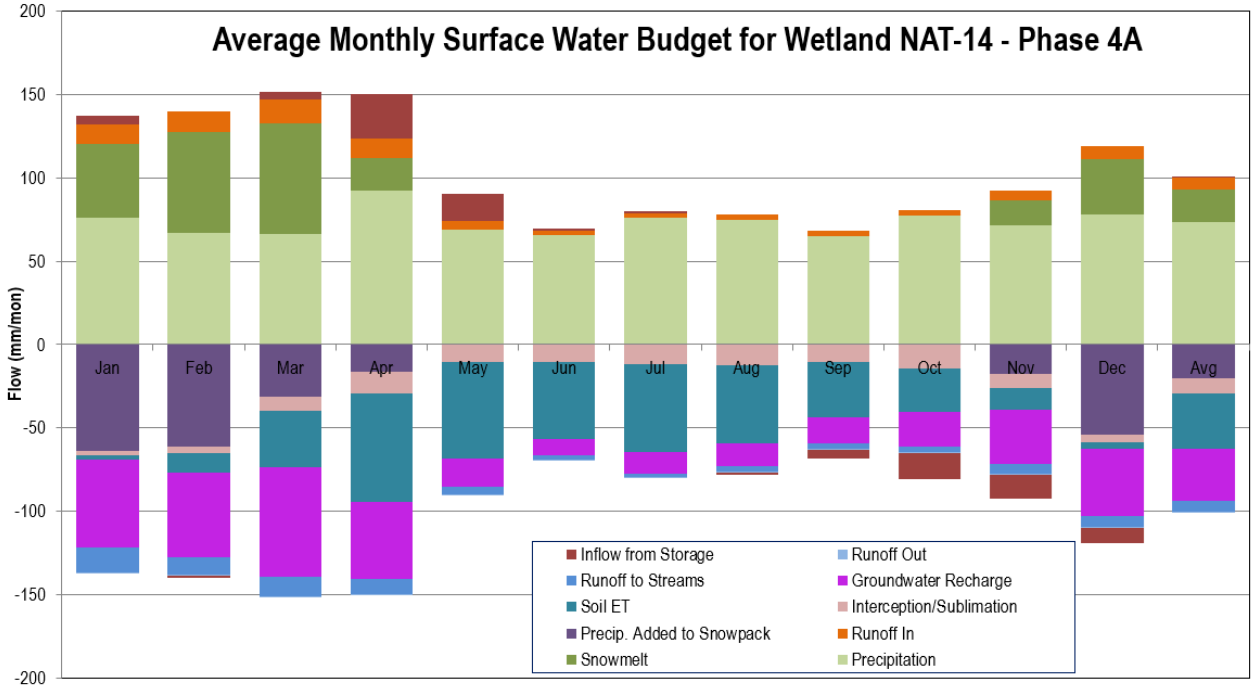


Table 23a – Monthly Surface Water Budget under Phase 4A Conditions (in mm/month) – Wetland NAT-14.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	75.92	66.77	66.36	92.13	69.05	65.58	75.80	75.01	65.16	77.60	71.24	77.90	73.21
Snowmelt	44.56	60.89	66.27	19.98	0.00	0.00	0.00	0.00	0.00	0.00	15.40	33.30	20.03
Runoff In	11.36	12.19	14.08	11.66	5.01	2.67	2.61	3.07	3.03	3.16	5.45	7.62	6.83
Precip. added to Snowpack	-63.63	-61.10	-31.19	-16.56	0.00	0.00	0.00	0.00	0.00	0.00	-17.58	-53.69	-20.31
Interception/Sublimation	-2.67	-3.86	-8.35	-12.62	-10.25	-10.46	-11.60	-12.50	-10.23	-14.30	-8.67	-4.65	-9.18
Soil ET	-2.82	-12.13	-34.26	-65.14	-57.89	-46.15	-53.07	-46.52	-33.52	-25.96	-12.57	-3.84	-32.82
Groundwater Recharge	-52.81	-50.15	-65.10	-46.35	-17.38	-9.91	-12.46	-14.10	-15.64	-20.75	-33.00	-40.49	-31.51
Runoff to Streams	-14.37	-10.68	-11.83	-8.89	-3.97	-2.27	-2.50	-3.17	-3.23	-3.30	-5.58	-6.87	-6.39
Runoff Out	-0.90	-0.95	-0.90	-0.84	-0.57	-0.49	-0.56	-0.56	-0.50	-0.56	-0.66	-0.71	-0.68
Inflow from Storage	5.35	-0.98	4.90	26.64	15.99	1.01	1.78	-1.23	-5.07	-15.90	-14.02	-8.57	0.83

Table 23b – Difference in Monthly Surface Water Budget (Baseline - Phase 4A) in mm/month – Wetland NAT-14.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precip. added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater Recharge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff to Streams	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

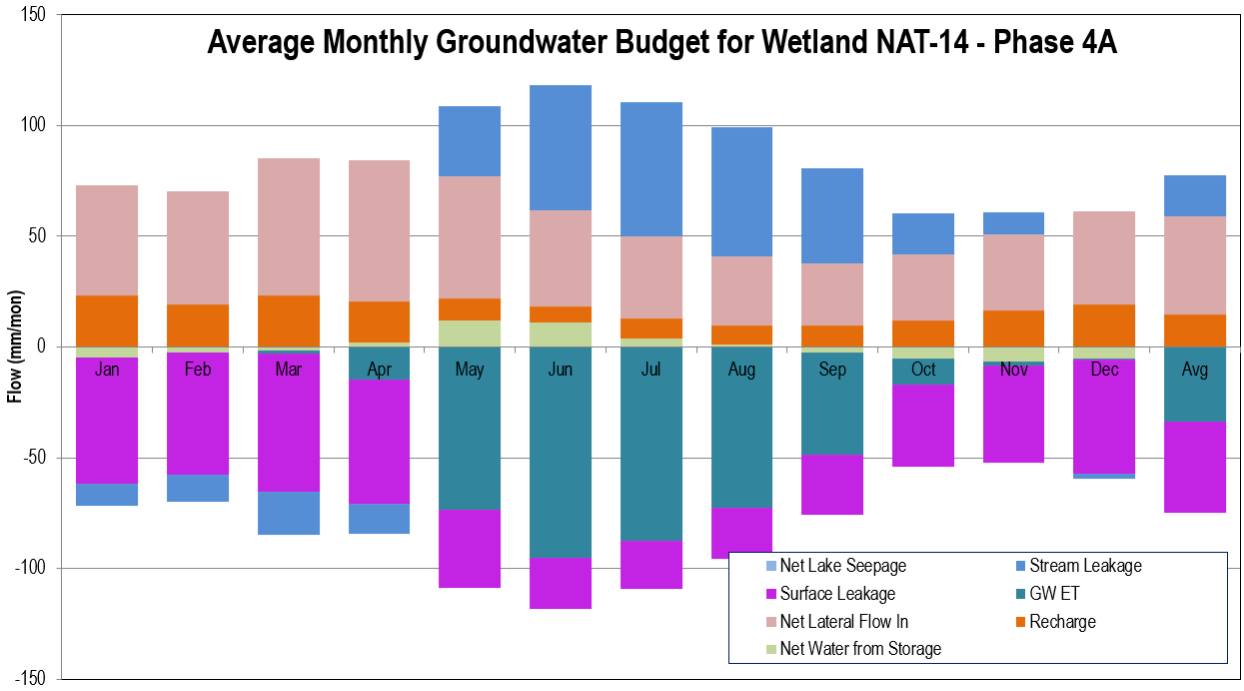


Table 23c – Monthly Groundwater Budget under Phase 4A Conditions (in mm/month) – Wetland NAT-14.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-4.65	-2.28	-1.68	2.04	11.89	11.12	3.94	1.12	-2.53	-5.38	-6.59	-5.24	0.15
Recharge	23.31	19.16	23.15	18.60	10.07	7.07	9.14	8.52	9.66	11.76	16.40	19.33	14.68
Net Lateral Flow In	49.70	51.16	62.06	63.87	55.25	43.35	36.83	31.26	28.13	30.21	34.40	42.05	44.02
GW ET	-0.24	-0.27	-1.41	-14.77	-73.66	-95.30	-87.47	-72.78	-46.06	-11.72	-1.72	-0.26	-33.80
Surface Leakage	-56.96	-55.08	-62.09	-56.17	-35.05	-22.80	-21.82	-22.74	-27.03	-36.81	-43.74	-51.81	-41.01
Stream Leakage	-9.67	-12.07	-19.74	-13.40	31.70	56.83	60.82	58.41	42.96	18.41	10.03	-1.96	18.53
Net Lake Seepage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 23d – Difference in Monthly Groundwater Budget (Baseline - Phase 4A) in mm/month – Wetland NAT-14.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	0.38	0.25	0.26	0.13	-0.59	-0.95	-0.70	-0.36	0.07	0.42	0.61	0.58
Recharge	-0.06	-0.16	-0.17	-0.01	0.07	0.11	0.01	0.14	0.02	0.08	0.03	0.03
Net Lateral Flow In	1.43	1.59	1.91	1.46	-0.45	-1.67	-1.96	-1.81	-1.30	-0.89	-0.11	0.83
GW ET	0.00	0.00	0.00	0.01	0.84	1.49	1.17	0.86	0.39	0.03	0.00	0.00
Surface Leakage	0.07	-0.15	-0.22	-0.04	0.49	0.61	0.61	0.57	0.76	0.71	0.60	0.22
Stream Leakage	0.48	-1.80	-2.38	-1.96	-0.64	0.11	0.67	-0.08	1.32	-0.06	1.58	-1.15
Net Lake Seepage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

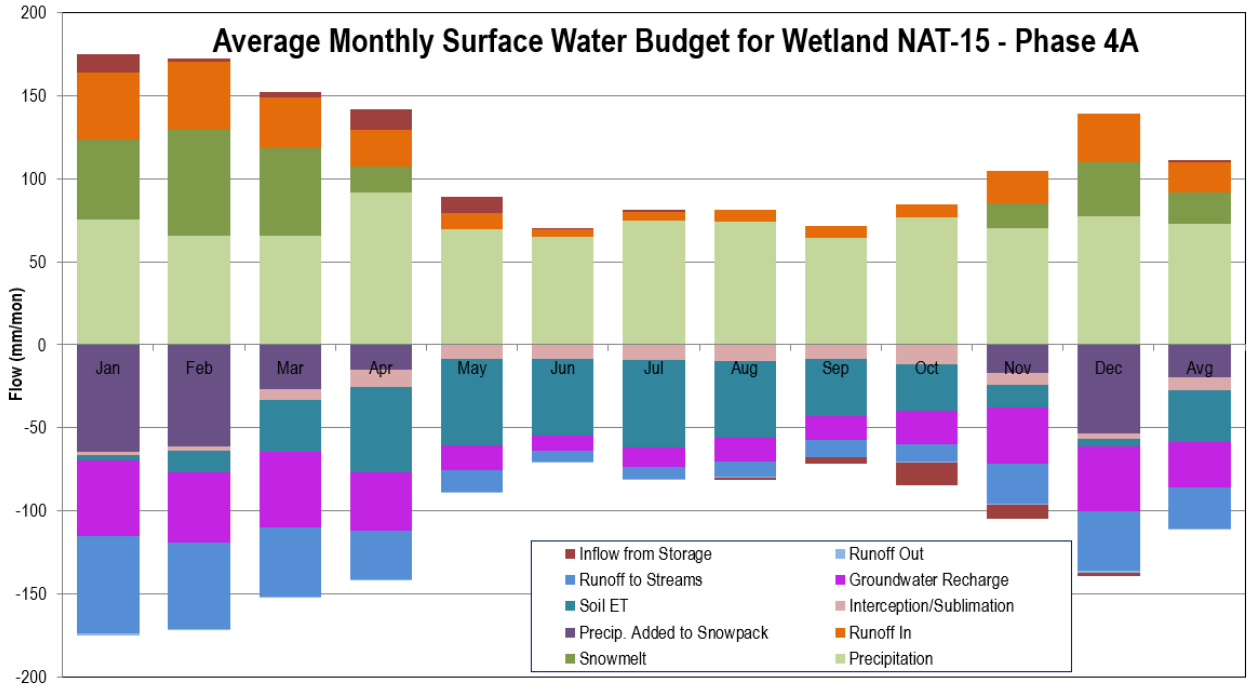


Table 24a – Monthly Surface Water Budget under Phase 4A Conditions (in mm/month) – Wetland NAT-15.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	75.13	65.93	65.60	91.46	69.58	65.04	74.79	74.34	64.15	76.79	70.33	77.17	72.53
Snowmelt	48.42	63.72	53.00	15.82	0.00	0.00	0.00	0.00	0.00	0.00	15.09	32.70	19.06
Runoff In	38.72	40.71	29.93	21.03	8.28	3.91	3.96	4.85	5.20	6.64	15.28	25.49	17.00
Precip. added to Snowpack	-64.53	-61.19	-26.60	-14.87	0.00	0.00	0.00	0.00	0.00	0.00	-16.90	-53.14	-19.77
Interception/Sublimation	-1.81	-2.42	-6.35	-10.23	-8.45	-8.56	-9.39	-10.10	-8.29	-11.96	-7.18	-3.63	-7.36
Soil ET	-3.52	-12.99	-32.07	-53.76	-53.70	-46.48	-52.94	-46.17	-34.65	-28.19	-13.96	-4.72	-31.93
Groundwater Recharge	-45.39	-42.54	-45.21	-34.59	-15.12	-8.96	-11.63	-14.10	-14.43	-19.50	-33.24	-38.62	-26.94
Runoff to Streams	-56.15	-51.62	-41.08	-28.37	-11.05	-5.59	-6.06	-7.32	-7.89	-9.47	-20.14	-31.75	-23.04
Runoff Out	-1.02	-1.03	-0.99	-0.69	-0.32	-0.15	-0.15	-0.21	-0.22	-0.22	-0.53	-0.80	-0.53
Inflow from Storage	10.14	1.43	3.77	14.19	10.77	0.80	1.43	-1.29	-3.88	-14.09	-8.74	-2.70	0.98

Table 24b – Difference in Monthly Surface Water Budget (Baseline - Phase 4A) in mm/month – Wetland NAT-15.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precip. added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater Recharge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff to Streams	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

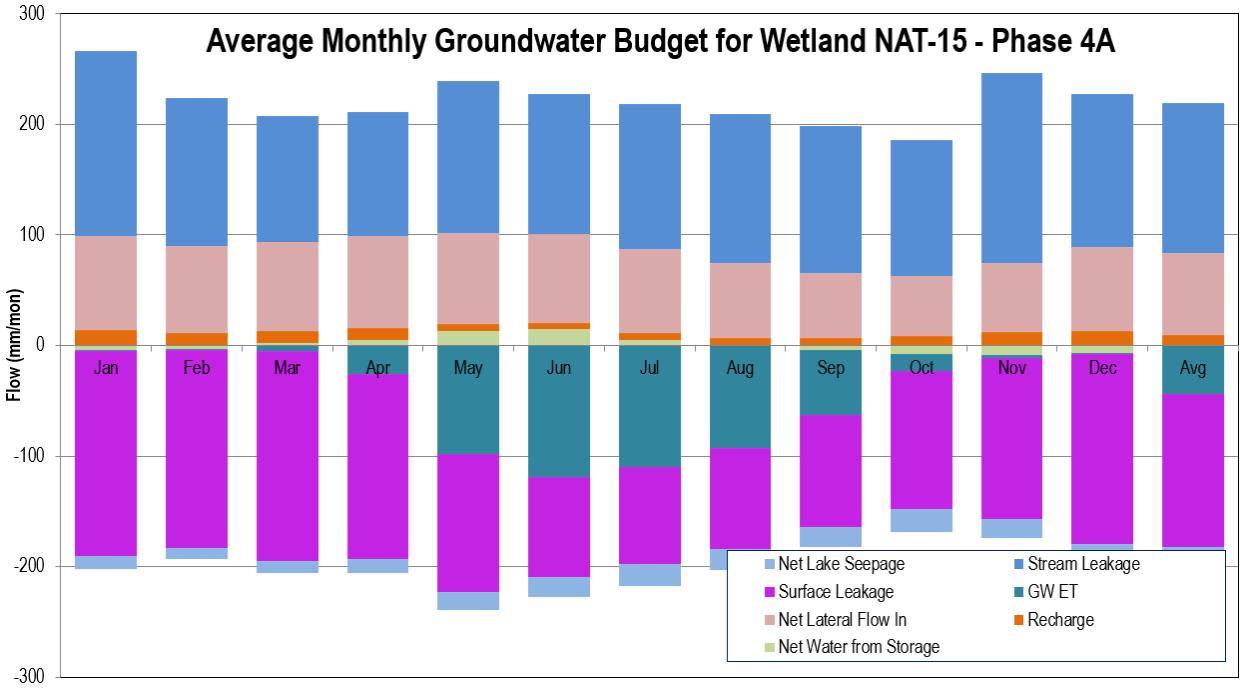


Table 24c – Monthly Groundwater Budget under Phase 4A Conditions (in mm/month) – Wetland NAT-15.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-4.14	-2.76	2.16	5.40	13.22	15.24	4.90	0.48	-4.09	-7.27	-8.93	-7.10	0.59
Recharge	13.88	11.53	10.66	10.56	6.36	4.95	6.72	6.03	6.92	8.43	11.84	13.29	9.26
Net Lateral Flow In	84.74	78.47	81.20	82.92	82.63	80.98	75.81	68.33	58.50	54.38	62.54	75.44	73.83
GW ET	-0.76	-1.04	-4.61	-25.40	-98.28	-119.0	-109.9	-92.56	-59.02	-15.53	-2.58	-0.79	-44.12
Surface Leakage	-185.7	-179.3	-190.7	-168.0	-124.9	-90.35	-88.14	-91.15	-100.8	-124.9	-145.5	-172.1	-138.5
Stream Leakage	167.6	133.9	113.2	112.1	137.2	126.1	130.9	134.8	133.5	123.2	172.3	138.8	135.3
Net Lake Seepage	-11.91	-10.06	-10.73	-12.58	-16.40	-17.94	-19.29	-19.00	-18.49	-20.79	-16.79	-14.09	-15.67

Table 24d – Difference in Monthly Groundwater Budget (Baseline - Phase 4A) in mm/month – Wetland NAT-15.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	-0.05	-0.04	0.01	-0.01	0.06	0.15	0.12	0.33	-0.20	-0.31	-0.08	-0.05
Recharge	0.01	0.03	0.00	0.02	0.00	0.00	0.03	0.12	0.00	0.00	0.01	0.02
Net Lateral Flow In	-0.48	-0.33	-0.49	-0.59	-0.57	-0.31	-0.06	0.29	-0.22	-0.58	-0.80	-0.89
GW ET	0.00	0.00	0.00	0.01	0.10	0.35	0.60	0.63	0.27	0.03	0.00	0.00
Surface Leakage	0.37	0.30	0.51	0.34	0.51	0.91	1.25	2.23	1.57	0.72	0.52	0.59
Stream Leakage	0.45	0.69	2.56	0.44	1.24	-0.58	-1.23	-2.25	-0.15	0.70	0.37	0.38
Net Lake Seepage	-0.78	-0.40	-0.49	-0.58	-0.75	-0.44	-0.25	-0.29	-0.59	-0.74	-0.92	-0.82

9.5 *Rehabilitation*

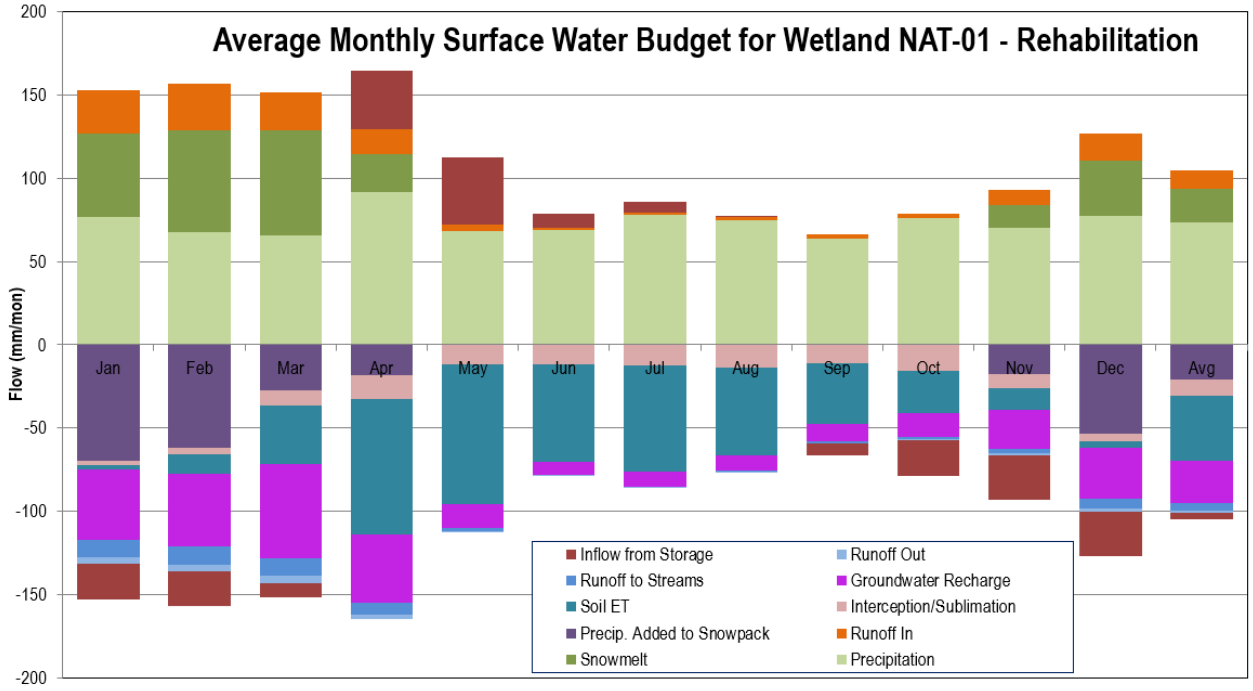


Table 25a – Monthly Surface Water Budget under Rehabilitation Conditions (in mm/month) – Wetland NAT-01.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	76.56	67.29	65.88	91.50	67.99	69.09	78.19	74.90	63.93	76.07	70.01	77.42	73.24
Snowmelt	49.93	61.44	62.98	23.01	0.12	0.00	0.00	0.00	0.00	0.00	14.07	33.02	20.38
Runoff In	26.29	28.00	22.85	14.75	4.12	1.08	1.01	1.54	2.56	2.72	8.66	16.60	10.85
Precip. added to Snowpack	-69.52	-61.54	-27.31	-18.57	-0.12	0.00	0.00	0.00	0.00	0.00	-17.40	-53.05	-20.63
Interception/Sublimation	-2.57	-3.99	-9.15	-13.83	-11.52	-11.96	-12.60	-13.61	-11.32	-15.33	-8.92	-4.70	-9.96
Soil ET	-2.87	-11.98	-35.13	-81.73	-84.27	-58.61	-63.41	-52.74	-36.24	-25.66	-12.57	-3.79	-39.08
Groundwater Recharge	-42.09	-43.30	-56.31	-40.99	-14.14	-7.30	-9.11	-9.36	-10.14	-14.64	-23.68	-31.10	-25.18
Runoff to Streams	-10.66	-11.33	-10.76	-6.81	-1.52	-0.32	-0.36	-0.63	-1.26	-1.00	-2.73	-5.55	-4.41
Runoff Out	-3.79	-4.00	-4.24	-2.80	-0.74	-0.24	-0.28	-0.35	-0.51	-0.50	-1.28	-2.25	-1.75
Inflow from Storage	-21.27	-20.59	-8.80	35.47	40.09	8.26	6.56	0.26	-7.03	-21.65	-26.16	-26.61	-3.46

Table 25b – Difference in Monthly Surface Water Budget (Baseline - Rehabilitation) in mm/month – Wetland NAT-01.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precip. added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater Recharge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff to Streams	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

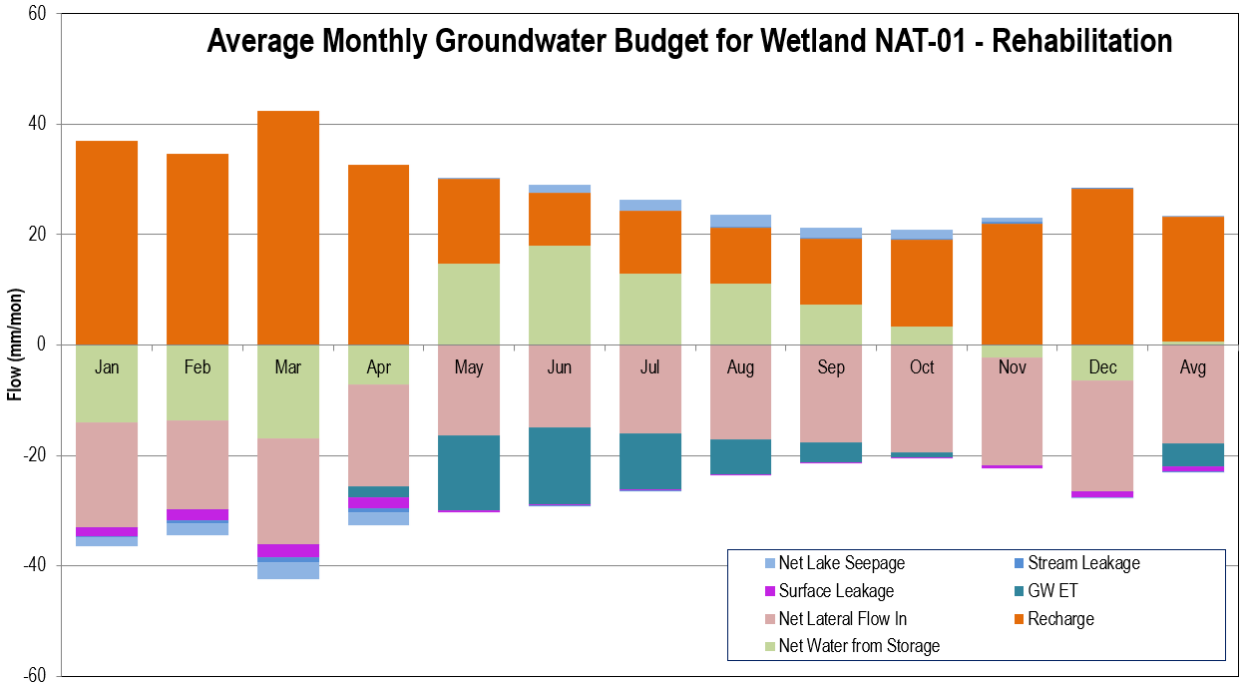


Table 25c – Monthly Groundwater Budget under Rehabilitation Conditions (in mm/month) – Wetland NAT-01.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-13.98	-13.59	-16.89	-7.11	14.79	18.09	13.01	11.07	7.30	3.37	-2.23	-6.50	0.61
Recharge	36.95	34.64	42.35	32.57	15.25	9.46	11.28	10.27	11.91	15.76	22.06	28.32	22.57
Net Lateral Flow In	-19.12	-16.22	-19.15	-18.48	-16.45	-14.90	-16.08	-17.09	-17.70	-19.37	-19.56	-20.03	-17.85
GW ET	0.00	-0.01	-0.05	-2.01	-13.43	-13.97	-10.07	-6.34	-3.51	-0.91	-0.10	0.00	-4.20
Surface Leakage	-1.57	-1.91	-2.41	-2.01	-0.44	-0.17	-0.17	-0.17	-0.17	-0.19	-0.43	-0.97	-0.88
Stream Leakage	-0.22	-0.51	-0.88	-0.77	0.13	-0.04	-0.03	0.02	0.20	0.10	0.23	0.11	-0.14
Net Lake Seepage	-1.53	-2.26	-2.97	-2.22	0.12	1.54	2.04	2.18	1.94	1.69	0.86	-0.11	0.10

Table 25d – Difference in Monthly Groundwater Budget (Baseline - Rehabilitation) in mm/month – Wetland NAT-01.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	-0.68	-0.60	-0.55	-0.36	1.38	1.44	0.66	-0.01	-0.43	-0.72	-0.74	-0.69
Recharge	-0.03	-0.04	-0.09	-0.09	-0.04	-0.05	0.00	0.00	0.00	-0.01	-0.01	-0.02
Net Lateral Flow In	1.06	1.06	1.12	1.07	1.24	1.23	1.15	0.96	0.79	0.77	0.81	0.91
GW ET	0.00	0.00	0.00	-0.26	-2.50	-2.77	-2.00	-1.15	-0.53	-0.14	-0.01	0.00
Surface Leakage	-0.06	-0.06	-0.07	-0.07	-0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.02	-0.05
Stream Leakage	-0.04	-0.04	-0.04	-0.04	-0.01	0.00	0.00	0.00	-0.01	-0.01	-0.01	-0.02
Net Lake Seepage	-0.24	-0.31	-0.34	-0.26	-0.04	0.13	0.21	0.23	0.21	0.15	0.04	-0.09

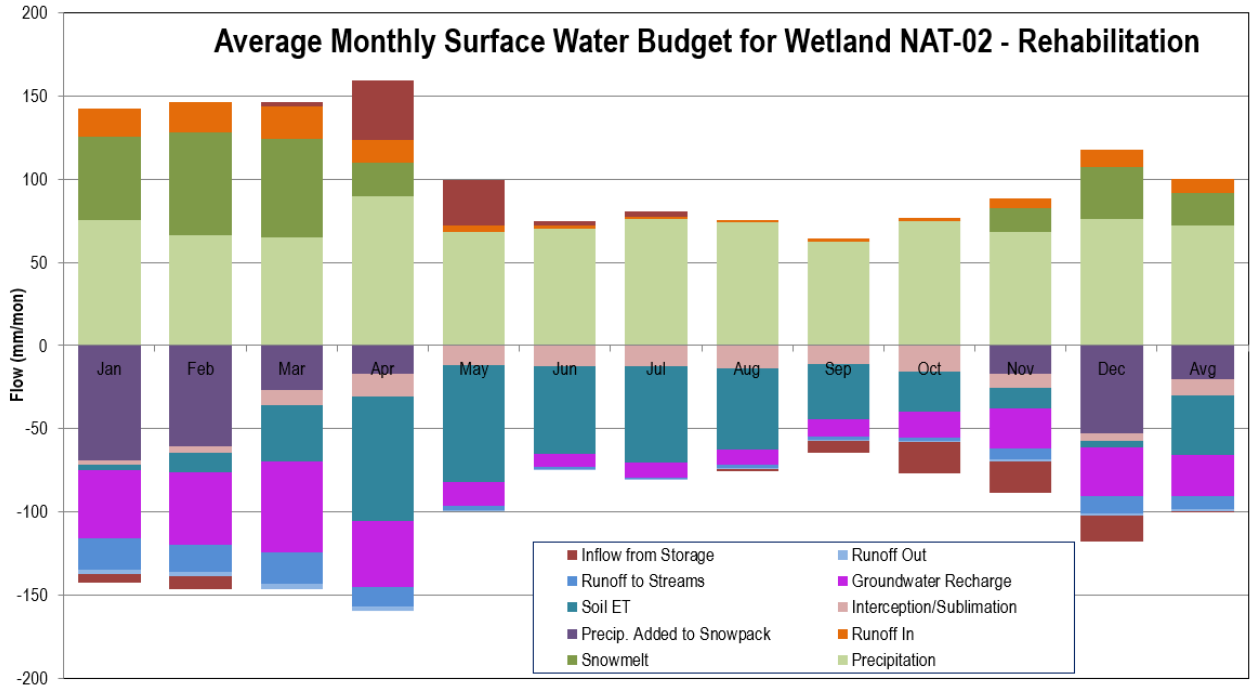


Table 26a – Monthly Surface Water Budget under Rehabilitation Conditions (in mm/month) – Wetland NAT-02.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	75.14	66.03	64.85	90.01	68.18	70.44	76.23	73.87	62.18	74.47	68.21	75.79	72.12
Snowmelt	50.18	61.72	59.06	19.79	0.00	0.00	0.00	0.00	0.00	0.00	14.59	31.73	19.76
Runoff In	17.27	18.71	19.91	13.56	4.18	1.55	1.07	1.42	2.00	1.99	5.81	9.91	8.11
Precip. added to Snowpack	-69.20	-60.51	-26.68	-16.70	0.00	0.00	0.00	0.00	0.00	-0.01	-16.78	-52.65	-20.21
Interception/Sublimation	-2.20	-3.59	-9.01	-13.99	-11.65	-12.16	-12.47	-13.41	-11.13	-15.48	-8.86	-4.40	-9.86
Soil ET	-3.19	-12.28	-34.22	-74.73	-70.58	-53.16	-57.77	-48.80	-33.35	-24.30	-12.05	-4.00	-35.70
Groundwater Recharge	-41.46	-43.35	-54.60	-39.67	-13.74	-7.59	-8.95	-9.66	-10.20	-15.22	-23.87	-29.56	-24.82
Runoff to Streams	-18.47	-16.33	-18.70	-11.76	-2.86	-0.98	-0.90	-1.45	-2.19	-2.23	-6.74	-10.13	-7.73
Runoff Out	-2.63	-2.77	-3.22	-2.33	-0.89	-0.57	-0.56	-0.60	-0.60	-0.64	-1.13	-1.66	-1.47
Inflow from Storage	-5.43	-7.62	2.60	35.82	27.37	2.46	3.35	-1.36	-6.71	-18.59	-19.17	-15.02	-0.19

Table 26b – Difference in Monthly Surface Water Budget (Baseline - Rehabilitation) in mm/month – Wetland NAT-02.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
Precip. added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater Recharge	-0.02	-0.02	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01
Runoff to Streams	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

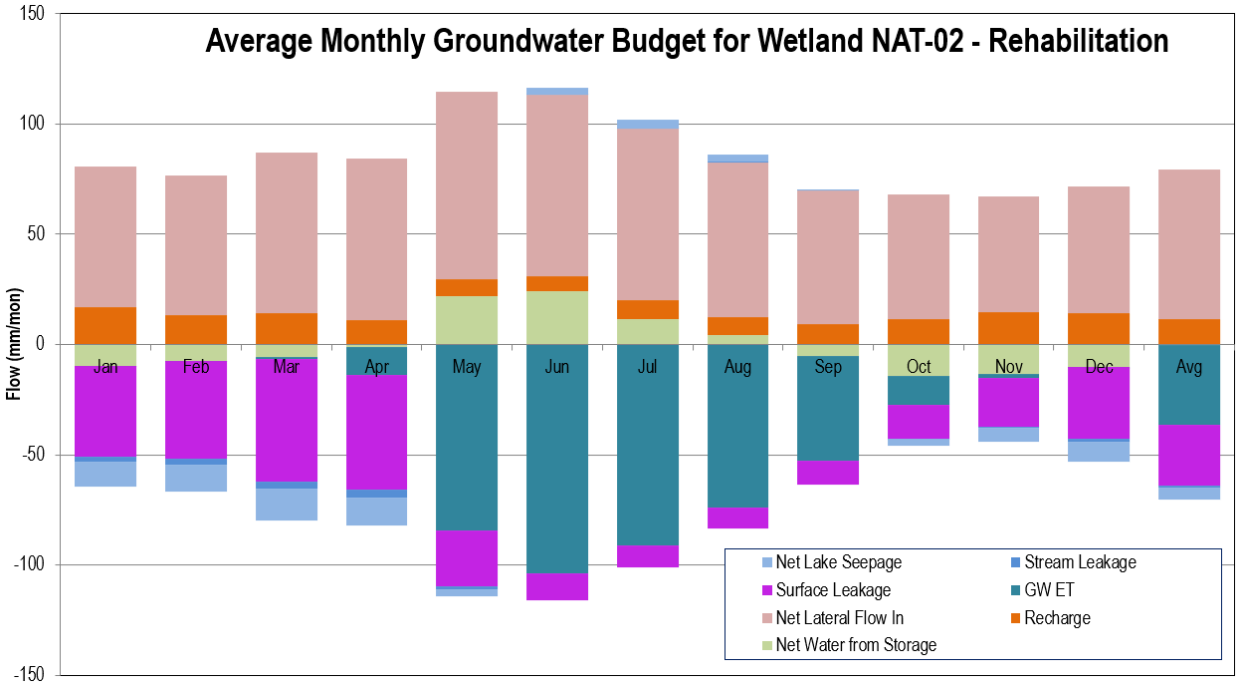


Table 26c – Monthly Groundwater Budget under Rehabilitation Conditions (in mm/month) – Wetland NAT-02.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-9.76	-7.25	-5.55	-0.95	21.72	23.98	11.60	4.14	-5.07	-14.39	-13.28	-10.19	-0.42
Recharge	16.86	13.45	14.04	10.98	7.73	6.96	8.64	8.09	9.15	11.74	14.48	14.38	11.38
Net Lateral Flow In	63.77	63.43	72.95	73.21	85.15	82.47	77.70	70.43	60.65	56.13	52.88	57.20	68.00
GW ET	-0.18	-0.20	-1.09	-12.72	-84.53	-104.01	-91.34	-73.79	-47.50	-13.12	-1.98	-0.20	-35.89
Surface Leakage	-40.95	-44.56	-55.41	-52.33	-25.39	-12.24	-9.89	-9.61	-10.87	-15.23	-22.03	-32.17	-27.56
Stream Leakage	-2.17	-2.66	-3.42	-3.31	-1.12	0.00	0.12	0.34	0.13	-0.12	-0.63	-1.38	-1.18
Net Lake Seepage	-11.59	-12.26	-14.28	-12.78	-3.28	3.10	4.08	3.24	0.61	-3.24	-6.32	-9.01	-5.14

Table 26d – Difference in Monthly Groundwater Budget (Baseline - Rehabilitation) in mm/month – Wetland NAT-02.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	-0.22	-0.24	-0.22	-0.04	0.30	0.24	0.22	0.13	0.15	-0.17	-0.13	-0.29
Recharge	0.50	0.53	0.76	0.50	0.22	0.11	0.10	0.09	0.10	0.16	0.18	0.30
Net Lateral Flow In	-1.96	-2.06	-2.74	-2.78	-3.16	-3.21	-3.16	-3.05	-2.61	-2.78	-2.23	-2.23
GW ET	0.00	0.00	0.00	0.08	0.97	1.65	1.74	1.56	1.06	0.25	0.03	0.00
Surface Leakage	1.01	1.04	1.11	1.05	0.73	0.43	0.38	0.34	0.47	0.51	0.68	0.73
Stream Leakage	0.56	0.52	0.50	0.48	0.42	0.29	0.26	0.21	0.19	0.32	0.45	0.51
Net Lake Seepage	0.79	0.67	0.63	0.61	0.61	0.57	0.58	0.58	0.57	0.68	0.79	0.81

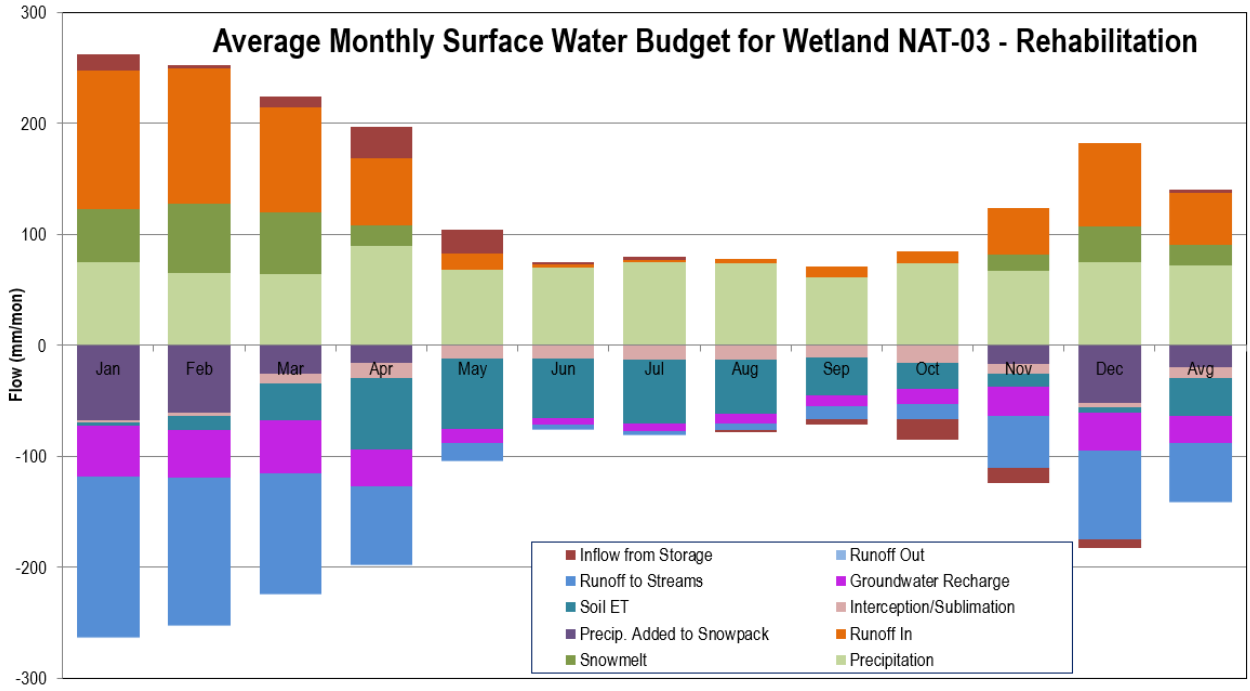


Table 27a – Monthly Surface Water Budget under Rehabilitation Conditions (in mm/month) – Wetland NAT-03.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	74.66	65.43	64.44	89.68	68.61	70.57	75.15	73.73	61.69	73.90	67.57	75.24	71.72
Snowmelt	47.92	62.01	55.70	18.16	0.00	0.00	0.00	0.00	0.00	0.01	14.51	31.61	19.16
Runoff In	125.4	121.9	94.07	60.85	14.50	2.97	2.12	4.34	9.88	11.24	41.66	75.55	47.04
Precip. added to Snowpack	-67.02	-60.47	-25.60	-16.06	0.00	0.00	0.00	0.00	0.00	-0.01	-16.57	-51.78	-19.79
Interception/Sublimation	-1.91	-3.12	-8.58	-13.71	-11.49	-11.92	-12.28	-13.17	-10.93	-15.37	-8.74	-4.19	-9.62
Soil ET	-3.48	-12.63	-32.71	-63.57	-63.97	-53.11	-57.76	-48.79	-34.07	-23.56	-11.99	-4.18	-34.15
Groundwater Recharge	-45.31	-42.82	-48.71	-33.31	-11.91	-6.44	-7.37	-8.41	-9.40	-14.15	-26.21	-34.65	-24.06
Runoff to Streams	-144.6	-132.9	-107.9	-70.01	-16.47	-3.51	-2.90	-5.85	-12.10	-13.49	-46.88	-79.94	-53.04
Runoff Out	-0.43	-0.40	-0.51	-0.35	-0.09	-0.03	-0.03	-0.04	-0.06	-0.06	-0.20	-0.33	-0.21
Inflow from Storage	14.78	3.05	9.76	28.32	20.82	1.47	3.06	-1.80	-5.00	-18.51	-13.15	-7.33	2.96

Table 27b – Difference in Monthly Surface Water Budget (Baseline - Rehabilitation) in mm/month – Wetland NAT-03.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precip. added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater Recharge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff to Streams	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

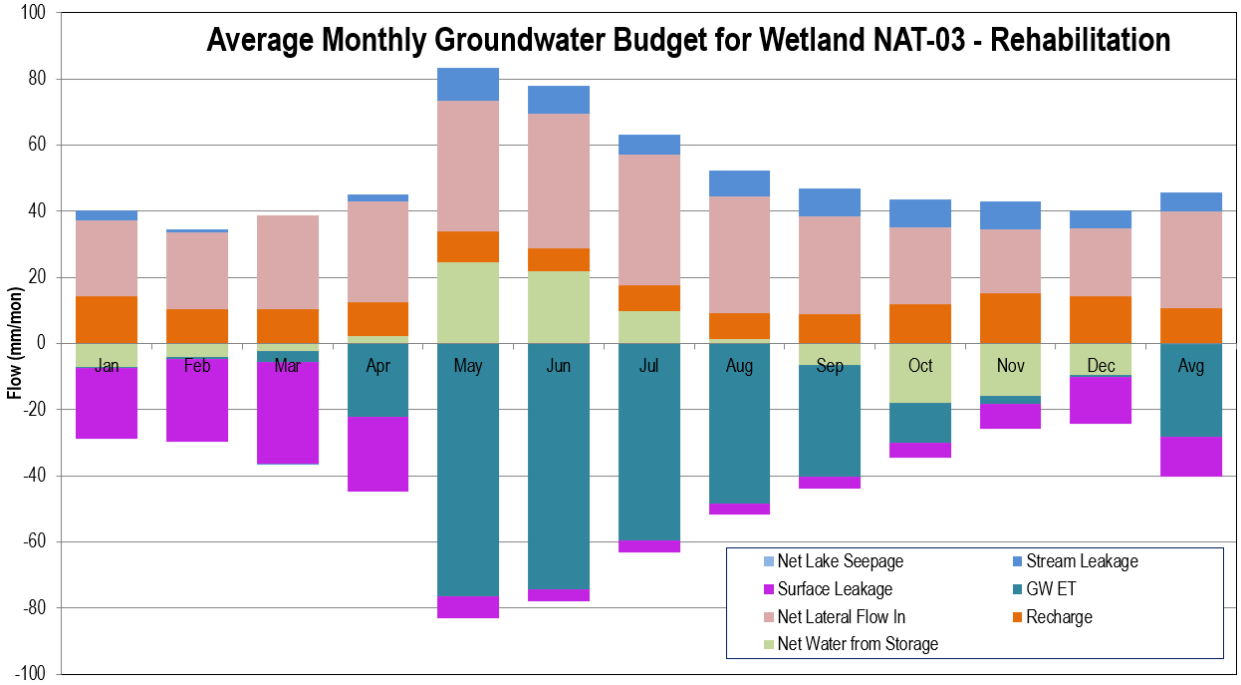


Table 27c – Monthly Groundwater Budget under Rehabilitation Conditions (in mm/month) – Wetland NAT-03.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-6.96	-3.92	-2.30	2.13	24.68	21.98	9.81	1.38	-6.42	-17.81	-15.82	-9.64	-0.24
Recharge	14.24	10.37	10.36	10.31	9.29	6.94	7.92	7.92	8.96	11.86	15.31	14.43	10.66
Net Lateral Flow In	23.06	23.24	28.34	30.54	39.59	40.47	39.28	35.18	29.39	23.19	19.33	20.47	29.34
GW ET	-0.53	-0.63	-3.21	-22.20	-76.38	-74.31	-59.63	-48.35	-33.77	-12.24	-2.57	-0.58	-27.87
Surface Leakage	-21.42	-25.11	-30.92	-22.65	-6.69	-3.65	-3.49	-3.50	-3.65	-4.44	-7.36	-14.08	-12.25
Stream Leakage	2.82	0.86	-0.03	2.08	9.71	8.70	6.28	7.70	8.41	8.39	8.36	5.31	5.72
Net Lake Seepage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 27d – Difference in Monthly Groundwater Budget (Baseline - Rehabilitation) in mm/month – Wetland NAT-03.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	-0.03	-0.01	0.00	0.01	0.00	0.02	0.02	0.04	0.05	-0.05	-0.05	-0.02
Recharge	0.01	0.01	0.00	0.00	-0.16	0.00	0.01	0.00	0.00	0.01	0.03	0.02
Net Lateral Flow In	-0.02	-0.04	-0.04	-0.02	-0.03	-0.01	-0.01	0.01	0.03	0.00	-0.04	-0.02
GW ET	0.00	0.00	0.00	0.00	0.03	0.06	0.09	0.11	0.11	0.03	0.00	0.00
Surface Leakage	0.03	0.01	0.02	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03
Stream Leakage	0.00	0.00	0.01	-0.01	-0.02	-0.07	-0.11	-0.14	-0.23	-0.07	-0.03	0.40
Net Lake Seepage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

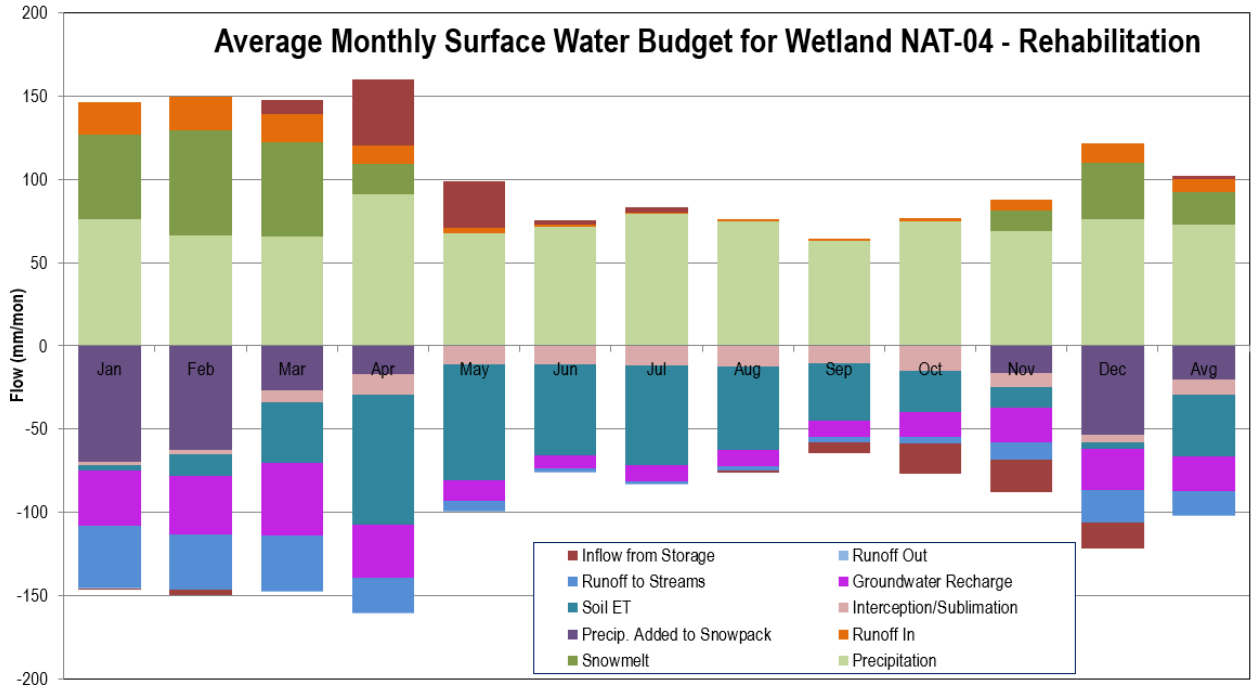


Table 28a – Monthly Surface Water Budget under Rehabilitation Conditions (in mm/month) – Wetland NAT-04.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	75.88	66.60	65.32	90.72	67.38	71.74	79.00	74.79	62.71	74.78	68.62	76.26	72.82
Snowmelt	50.92	62.52	57.11	18.58	0.09	0.00	0.00	0.00	0.00	0.00	12.94	33.46	19.64
Runoff In	19.24	20.27	16.37	10.92	3.28	1.09	0.92	1.20	1.80	1.96	6.01	11.98	7.92
Precip. added to Snowpack	-69.72	-62.18	-26.40	-16.74	-0.09	0.00	0.00	0.00	0.00	-0.01	-16.18	-53.68	-20.42
Interception/Sublimation	-1.74	-2.57	-7.74	-12.78	-10.83	-11.18	-11.71	-12.55	-10.58	-14.68	-8.47	-3.91	-9.06
Soil ET	-3.65	-13.31	-35.97	-78.03	-69.64	-54.29	-59.81	-50.17	-34.07	-25.15	-12.54	-4.52	-36.76
Groundwater Recharge	-33.04	-35.14	-43.56	-31.54	-12.29	-7.86	-9.60	-9.73	-9.94	-14.97	-20.57	-24.46	-21.06
Runoff to Streams	-37.19	-33.05	-33.58	-20.87	-5.82	-1.93	-1.68	-2.28	-3.53	-3.79	-10.47	-19.14	-14.45
Runoff Out	-0.20	-0.22	-0.19	-0.18	-0.12	-0.12	-0.13	-0.12	-0.10	-0.11	-0.12	-0.14	-0.15
Inflow from Storage	-0.50	-2.91	8.66	39.92	28.04	2.55	3.02	-1.13	-6.30	-18.04	-19.21	-15.84	1.52

Table 28b – Difference in Monthly Surface Water Budget (Baseline - Rehabilitation) in mm/month – Wetland NAT-04.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precip. added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater Recharge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff to Streams	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

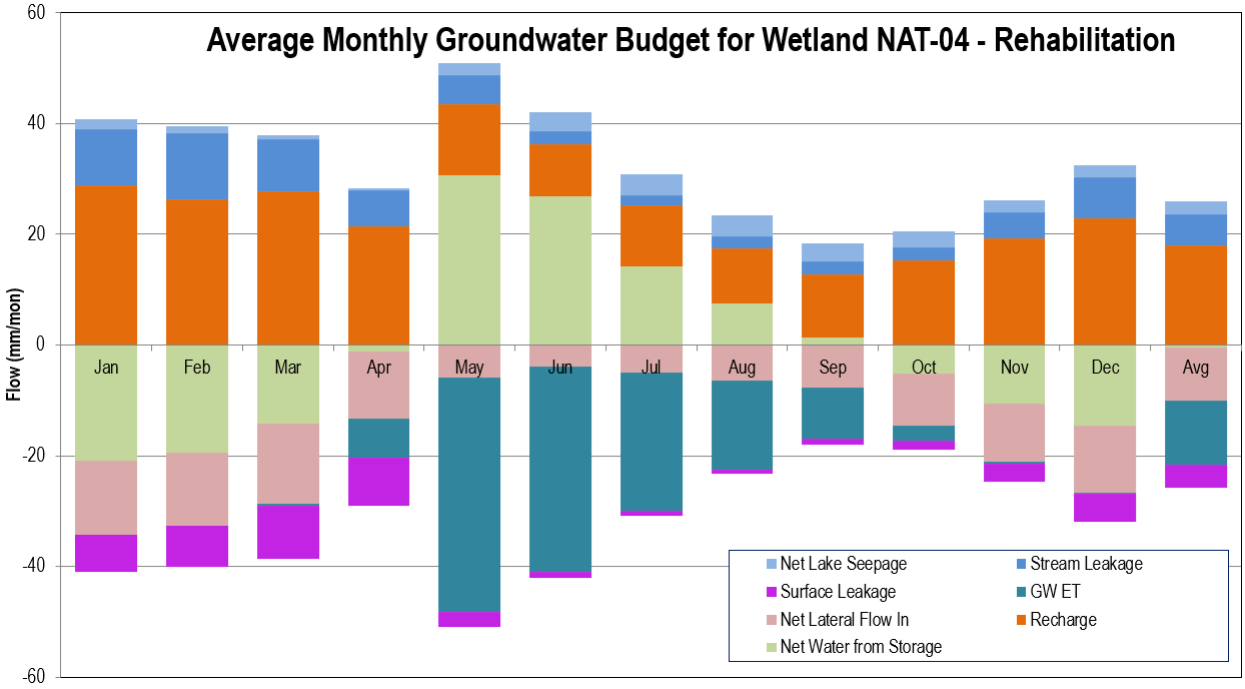


Table 280c – Monthly Groundwater Budget under Rehabilitation Conditions (in mm/month) – Wetland NAT-04.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-20.85	-19.38	-14.15	-1.26	30.65	26.85	14.22	7.46	1.41	-5.19	-10.63	-14.65	-0.46
Recharge	28.94	26.33	27.84	21.42	12.79	9.41	11.01	10.02	11.30	15.28	19.33	22.93	18.05
Net Lateral Flow In	-13.43	-13.29	-14.54	-12.13	-5.93	-3.83	-5.02	-6.49	-7.63	-9.32	-10.44	-12.08	-9.51
GW ET	-0.06	-0.06	-0.38	-6.91	-42.31	-37.24	-24.94	-15.95	-9.37	-2.71	-0.46	-0.06	-11.71
Surface Leakage	-6.68	-7.40	-9.52	-8.70	-2.74	-1.01	-0.86	-0.88	-0.97	-1.70	-3.21	-5.10	-4.06
Stream Leakage	10.11	11.96	9.41	6.57	5.29	2.39	1.79	2.13	2.33	2.33	4.60	7.46	5.53
Net Lake Seepage	1.77	1.18	0.60	0.32	2.21	3.43	3.88	3.81	3.38	2.92	2.27	2.09	2.32

Table 28d – Difference in Monthly Groundwater Budget (Baseline - Rehabilitation) in mm/month – Wetland NAT-04.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	-0.07	0.02	0.01	-0.02	-0.03	0.01	-0.02	0.01	0.01	0.01	-0.05	0.00
Recharge	0.00	0.00	0.00	-0.06	-0.04	0.00	0.00	0.00	0.00	0.00	-0.14	0.12
Net Lateral Flow In	-0.04	-0.01	0.00	0.00	0.00	-0.01	-0.01	-0.02	0.00	-0.01	-0.03	-0.02
GW ET	0.00	0.00	0.00	0.00	-0.02	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00
Surface Leakage	-0.01	-0.01	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	-0.02	-0.01
Stream Leakage	0.11	0.02	0.00	0.02	0.04	0.00	0.05	0.01	0.01	0.00	0.10	0.04
Net Lake Seepage	0.01	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.02	0.04

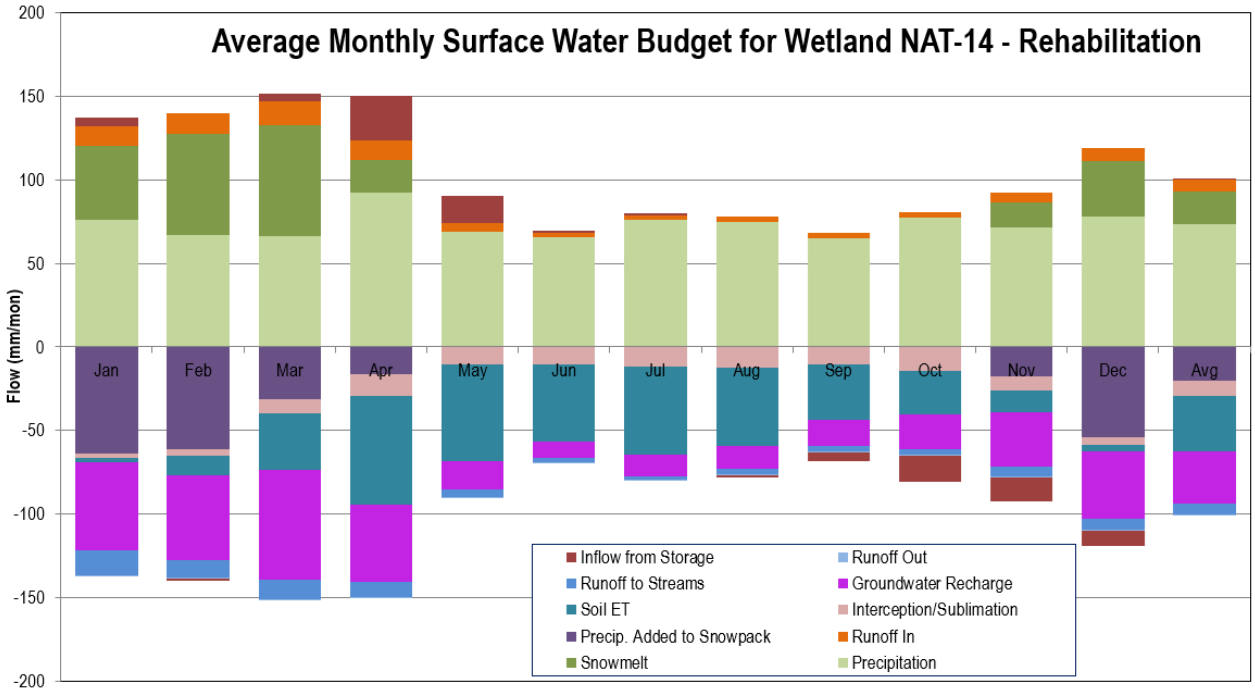


Table 29a – Monthly Surface Water Budget under Rehabilitation Conditions (in mm/month) – Wetland NAT-14.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	75.92	66.77	66.36	92.13	69.05	65.58	75.80	75.01	65.16	77.60	71.24	77.90	73.21
Snowmelt	44.56	60.89	66.27	19.98	0.00	0.00	0.00	0.00	0.00	0.00	15.40	33.30	20.03
Runoff In	11.36	12.19	14.08	11.66	5.01	2.67	2.61	3.07	3.03	3.16	5.45	7.62	6.83
Precip. added to Snowpack	-63.63	-61.10	-31.19	-16.56	0.00	0.00	0.00	0.00	0.00	0.00	-17.58	-53.69	-20.31
Interception/Sublimation	-2.67	-3.86	-8.35	-12.62	-10.25	-10.46	-11.60	-12.50	-10.23	-14.30	-8.67	-4.65	-9.18
Soil ET	-2.82	-12.13	-34.26	-65.14	-57.89	-46.15	-53.07	-46.52	-33.52	-25.96	-12.57	-3.84	-32.82
Groundwater Recharge	-52.81	-50.15	-65.10	-46.35	-17.38	-9.91	-12.46	-14.10	-15.64	-20.75	-33.00	-40.49	-31.51
Runoff to Streams	-14.37	-10.68	-11.83	-8.89	-3.97	-2.27	-2.50	-3.17	-3.23	-3.30	-5.58	-6.87	-6.39
Runoff Out	-0.90	-0.95	-0.90	-0.84	-0.57	-0.49	-0.56	-0.56	-0.50	-0.56	-0.66	-0.71	-0.68
Inflow from Storage	5.35	-0.98	4.90	26.64	15.99	1.01	1.78	-1.23	-5.07	-15.90	-14.02	-8.57	0.83

Table 29b – Difference in Monthly Surface Water Budget (Baseline - Rehabilitation) in mm/month – Wetland NAT-14.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precip. added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater Recharge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff to Streams	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

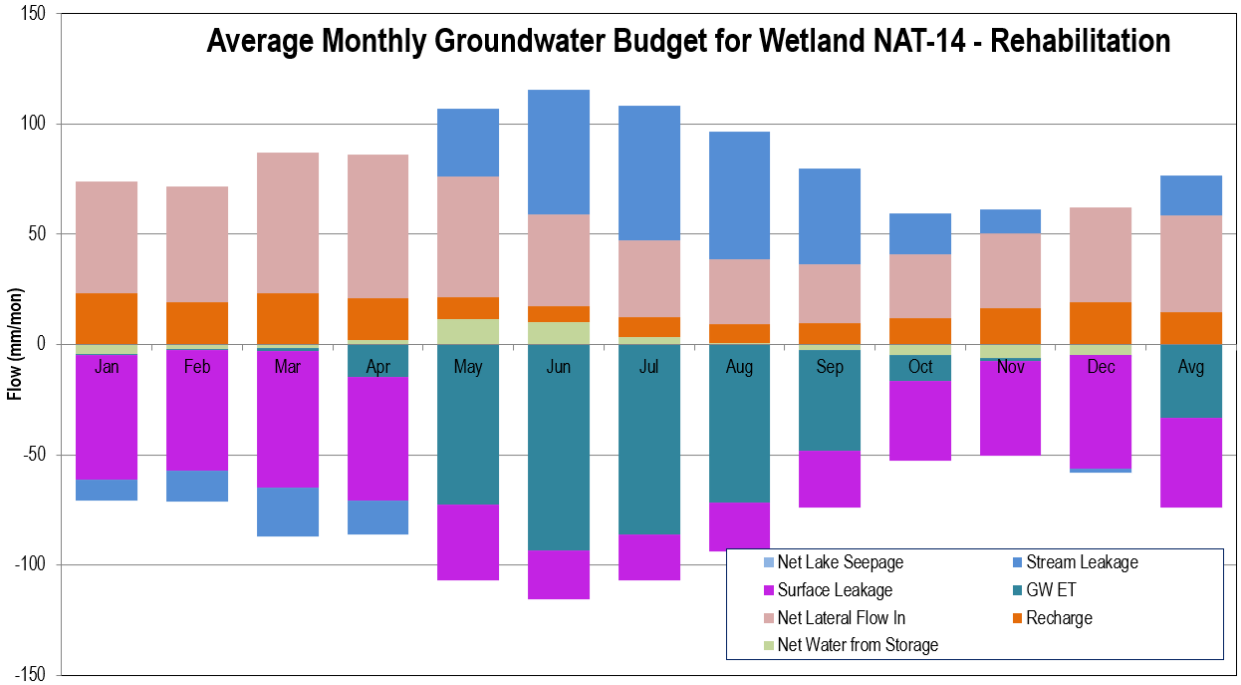


Table 29c – Monthly Groundwater Budget under Rehabilitation Conditions (in mm/month) – Wetland NAT-14.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-4.34	-2.08	-1.43	2.21	11.35	10.22	3.24	0.81	-2.44	-4.97	-5.96	-4.70	0.16
Recharge	23.29	19.03	23.09	18.64	10.23	7.22	9.17	8.68	9.74	11.87	16.49	19.45	14.74
Net Lateral Flow In	50.88	52.56	63.81	65.23	54.75	41.65	34.78	29.35	26.61	29.13	34.01	42.65	43.78
GW ET	-0.24	-0.27	-1.41	-14.74	-72.71	-93.62	-86.13	-71.74	-45.56	-11.66	-1.72	-0.26	-33.34
Surface Leakage	-56.60	-55.00	-62.11	-55.98	-34.37	-22.03	-21.06	-22.00	-26.09	-35.87	-42.85	-51.27	-40.44
Stream Leakage	-9.49	-13.89	-22.22	-15.44	30.77	56.55	61.18	57.93	43.46	18.28	10.70	-1.95	17.99
Net Lake Seepage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 29d – Difference in Monthly Groundwater Budget (Baseline - Rehabilitation) in mm/month – Wetland NAT-14.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	0.07	0.05	0.01	-0.04	-0.06	-0.04	0.00	-0.05	-0.02	0.01	-0.02	0.04
Recharge	-0.04	-0.03	-0.11	-0.04	-0.09	-0.04	-0.01	-0.01	-0.06	-0.03	-0.06	-0.09
Net Lateral Flow In	0.25	0.19	0.16	0.10	0.05	0.03	0.09	0.10	0.22	0.19	0.28	0.23
GW ET	0.00	0.00	0.00	-0.01	-0.11	-0.18	-0.17	-0.18	-0.12	-0.03	0.00	0.00
Surface Leakage	-0.30	-0.23	-0.21	-0.22	-0.19	-0.16	-0.15	-0.18	-0.18	-0.24	-0.29	-0.32
Stream Leakage	0.30	0.02	0.11	0.08	0.28	0.39	0.31	0.41	0.81	0.08	0.91	-1.16
Net Lake Seepage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

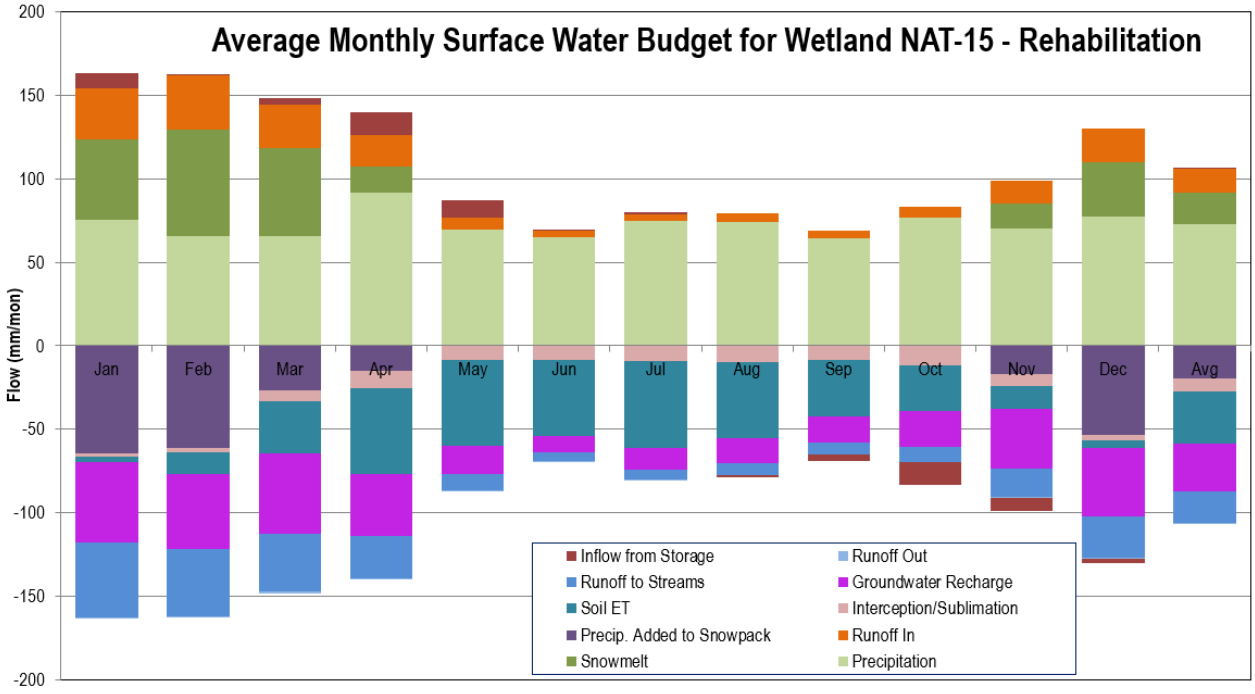


Table 30a – Monthly Surface Water Budget under Rehabilitation Conditions (in mm/month) – Wetland NAT-15.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Precipitation	75.13	65.93	65.60	91.46	69.58	65.04	74.79	74.34	64.15	76.79	70.33	77.17	72.53
Snowmelt	48.42	63.72	53.00	15.82	0.00	0.00	0.00	0.00	0.00	0.00	15.09	32.70	19.06
Runoff In	38.72	40.71	29.93	21.03	8.28	3.91	3.96	4.85	5.20	6.64	15.28	25.49	17.00
Precip. added to Snowpack	-64.53	-61.19	-26.60	-14.87	0.00	0.00	0.00	0.00	0.00	0.00	-16.90	-53.14	-19.77
Interception/Sublimation	-1.81	-2.42	-6.35	-10.23	-8.45	-8.56	-9.39	-10.10	-8.29	-11.96	-7.18	-3.63	-7.36
Soil ET	-3.52	-12.99	-32.07	-53.76	-53.70	-46.48	-52.94	-46.17	-34.65	-28.19	-13.96	-4.72	-31.93
Groundwater Recharge	-45.39	-42.54	-45.21	-34.59	-15.12	-8.96	-11.63	-14.10	-14.43	-19.50	-33.24	-38.62	-26.94
Runoff to Streams	-56.15	-51.62	-41.08	-28.37	-11.05	-5.59	-6.06	-7.32	-7.89	-9.47	-20.14	-31.75	-23.04
Runoff Out	-1.02	-1.03	-0.99	-0.69	-0.32	-0.15	-0.15	-0.21	-0.22	-0.22	-0.53	-0.80	-0.53
Inflow from Storage	10.14	1.43	3.77	14.19	10.77	0.80	1.43	-1.29	-3.88	-14.09	-8.74	-2.70	0.98

Table 30b – Difference in Monthly Surface Water Budget (Baseline - Rehabilitation) in mm/month – Wetland NAT-15.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snowmelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff In	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precip. added to Snowpack	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interception/Sublimation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil ET	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater Recharge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff to Streams	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Runoff Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

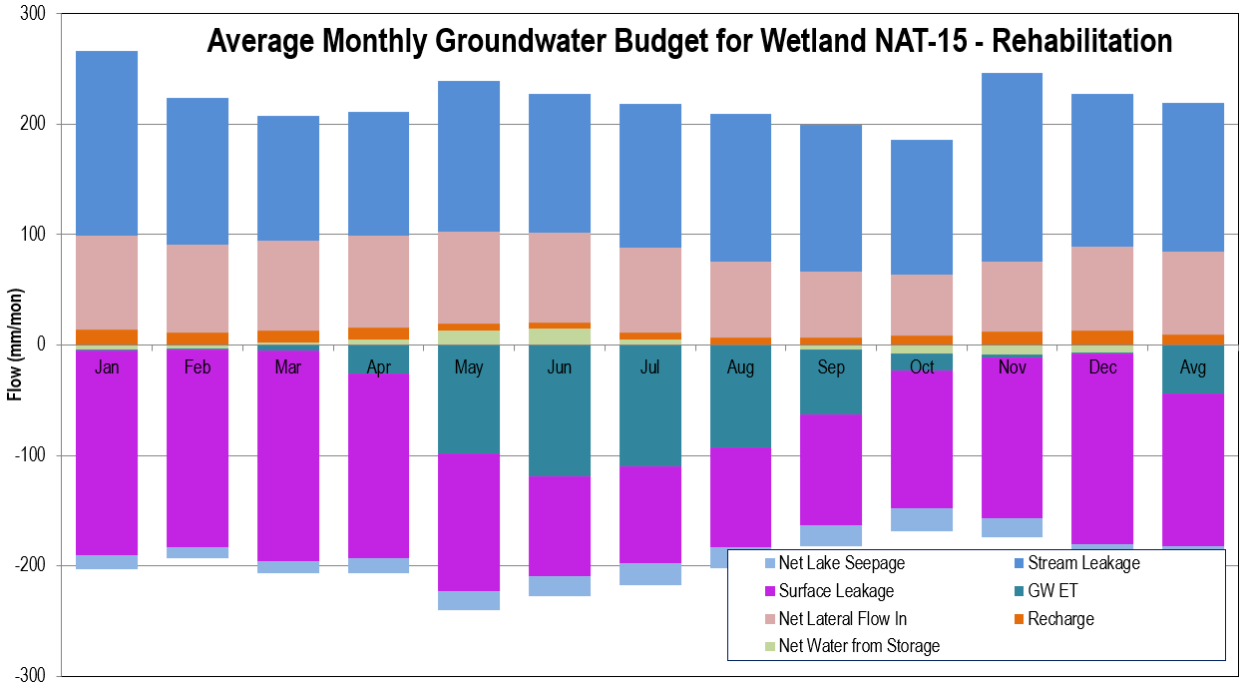


Table 30c – Monthly Groundwater Budget under Rehabilitation Conditions (in mm/month) – Wetland NAT-15.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Net Water from Storage	-4.16	-2.79	2.11	5.36	13.19	15.24	4.89	0.59	-4.16	-7.47	-8.95	-7.14	0.56
Recharge	13.88	11.53	10.66	10.55	6.35	4.96	6.72	6.12	6.92	8.42	11.84	13.29	9.27
Net Lateral Flow In	85.52	79.01	81.89	83.61	83.32	81.60	76.45	69.10	59.17	55.02	63.38	75.95	74.50
GW ET	-0.76	-1.04	-4.61	-25.41	-98.29	-118.93	-109.74	-92.42	-58.93	-15.53	-2.58	-0.79	-44.09
Surface Leakage	-185.8	-179.5	-190.9	-168.2	-125.0	-90.44	-88.15	-90.76	-100.5	-125.0	-145.6	-172.2	-138.5
Stream Leakage	167.3	133.8	112.7	111.5	136.7	125.7	130.4	133.4	133.1	122.7	171.4	138.3	134.7
Net Lake Seepage	-12.04	-10.21	-10.89	-12.73	-16.55	-18.09	-19.48	-19.09	-18.60	-20.94	-16.95	-14.27	-15.82

Table 30d – Difference in Monthly Groundwater Budget (Baseline - Rehabilitation) in mm/month – Wetland NAT-15.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Water from Storage	-0.04	0.00	0.06	0.04	0.09	0.15	0.14	0.22	-0.14	-0.12	-0.06	-0.01
Recharge	0.01	0.03	0.00	0.04	0.00	0.00	0.02	0.03	0.00	0.01	0.01	0.02
Net Lateral Flow In	-1.26	-0.87	-1.18	-1.29	-1.26	-0.93	-0.70	-0.48	-0.89	-1.22	-1.64	-1.40
GW ET	0.00	0.00	0.00	0.01	0.12	0.31	0.42	0.48	0.19	0.03	0.00	0.00
Surface Leakage	0.47	0.43	0.66	0.48	0.62	1.00	1.25	1.85	1.24	0.87	0.63	0.62
Stream Leakage	0.80	0.79	3.09	1.04	1.65	-0.14	-0.70	-0.86	0.25	1.17	1.31	0.82
Net Lake Seepage	-0.65	-0.25	-0.33	-0.43	-0.59	-0.29	-0.06	-0.20	-0.47	-0.59	-0.76	-0.64

10 Geotechnical Assessment

10.1 *Overview*

A Geotechnical Feasibility Study was carried out by a Professional Engineer to confirm the feasibly of the proposed pit/quarry berms, infiltration trench and infiltration pond construction. The full Geotechnical Feasibility Study is provided below. The Geotechnical Feasibility Study focused on evaluating the feasibility of the conceptual berm, infiltration trench and infiltration pond construction configurations with the understanding that in-situ testing would need to be carried out prior to construction to verify site conditions.

Based on the Geotechnical Feasibility Study the following recommendations are provided:

- The proposed quarry berms are to be constructed at a 2H:1V slope (max) as a composite berm structure. The composite berm should include a sufficiently impermeable (i.e. clay-like) 'core' with a well compacted cohesionless granular shell or outer material comprising of the majority of the berm backfill.
- The proposed infiltration trench is to be constructed at a 2H:1V slope (max).
- The proposed infiltration ponds are to be constructed at 2H:1V slopes (max) where the pond walls will be formed by excavating native permeable materials, and 3H:1V slopes (max) where an impermeable liner will be incorporated.
- The infiltration trench and infiltration pond side slopes are to be protected from erosion due to the rapid drawdown of water with suitable erosion protection measures (topsoil, hydroseed and erosion control blanket, rip rap, etc.) approved by a geotechnical engineer at the time of trench and pond construction.
- The fine grained till soils on-site may be considered sufficiently impermeable and may be able to be utilized in the construction of the composite berm 'core' and/or pond liner. The geotechnical suitability of the on-site till soils is to be confirmed prior to berm and/or pond liner construction by a geotechnical engineer. If on-site soils cannot be utilized suitable off-site soil (i.e. clay) will need to be imported.

10.2 *Geotechnical Report*

The full geotechnical report is attached below.

GEMTEC Consulting Engineers and Scientists Limited
6695 Millcreek Drive, Unit 7,
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L5N 5M4

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October 4, 2024

File: 1000876.086 – Rev2

Tatham Engineering Limited
41 King Street, Unit 4
Barrie, Ontario
L4N 685

Attention: Alicia Kimberley, P.Geo., Group Leader - Hydrogeology

Re: Geotechnical Berm and Slope Stability Feasibility Study
Proposed Strata Shelburne Quarry/Pit, 437159 4 Line, Melancthon, Ontario

Enclosed is our Geotechnical Feasibility Study to support the proposed quarry/pit berms, trench, and ponds of the proposed Shelburne Quarry/Pit in Melancthon, Ontario. The report presented herein is based on the scope of work summarized in our proposal dated April 16, 2024, the subsequent change order dated June 10, 2024, and peer review comments received on August 27, 2024. Authorization to proceed was given by Grant C. Horan of Strada Aggregates on May 16, 2024 for the original scope of work, and on June 11, 2024 for the extended scope of work. This report was prepared by Connor McCormick, P.Eng., and reviewed by Graeme Skinner, PhD., P.Eng.

Connor McCormick, P.Eng.
Geotechnical Engineering

Graeme Skinner, PhD., P.Eng.
Principal Geotechnical Engineer

JCM/GDS/sv/af

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1.0 INTRODUCTION

GEMTEC Consulting Engineers and Scientists Limited (GEMTEC) has been requested by Strada Aggregates (Strada/the Client) to carry out a feasibility level slope stability and limited geotechnical considerations study to support the design of a proposed Strada Shelburne Quarry/Pit at 437159 4 Line, Melancthon, Ontario (ON), herein referred to as the "site".

The purpose of the study outlined herein was to assess the general subsurface conditions at the site by means of publicly available information and nearby investigations/reports provided by the Client and, based on the factual data reviewed, to provide engineering comments and recommendations, at the feasibility level, on the slope stability, and geotechnical design aspects of the site with respect to the proposed berm, trench and pond slopes. For further clarity, it is noted that no geotechnical field or site investigation activities or visits were undertaken by GEMTEC at this stage of the project / study. A detailed geotechnical investigation, including site specific boreholes and sampling, should be undertaken to confirm the recommendations provided herein and to inform the detailed design, prior to any construction activities with respect to the berms, trenches, or ponds discussed in this report.

This report / study is subject to the *Conditions and Limitations of this Report*, which follow the text of this report and are considered an integral part of the report. The factual data, interpretations and recommendations contained in this report pertain to a specific project as described in the report and are not applicable to any other project or site location. If the project is modified in concept, location, elevation, or if the project is not initiated within eighteen months of the date of this report, GEMTEC should be given an opportunity to confirm that the recommendations of this report are still valid.

2.0 PROJECT DESCRIPTION

2.1 Background

The subject site is located on the east side of 4 Line and extends from Dufferin County Road 17 to about 1.6 km North of Dufferin County Road 17 at the municipal address 437159 4 Line, Melancthon, Ontario. The site is approximately 250 acres and is understood to be currently licensed as above groundwater pit site consisting of multiple lots. The site is generally bounded to the south by Dufferin County Road 17, to the west by 4 Line and to the north and east by woodlot and farmland.

It is understood that Strada proposed to develop an aggregate quarry/pit with associated infrastructure (infiltration trenches, ponds, etc.) within the site. Hydrogeological modeling indicates that substantial groundwater infiltration through the permeable soil and bedrock units would be expected. The Client proposed the use of "impermeable" berms placed at the excavation / cut face of permeable soil and bedrock units in order to limit groundwater infiltration into the quarry/pit. In addition to the berms, infiltration trenches and ponds would be required to manage

the groundwater flows. GEMTEC was retained to evaluate the feasibility of these conceptual mitigation measures with respect to slope stability and general geotechnical considerations.

3.0 SUBSURFACE CONDITIONS

As previously indicated, no field work or site specific geotechnical investigations or visits were carried out as part of this study. The subsurface conditions were inferred from publicly available regional data and Borehole Logs provided by the client; the reference Borehole Location Plan is attached, and the Borehole Logs (abbreviated) and associated particle size laboratory testing are included in Appendix A. Additionally grain size analysis test results for two shallow Guelph Permeameter tests conducted on-site were provided by the Client and included in Appendix A. The nearest reference boreholes (Boreholes BH08-18 and BH08-19) are located about 300 m and 150 m from the subject site, respectively.

The subsurface soil conditions at the site generally comprise of an upper layer of sand and gravel underlain by a fine-grained till. The depth and thicknesses of the soil strata and bedrock were provided in cross sections developed by the Client (see Appendix B).

4.0 DISCUSSION

The following sections of the report provide feasibility level guidance on the geotechnical engineering design aspects of the project based on our interpretation of the limited subsurface information provided by the Client. It is stressed that the information in the following sections is provided for the guidance of the designers and is intended for this project only. Contractors bidding on or undertaking the works should examine the factual results of the investigation / information provided, satisfy themselves as to the adequacy of the information for construction, and make their own interpretation of the factual data as it affects their construction techniques, schedule, safety, and equipment capabilities. GEMTEC will not assume any responsibility for construction-related decisions made by contractors on the basis of this report.

The professional services retained for this project include only the geotechnical aspects of the subsurface conditions at this site. The presence or implications of possible surface and/or subsurface geo-environmental concerns resulting from previous uses or activities of this site or adjacent properties, and/or resulting from the introduction onto the site of materials from off-site sources are outside the terms of reference for this report and have not been investigated or addressed herein.

4.1 Stability Analysis

Stability analyses were carried out for three proposed features within the site, the quarry/pit, trench and pond, in order to evaluate the conceptual designs at a feasibility level. The site stratigraphy and geometry of the proposed features was provided by the Client.

4.1.1 Quarry/Pit Berm Global and Sliding Stability Analysis

It is understood that the current conceptual design of the quarry/pit excavation includes the use of low permeability/impermeable berms to limit infiltration of groundwater through the identified permeable soil and bedrock strata. The proposed berms would be placed on the benches where the permeable units have been identified. The Client provided three (3) cross sections showing the proposed quarry/pit and berm construction (Sections A-A', B-B' and C-C'; see Appendix B). The stratigraphy elevations and composition included in the preliminary stability assessment discussed herein were taken directly from these cross sections. While the Client cross sections appear to show the berms as near vertical features (due to horizontal versus vertical scale exaggeration), it was confirmed that they would have a typical inclination of 2 Horizontal to 1 Vertical (2H:1V). Section C-C' was identified as the critical section, due to the presence of relatively thick overburden, and high groundwater (head) pressure from the hydrogeological models. The proposed upper berm will abut the soil overburden at the site, while the middle and lower berms will abut permeable bedrock; and all berms are expected to be founded on competent bedrock. The Factor of Safety (FOS) for global stability of the berm slopes was analysed based on limit equilibrium analysis using the commercially available program Slide 2018, produced by Rocscience Inc., employing the Morgenstern Price method of analysis for static loading conditions. The lowest, or minimum, FOS against slope instability is presented herein. The FOS against potential sliding of the berms along the berm / bedrock interface was analyzed and is presented herein. The results of the global slope stability and sliding analyses for quarry/pit Section C-C' are provided below:

Section	Berm Inclination	Berm Height (m)	Stability Mode	Estimated Minimum Factor of Safety	Target Factor of Safety
Section C-C' (Upper Quarry/Pit Section)	2H:1V	19.6	Global[1]	0.90	1.3 to 1.5
			Sliding[2]	1.0	2.0
Section C-C' (Middle Quarry/Pit Section)	2H:1V	10.8	Global[1]	0.74	1.3 to 1.5
			Sliding[2]	1.0	2.0
Section C-C' (Lower Quarry/Pit Section)	2H:1V	12.2	Global[1]	0.73	1.3 to 1.5
			Sliding[2]	1.0	2.0

Note: 1. The global stability analysis evaluates the stability of the berm but does not fully account for the potential high hydraulic pressures found in the lower berms.
2. The sliding analysis assumes the berms will behave "monolithically", and potential instability of the berm due to groundwater pressures was not assessed.

Based on the results of our analyses, the current berm configurations (i.e., 2H:1V slopes) are not meeting the target minimum FOS for global stability or sliding.

The FOS for the berms can be increased by:

- Decreasing the slope inclination from 2H:1V to 3H:1V;
- Adding positive drainage to the berms (i.e., lower the groundwater level in the berms); and / or,
- A combination of both.

A preliminary global and sliding stability assessment was undertaken incorporating the additional stability measures outlined above, and it showed that these measures still fall short of the target minimum FOS where the berm is composed entirely of impermeable (i.e., clayey) material.

Therefore, it is recommended that, at the feasibility level, a composite berm construction using a 'core' of impermeable clay (or sufficiently impermeable material) with a well compacted cohesionless granular shell or outer material comprising of the majority of the berm backfill be utilized for the berm construction. Based on an initial limited global stability and sliding assessment, a composite berm structure could provide satisfactory FOS for both global and sliding stability at a 2H:1V slope. It should be noted that potential high hydraulic heads are anticipated at the lowest berms, and consideration may need to be given to raising the berm height in order to extend the "clay core" across the bedrock units, while also increasing the berm thickness (and stability) at contact. This would be expected to limit groundwater "punching" through the berm where it is thinnest. As noted above, the feasibility level sliding analysis did not consider partial failure i.e., "punching" or "piping" of the berms, and the overall stability of the berms, including these potential failure mechanisms, should be confirmed during the detailed design stage based on a site-specific geotechnical field investigation and prior to construction.

4.1.2 Quarry/Pit Trench and Pond Global Stability Analysis

Global slope stability analyses were carried out for two water control features. A drainage trench located toward the northwest end of the site (within Section A-A'; see Appendix B) and an infiltration pond located south of the main quarry pit (within Section C-C'; see Appendix B). Cross sections for the trench and pond were provided by the Client (Appendix B). Further, based on information provided by the Client, it is understood that the trench would have a bottom elevation of about 503.0 m (about 7.0 m below grade) and that the West wall of the trench would be coincidental with the back side of a quarry/pit berm. It is understood that the north and west pond walls would be provided with an impermeable (i.e., clayey) liner, while the south and east walls would be left as native soils. The global stability of the trench and pond slopes was analyzed based on limit equilibrium analysis, again using the commercially available program Slope/W®, produced by Geo-Slope International Ltd., employing the Morgenstern Price method of analysis for static loading conditions. The slope stability assessment considered both the steady-state and elevated design groundwater level in the trench, while the pond only considered the design

steady-state groundwater level, and it is understood the temporary elevated groundwater level is not applicable to the feasibility design at this time. The results of the global stability analysis are provided below:

Section	Berm Inclination	Slope Height (m)	Minimum Factor of Safety		Target Factor of Safety
			Steady-State Groundwater Level (Dry)	Temporary Elevated Groundwater	
Section A-A' (West Trench Wall)	2 H : 1 V	7.0	1.68	1.54	1.3 to 1.5
Section A-A' (East Trench Wall)	2 H : 1 V	7.0	1.37	1.28	1.3 to 1.5
Section C-C' (North Pond Wall)	3 H : 1 V*	17.0	1.84	N/A	1.3 to 1.5
Section C-C' (South Pond Wall)	2 H : 1 V	17.0	1.40	N/A	1.3 to 1.5

* The impermeable liner on the north pond wall is expected to be unstable / marginally stable at inclinations steeper than 3 H:1V.
N/A – Not applicable.

Based on the results of our feasibility analysis, we expect that these two water control features will generally be stable with respect global stability at the given FOS ranges. With that said, we note that both the trench and pond walls may be marginally stable to unstable in the event of rapid drawdown and with an impermeable liner. The effects of rapid drawdown and slope liner stability should be further analyzed during the detailed design stage using site specific information.

4.2 Re-Use of On-Site Soils for Impermeable Layers

It is understood that the quarry/pit developer is proposing to re-use any on-site fine grained (i.e., clayey) soils from the site to construct the impermeable pond liner and cores which form part of the composite berms. An initial review of the soils from the available borehole information (see Appendix A) indicate that the fine grained till present on site may be suitable for re-use as an impermeable liner for the pond and berms. However, site specific borings (i.e., field investigation drilling and sampling), particle size analyses and Atterberg Limits testing would be required to verify that the soils encountered on site are suitable for this use, which should be conducted prior to construction and re-use of soils on site as detailed below.

All materials to be used in the construction of a compacted clay / impermeable liner shall be analyzed for particle size distribution following ASTM D2487 and ASTM 422-63, and Atterberg

Limits following ASTM D4318, or any other method pre-approved by the ultimate approval / regulatory agency (as applicable).

Typical particle size ranges (by weight) for a compacted clay liner are provided below, where the fines are defined as the soil fraction which passes through a No. 200 (75 µm) US standard sieve, and clay and sand are defined in the ASTM Standard D2487-00:

- Percents fines ≥ 50%;
- Clay Content ≥ 20%; and,
- Sand content ≤ 45%.

Acceptable Atterberg Limits:

- Plasticity Index (PI): PI ≥ 20%; and
- Liquid Limit (LL): LL≥ 30%.

A detailed geotechnical study including site specific boreholes and relevant geotechnical testing should be carried out during the detailed design phase and prior to construction and re-use of on-site materials for the berm construction. Should the fine grained material on-site not meet these requirements then additional testing may be conducted to demonstrate a design (i.e., laboratory testing) and / or an "as-constructed" field hydraulic conductivity of $1x10^{-9}$ m/s or less. Otherwise, importing of suitable low-permeable materials may be required.

4.3 Constructability Considerations

During the Phase 2 stage of excavation of the quarry, it has been noted that there will be a point where about 2 m of the Ancaster/Niagara Formation would be left overlying the permeable Gasport unit. The effects of groundwater uplift on the underside of the 2 m layer of the Ancaster/Niagara Falls unit should be considered during the detailed design phase. At the current feasibility level assessment, it is anticipated that potential excess pressures from the Gasport unit can be manages with through pressure relief wells and drainage galleries within the excavation.

At the final (Phase 4) stage of the excavation, it is not expected that significant uplift pressures would develop within the relatively thick layer of Cabot Head Shale (generally understood to be impermeable). However, if evidence of fractures and / or bulging due to uplift are noticed, then again, these pressures are anticipated to be manageable through the use of pressure and drainage galleries in the excavation.

Again, both aspects of the quarry development should be reviewed during the detailed design phase.

5.0 GEOTECHNICAL SUMMARY

Based on the available geotechnical information and Client provided cross-sections, the following general conclusions may be drawn from the limited feasibility level geotechnical assessment:

- A composite berm design (i.e., clay core and predominant granular shell) should be considered, and is expected to be stable at an inclination of about 2H:1V. Berms constructed entirely of clay/impermeable materials at this inclination (i.e., 2H:1V) are not suitable for this site.
- Subdrains may be added to the composite berms to increase the overall stability.
- The proposed trench and pond configurations are expected to be stable. However, further detailed analysis should be conducted to assess the stability for a wider range of groundwater and liner conditions (i.e., rapid drawdown and liner stability) prior to construction.
- The fine grained soils on site may be suitable for re-use as a compacted clay / impermeable liner and berm 'cores' on-site. However, site specific investigation, analysis and testing will be required to confirm.

Thus, it may be expected that the current quarry/pit design features assessed in this report may be considered feasible, pursuant to further detailed analysis using site specific information and designs updated based on the recommendations in this report. If changes are made to the preliminary designs prior to finalizing the project design plans at this stage, GEMTEC should be provided an opportunity to review and update the recommendations provided herein.

6.0 CLOSURE

We trust that this report meets your immediate requirements. If you have any questions or require additional information, please contact the undersigned.

Regards,

GEMTEC Consulting Engineers and Scientists Limited



Connor McCormick, P.Eng.
Geotechnical Engineer



Graeme Skinner, PhD., P.Eng.
Reviewer, Principal Geotechnical Engineer

Attachments: Conditions and Limitations of This Report
Borehole Location Plan

Appendix A: Background Geotechnical Information Provide by Client (Abbreviated)
Appendix B: Proposed Cross Sections Provided by Client
Appendix C: Global Slope Stability Analysis Results

ATTACHMENTS

Conditions and Limitations of This Report
Borehole Location Plan

Conditions and Limitations of This Report

1. **Standard of Care:** GEMTEC has prepared this report in a manner consistent with generally accepted engineering or environmental consulting practice in the jurisdiction in which the services are provided at the time of the report. No other warranty, expressed or implied is made.
2. **Copyright:** The contents of this report are subject to copyright owned by GEMTEC, save to the extent that copyright has been legally assigned by us to another party or is used by GEMTEC under license. To the extent that GEMTEC owns the copyright in this report, it may not be copied without our prior written agreement for any purpose other than the purpose indicated in this report. The methodology (if any) contained in this report is provided to the Client in confidence and must not be disclosed or copied to third parties without the prior written agreement of GEMTEC. Disclosure of that information may constitute an actionable breach of confidence or may otherwise prejudice our commercial interests.
3. **Complete Report:** This report is of a summary nature and is not intended to stand alone without reference to the instructions given to GEMTEC by the Client, communications between GEMTEC and the Client and to any other reports prepared by GEMTEC for the Client relative to the specific site described in the report. In order to properly understand the suggestions, recommendations and opinions expressed in this report, reference must be made to the whole of the report. GEMTEC can not be responsible for use of portions of the report without reference to the entire report.
4. **Basis of Report:** This Report has been prepared for the specific site, development, design objectives and purposes that were described to GEMTEC by the Client. The factual data, interpretations and recommendations pertain to a specific project as described in this report and are not applicable to any other project or site location. The applicability and reliability of any of the findings, recommendations, suggestions, or opinions expressed in the document, subject to the limitations provided herein, are only valid to the extent that this report expressly addresses the proposed development, design objectives and purposes. Any change of site conditions, purpose or development plans may alter the validity of the report and GEMTEC cannot be responsible for use of this report, or portions thereof, unless GEMTEC is requested to review any changes and, if necessary, revise the report.
5. **Time Dependence:** If the proposed project is not undertaken by the Client within 18 months following the issuance of this report, or within the timeframe understood by GEMTEC to be contemplated by the Client, the guidance and recommendations within the report should not be considered valid unless reviewed and amended or validated by GEMTEC in writing.
6. **Use of This Report:** The information, recommendations and opinions expressed in this report are for the sole benefit of the Client. No other party may use or rely on this report or any portion thereof without GEMTEC's express written consent. If the report was prepared to be included for a specific permit application process, then upon the reasonable request of the client, GEMTEC may authorize in writing the use of this report by the regulatory agency as an Approved User for the specific and identified purpose of the applicable permit review process.

   Contractors bidding on, or undertaking the work, should rely on their own investigations, as well as their own interpretations of the factual data presented in the report, as to how subsurface conditions may affect their work, including but not limited to proposed construction techniques, schedule, safety and equipment capabilities.
7. **No Legal Representations:** GEMTEC makes no representations whatsoever concerning the legal significance of its findings, or as to other legal matters touched on in this report, including but not limited to, ownership of any property, or the application of any law to the facts set forth herein. With respect to regulatory compliance issues, regulatory statutes are subject to interpretation and change. Such interpretations and regulatory changes should be reviewed with legal counsel.

8. **Decrease in property value:** GEMTEC shall not be responsible for any decrease, real or perceived, of the property or site's value or failure to complete a transaction, as a consequence of the information contained in this report.
9. **Reliance on Provided Information:** The evaluation and conclusions contained in this report have been prepared on the basis of conditions in evidence at the time of site inspections and on the basis of information provided to us. We have relied in good faith upon representations. information and instructions provided by the Client and others concerning the site. Accordingly, we cannot accept responsibility for any deficiency, misstatement or inaccuracy contained in this report as a result of misstatements, omissions, misrepresentations. or fraudulent acts of the Client or other persons providing information relied on by us. We are entitled to rely on such representations, information and instructions and are not required to carry out investigations to determine the truth or accuracy of such representations, information and instructions.
10. **Investigation Limitations:** Site investigation programs are a professional estimate of the scope of investigation required to provide a general profile of subsurface conditions but even a comprehensive investigation, sampling and testing program may fail to detect all or certain subsurface conditions.

    The data derived from the site investigation program and subsequent laboratory testing are interpreted by trained personnel and extrapolated across the site to form an inferred geological representation and an engineering opinion is rendered about overall subsurface conditions and their likely behaviour with regard to the proposed development. Conditions between and beyond the borehole/test hole locations may differ from those encountered at the borehole/test hole locations and the actual conditions at the site might differ from those inferred to exist, since no subsurface exploration program, no matter how comprehensive, can reveal all subsurface details and anomalies. Accordingly, GEMTEC does not warrant or guarantee the exactness of of the subsurface descriptions.

    Soil and groundwater conditions shown in the factual data and described in the report are the observed conditions at the time of their determination-or measurement. Unless otherwise noted, those conditions form the basis of the recommendations in the report. Groundwater conditions may vary between and beyond reported locations and can be affected by annual, seasonal and meteorological conditions. The condition of the soil, rock and groundwater may be significantly altered by construction activities (traffic, excavation, groundwater level lowering, pile driving, blasting, etc.) on the site or on adjacent sites. Excavation may expose the soils to changes due to wetting, drying or frost. Unless otherwise indicated the soil must be protected from these changes during construction.

    In addition, fill of variable physical and chemical composition can be present over portions of the site or on adjacent properties. The professional services retained for this project include only the geotechnical aspects of the subsurface conditions at the site, unless otherwise specifically stated and identified in the report. The presence or implication(s) of possible surface and/or subsurface contamination resulting from previous activities or uses of the site and/or resulting from the introduction onto the site of materials from off-site sources are outside the terms of reference for this project and have not been investigated or addressed.
11. **Sample Disposal:** GEMTEC will dispose of all uncontaminated soil and/or rock samples 60 days following issue of this report or, upon written request of the Client, will store uncontaminated samples and materials at the Client's expense. In the event that actual contaminated soils, fills or groundwater are encountered or are inferred to be present, all contaminated samples shall remain the property and responsibility of the Client for proper disposal.
12. **Follow-Up and Construction Services:** All details of the design were not known at the time of submission of GEMTEC's report. GEMTEC should be retained to review the final design, project plans and documents prior to construction, to confirm that they are consistent with the intent of GEMTEC's report.

    During construction, GEMTEC should be retained to perform sufficient and timely observations of encountered conditions to confirm and document that the subsurface conditions do not

materially differ from those interpreted conditions considered in the preparation of GEMTEC's report and to confirm and document that construction activities do not adversely affect the suggestions, recommendations and opinions contained in GEMTEC's report. Adequate field review, observation and testing during construction are necessary for GEMTEC to be able to provide letters of assurance, in accordance with the requirements of many regulatory authorities. In cases where this recommendation is not followed, GEMTEC's responsibility is limited to interpreting accurately the information encountered at the borehole locations, at the time of their initial determination or measurement during the preparation of the Report.

13. **Changed Conditions:** Where conditions encountered at the site differ significantly from those anticipated in this report, either due to natural variability of subsurface conditions or construction activities, it is a condition of this report that GEMTEC be notified of any changes and be provided with an opportunity to review or revise the recommendations within this report. Recognition of changed soil and rock conditions requires experience and it is recommended that GEMTEC be employed to visit the site with sufficient frequency to detect if conditions have changed significantly.
14. **Drainage:** Drainage of subsurface water is commonly required either for temporary or permanent installations for the project. Improper design or construction of drainage or dewatering can have serious consequences. GEMTEC takes no responsibility for the effects of drainage unless specifically involved in the detailed design and construction monitoring of the system.

BH08-1
BH08-2
BH08-7
BH09-37
BH08-4-1
BH08-4-2
BH08-4
BH10-39
BH08-9
BH08-6
BH08-29
BH08-5
BH08-28
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BH08-19
BH08-18
Shrigley
Redickville
Honeywood
Conover
Black Bank
Black Bank Hill
Horning's Mills
Mulmur Hills
Pine River
Sideroad 30
Sideroad 240
Sideroad 350
Sideroad 250
Sideroad 270
Sideroad 15
Sideroad 280
4th Line
5th Line
6th Line NE
8th Line NE
2nd Line W
Centre Rd
Prince of Wales Rd
Mulmur Melancthon Townline
County Road 124
4897500
4895000
4892500
4890000
4887500
557500
560000
562500
565000
567500

Legend:

- Roads
- Express/Highway
- Freeway
- Municipal Boundary
- Strada Property Limit
- Proposed Quarry Limit
- Highland BH Locations
- River/Stream
- Lake
- Wetland
- Model Boundary
- Escarpment Brow
- NRSI Mapped Streams

0 1000 2000

Units: UTM NAD83 Zone 17

Data Sources:
Produced with information provided by the Ministry of Natural Resources,
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Strada Aggregates Proposed Shelburne Pit/Quarry

Genivar Locations with Geotechnical Information

Drawing prepared 2024-10-08

STRADA

EARTHfx INCORPORATED

APPENDIX A

Background Geotechnical Information Provide by Client
(Abbreviated)

BOREHOLE NO. BH08-11

PROJECT NAME: MELANCTHON HYDROGEOLOGIC & HYDROLOGIC ASSESSMENT **PROJECT NO.:** 00-082032.09

CLIENT: THE HIGHLAND COMPANIES **DATE COMPLETED:** May 28, 2008

BOREHOLE TYPE: 222 mm OD MUD ROTARY **SUPERVISOR:** LJM

GROUND ELEVATION: NOT DETERMINED **REVIEWER:** JTB

DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATIGRAPHY	MONITOR DETAILS	SAMPLE TYPE	SAMPLE N VALUE	SAMPLE % WATER	SAMPLE % RECOVERY	SAMPLE RQD (%)	CONE PENETRATION "N" VALUE / SHEAR STRENGTH	WATER CONTENT % (W_P – W_L)	REMARKS
0.0											
1.0	TOPSOIL: DARK BROWN TOPSOIL, TURNING SANDY SILT TO SILTY SAND, COMPACT, MOIST.			SS1	11		75				
1.1	SAND AND GRAVEL: LIGHT BROWN MEDIUM TO COARSE SAND AND GRAVEL, SOME SILT, TRACE CRUSHED ROCK, DENSE TO VERY DENSE, MOIST.			SS2	34		50				
2.0											
3.0				SS3	79		92		79		
4.0											
4.1	SAND: BROWN MEDIUM TO FINE SAND, SOME SILT, INCREASING SILT CONTENT WITH DEPTH, COMPACT TO DENSE, MOIST TO SATURATED.			SS4	46		100		46		
5.0											
6.0				SS5	17		75				
7.0											
8.0				SS6	34		75				
8.7	SILT AND SAND: BROWN SILT AND FINE SAND, DENSE, WET TO SATURATED.										
9.0				SS7	47		100		47		
10.0											
11.0				SS8	68		100		68		
11.7	SAND: LIGHT BROWN SILTY GRAVELLY SAND, VERY DENSE, WET TO SATURATED.										
12.0				SS9	87		100		87		
12.5	WEATHERED BEDROCK: BEIGE WEATHERED BEDROCK.										
13.0											
13.4	BEDROCK: BEIGE BEDROCK.										
14.0											
14.9	BOREHOLE TERMINATED AT 14.9 m IN BEDROCK.										
15.0											
16.0											
17.0											
18.0											
19.0											
20.0											

GENIVAR GEOLOGIC B/W (METRIC) 0-08203209 DOWNEY PROPERTY.GPJ JAGGER HIMS BASIC.GDT 11/29/10

BOREHOLE NO. BH08-12

PROJECT NAME: MELANCTHON HYDROGEOLOGIC & HYDROLOGIC ASSESSMENT **PROJECT NO.:** 00-082032.09

CLIENT: THE HIGHLAND COMPANIES **DATE COMPLETED:** Jun 03, 2008

BOREHOLE TYPE: 222 mm OD MUD ROTARY **SUPERVISOR:** LJM

GROUND ELEVATION: NOT DETERMINED **REVIEWER:** JTB

DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATIGRAPHY	MONITOR DETAILS	SAMPLE TYPE	SAMPLE N VALUE	SAMPLE % WATER	SAMPLE % RECOVERY	SAMPLE RQD (%)	CONE PENETRATION "N" VALUE / SHEAR STRENGTH	WATER CONTENT % (W_P – W_L)	REMARKS
0.0											
0.1	TOPSOIL: DARK BROWN TOPSOIL WITH ORGANICS PRESENT.			GS1							
1.0	SAND AND GRAVEL: BROWN SAND AND GRAVEL, TRACE TO SOME SILT, INCREASED SILT CONTENT WITH DEPTH.			GS2							
2.0											
3.0				GS3							
4.0											
5.0				GS4							
6.0											
7.0				GS5							
8.0											
9.0				GS6							
10.0											
11.0				GS7							
12.0											
13.0				GS8							
14.0											
14.4	SILTY GRAVEL: BROWN SILTY GRAVEL, SOME SAND WITH SOME WEATHERED BEDROCK PIECES.			GS9							
15.0											
15.8	BEDROCK: BEIGE BEDROCK.			GS10							
16.0											
17.0				GS11							
17.4	BOREHOLE TERMINATED AT 17.4 m IN BEDROCK.			GS12							
18.0											
19.0											
20.0											

GENIVAR GEOLOGIC B/W (METRIC) 0-08203209 DOWNEY PROPERTY.GPJ JAGGER HIMS BASIC.GDT 11/29/10

BOREHOLE NO. BH08-13

PROJECT NAME: MELANCTHON HYDROGEOLOGIC & HYDROLOGIC ASSESSMENT **PROJECT NO.:** 00-082032.09

CLIENT: THE HIGHLAND COMPANIES **DATE COMPLETED:** Jun 03, 2008

BOREHOLE TYPE: 222 mm OD MUD ROTARY **SUPERVISOR:** LJM

GROUND ELEVATION: NOT DETERMINED **REVIEWER:** JTB

DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATIGRAPHY	MONITOR DETAILS	SAMPLE TYPE	SAMPLE N VALUE	SAMPLE % WATER	SAMPLE % RECOVERY	SAMPLE RQD (%)	CONE PENETRATION "N" VALUE / SHEAR STRENGTH	WATER CONTENT % (W_P – W_L)	REMARKS
0.0											
0.6	TOPSOIL: DARK BROWN TOPSOIL WITH ORGANICS PRESENT.			GS1							
1.0	CLAYEY SILT: BROWN CLAYEY SILT TO SILT WITH TRACE SAND AND GRAVEL.										
2.0				GS2							
3.0											
4.0				GS3							
4.6	SAND: BROWN SAND AND GRAVEL, TRACE SILT, WITH TRACE TO SOME WEATHERED BEDROCK PIECES.										
5.0				GS4							
5.5	WEATHERED BEDROCK: BEIGE WEATHERED BEDROCK WITH TRACE TO SOME SILT.										
6.0											
7.0				GS5							
8.0											
8.5	BEDROCK: BEIGE BEDROCK.			GS6							
9.0											
10.0				GS7							
10.1	BOREHOLE TERMINATED AT 10.1 m IN BEDROCK.										
11.0											
12.0											
13.0											
14.0											
15.0											
16.0											
17.0											
18.0											
19.0											
20.0											

GENIVAR GEOLOGIC B/W (METRIC) 0-08203209 DOWNEY PROPERTY.GPJ JAGGER HIMS BASIC.GDT 11/29/10

BOREHOLE NO. BH08-14

PROJECT NAME: MELANCTHON HYDROGEOLOGIC & HYDROLOGIC ASSESSMENT **PROJECT NO.:** 00-082032.09

CLIENT: THE HIGHLAND COMPANIES **DATE COMPLETED:** Jun 03, 2008

BOREHOLE TYPE: 222 mm OD MUD ROTARY **SUPERVISOR:** LJM

GROUND ELEVATION: NOT DETERMINED **REVIEWER:** JTB

DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATIGRAPHY	MONITOR DETAILS	SAMPLE TYPE	SAMPLE N VALUE	SAMPLE % WATER	SAMPLE % RECOVERY	SAMPLE RQD (%)	CONE PENETRATION "N" VALUE 10 20 30 / SHEAR STRENGTH	WATER CONTENT % 10 20 30 (W_P – W_L)	REMARKS
0.0											
0.6	TOPSOIL: DARK BROWN TOPSOIL, TURNING SANDY SILT TO SILTY SAND, MOIST.			GS1							
1.0	SANDY SILT: BROWN TO GREY AT 7.0 m, SILTY SAND TO SANDY SILT, TRACE GRAVEL TO GRAVEL.										
2.0				GS2							
3.0											
4.0				GS3							
5.0											
6.0				GS4							
7.0				GS5							
7.6	WEATHERED BEDROCK: BEIGE WEATHERED BEDROCK.										
8.0				GS6							
8.5	BEDROCK: BEIGE BEDROCK.										
9.0											
10.0				GS7							
10.7	BOREHOLE TERMINATED AT 10.7 m IN BEDROCK.										
11.0											
12.0											
13.0											
14.0											
15.0											
16.0											
17.0											
18.0											
19.0											
20.0											

GENIVAR GEOLOGIC B/W (METRIC) 0-08203209 DOWNEY PROPERTY.GPJ JAGGER HIMS BASIC.GDT 11/29/10

BOREHOLE NO. BH08-15

PROJECT NAME: MELANCTHON HYDROGEOLOGIC & HYDROLOGIC ASSESSMENT **PROJECT NO.:** 00-082032.09

CLIENT: THE HIGHLAND COMPANIES **DATE COMPLETED:** Jun 04, 2008

BOREHOLE TYPE: 222 mm OD MUD ROTARY **SUPERVISOR:** LJM

GROUND ELEVATION: NOT DETERMINED **REVIEWER:** JTB

DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATIGRAPHY	MONITOR DETAILS	SAMPLE TYPE	SAMPLE N VALUE	SAMPLE % WATER	SAMPLE % RECOVERY	SAMPLE RQD (%)	CONE PENETRATION "N" VALUE 10 20 30 / SHEAR STRENGTH	WATER CONTENT % 10 20 30 / W_P W_L	REMARKS
0.0											
0.6	TOPSOIL: DARK BROWN TOPSOIL WITH ORGANICS PRESENT.										
1.0	SAND AND GRAVEL: BROWN SAND WITH GRAVEL, INCREASING SILT CONTENT WITH DEPTH.			GS1							
2.0				GS2							
3.0											
4.0				GS3							
5.0				GS4							
6.0											
7.0				GS5							
8.0				GS6							
9.0											
10.0				GS7							
11.0											
12.0				GS8							
13.0				GS9							
14.0											
15.0				GS10							
16.0											
16.5	BEDROCK: BEIGE BEDROCK.			GS11							
17.0											
18.0				GS12							
18.3	BOREHOLE TERMINATED AT 18.3 m BEDROCK.										
19.0											
20.0											

GENIVAR GEOLOGIC B/W (METRIC) 0-08203209 DOWNEY PROPERTY.GPJ JAGGER HIMS BASIC.GDT 11/29/10

BOREHOLE NO. BH08-16

PROJECT NAME: MELANCTHON HYDROGEOLOGIC & HYDROLOGIC ASSESSMENT **PROJECT NO.:** 00-082032.09

CLIENT: THE HIGHLAND COMPANIES **DATE COMPLETED:** Jun 04, 2008

BOREHOLE TYPE: 222 mm OD MUD ROTARY **SUPERVISOR:** LJM

GROUND ELEVATION: NOT DETERMINED **REVIEWER:** JTB

DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATIGRAPHY	MONITOR DETAILS	SAMPLE TYPE	SAMPLE N VALUE	SAMPLE % WATER	SAMPLE % RECOVERY	SAMPLE RQD (%)	CONE PENETRATION "N" VALUE 10 20 30 / SHEAR STRENGTH	WATER CONTENT % 10 20 30 (W_P W_L)	REMARKS
0.0											
0.6	TOPSOIL: DARK BROWN TOPSOIL WITH ORGANICS PRESENT.			GS1							
1.0	SAND AND GRAVEL: BROWN SAND AND GRAVEL, WEATHERED BEDROCK PIECES FROM 3.0 m TO 4.6 m.										
2.0				GS2							
3.0											
4.0				GS3							
4.6	BEDROCK: BEIGE BEDROCK.										
5.0				GS4							
6.0											
6.1	BOREHOLE TERMINATED AT 6.1 m IN BEDROCK .										
7.0											
8.0											
9.0											
10.0											
11.0											
12.0											
13.0											
14.0											
15.0											
16.0											
17.0											
18.0											
19.0											
20.0											

GENIVAR GEOLOGIC B/W (METRIC) 0-08203209 DOWNEY PROPERTY.GPJ JAGGER HIMS BASIC.GDT 11/29/10

BOREHOLE NO. BH08-17

PROJECT NAME: MELANCTHON HYDROGEOLOGIC & HYDROLOGIC ASSESSMENT **PROJECT NO.:** 00-082032.09

CLIENT: THE HIGHLAND COMPANIES **DATE COMPLETED:** Jun 04, 2008

BOREHOLE TYPE: 222 mm OD MUD ROTARY **SUPERVISOR:** LJM

GROUND ELEVATION: NOT DETERMINED **REVIEWER:** JTB

DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATIGRAPHY	MONITOR DETAILS	SAMPLE TYPE	SAMPLE N VALUE	SAMPLE % WATER	SAMPLE % RECOVERY	SAMPLE RQD (%)	CONE PENETRATION "N" VALUE / SHEAR STRENGTH	WATER CONTENT % (W_P – W_L)	REMARKS
0.0											
0.6	TOPSOIL: DARK BROWN TOPSOIL WITH ORGANICS PRESENT.			GS1							
1.5	SILTY SAND: DARK BROWN SILTY SAND WITH SOME TO TRACE GRAVEL.			GS2							
	GRAVELLY SANDY SILT: BROWN TO GREY AT 7.0 m, GRAVELLY SANDY SILT, CONTAINS WEATHERED DOLOSTONE AT 9.1 m.			GS3							
				GS4							
				GS5							
				GS6							
				GS7							
10.1	BEDROCK: BEIGE BEDROCK.			GS8							
11.6	BOREHOLE TERMINATED AT 11.6 m IN BEDROCK.										

GENIVAR GEOLOGIC B/W (METRIC) 0-08203209 DOWNEY PROPERTY.GPJ JAGGER HIMS BASIC.GDT 11/29/10

BOREHOLE NO. BH08-18

PROJECT NAME: MELANCTHON HYDROGEOLOGIC AND HYDROLOGIC ASSESSMENT **PROJECT NO.:** 0-082032.09

CLIENT: THE HIGHLAND COMPANIES **DATE:** MAY 15 - 20, 2008

BOREHOLE TYPE: 222 mm O.D. MUD ROTARY / PQ CORE **SUPERVISOR:** BTC

GROUND ELEVATION: 516.61 m ASL **REVIEWER:** KJF/JTB

DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATIGRAPHY	MONITOR DETAILS	SAMPLE TYPE	SAMPLE N / RQD VALUE	SAMPLE % WATER	SAMPLE % RECOVERY	N VALUE / WATER CONTENT % / HYDRAULIC CONDUCTIVITY (LOG) (m / s)	REMARKS
0			I II					N VALUE 10 20 30; WATER CONTENT % 10 20 30; HYDRAULIC CONDUCTIVITY (LOG) (m / s) −10 −9 −8 −7 −6 −5 −4	
2	SILTY SAND: SILTY SAND, GRAVEL/COBBLES FROM 3.0 m TO 3.7 m, 6.1 m TO 9.1 m, 12.2 m TO 13.4 m, AND 16.5 m TO 18.3 m.			GS1					MONITORING WELLS INSTALLED IN SEPARATE BOREHOLES.
4				GS2					
6				GS3					
8				GS4					
10				GS5					HYDRAULIC CONDUCTIVITY FOR INTERVAL BASED ON SLUG TEST.
12									
14				GS6					
16									
18									
18.3	DOLOSTONE: LIGHT BUFF BROWN TO TAN BROWN BECOMING A DARKER GREYISH BROWN BELOW 44.8 m BECOMING MOTTLED BLUISH TO PINKISH GREY BELOW 75.3 m, MEDIUM TO COARSE GRAINED TO 22.6 m BECOMING FINER GRAINED BELOW 22.6 m, THICKLY BEDDED TO MASSIVE, HARD, SLIGHTLY WEATHERED TO 37.5 m WITH RUSTY STAINED FRACTURE SURFACES, POOR RQD TO ABOUT 25 m THEN TYPICALLY FAIR TO GOOD RQD, ZONE OF POOR RQD AT ABOUT 32 m. HIGHLY FRACTURED TO 22.6 m THEN MODERATELY FRACTURED TO 81.0 m, VUGGY TO PITTED APPEARANCE (3 mm TO 5 mm), TYPICALLY UP TO 5% BY VOLUME, SHARP LOWER CONTACT AT 81.0 m.			GS7					CONTACT BASED ON FIELD OBSEVATIONS. NO CORE RECOVERED 19.8 m TO 20.7 m DUE TO DRILLING METHODOLOGY. REEFAL FACIES APPEARANCE.
20									

BOREHOLE NO. BH08-18

PROJECT NAME: MELANCTHON HYDROGEOLOGIC AND HYDROLOGIC ASSESSMENT **PROJECT NO.:** 0-082032.09

CLIENT: THE HIGHLAND COMPANIES **DATE:** MAY 15 - 20, 2008

BOREHOLE TYPE: 222 mm O.D. MUD ROTARY / PQ CORE **SUPERVISOR:** BTC

GROUND ELEVATION: 516.61 m ASL **REVIEWER:** KJF/JTB

DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATIGRAPHY	MONITOR DETAILS	SAMPLE TYPE	SAMPLE N / RQD VALUE	SAMPLE % WATER	SAMPLE % RECOVERY	N VALUE 10 20 30 / WATER CONTENT % 10 20 30 / HYDRAULIC CONDUCTIVITY (LOG) (m / s) −10 −9 −8 −7 −6 −5 −4	REMARKS
20	DOLOSTONE: CONTINUED.		I						MONITORING WELLS INSTALLED IN SEPARATE BOREHOLES.
22				RC8	33		84		CASING ADVANCED TO 20.1 m IN BOREHOLE BH08-18-I. OPEN BOREHOLE BELOW 20.1 m.
24									
26				RC9	68		100		
28	ZONE OF BROKEN RECOVERY 26.8 m To 26.9 m								
30				RC10	52		91		
32	ZONE OF BROKEN RECOVERY 29.9 m TO 31.0 m CHALKY APPEARANCE 30.2 m TO 33.2 m .			RC11	39		83		
34	ZONE OF BROKEN RECOVERY 33.7 m TO 37.8 m								
36				RC12	50		85		
38				RC13	79		97		
40									

Reference No.: 0-08203209 BH08-18.dwg

BOREHOLE NO. BH08-18

PROJECT NAME: MELANCTHON HYDROGEOLOGIC AND HYDROLOGIC ASSESSMENT **PROJECT NO.:** 0-082032.09

CLIENT: THE HIGHLAND COMPANIES **DATE:** MAY 15 - 20, 2008

BOREHOLE TYPE: 222 mm O.D. MUD ROTARY / PQ CORE **SUPERVISOR:** BTC

GROUND ELEVATION: 516.61 m ASL **REVIEWER:** KJF/JTB

DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATIGRAPHY	MONITOR DETAILS	SAMPLE TYPE	SAMPLE N / RQD VALUE	SAMPLE % WATER	SAMPLE % RECOVERY	N VALUE / HYDRAULIC CONDUCTIVITY (LOG) (m / s)	WATER CONTENT %	REMARKS
40	DOLOSTONE: CONTINUED.			RC14	69		100			MONITORING WELLS INSTALLED IN SEPARATE BOREHOLES.
42										
44				RC15	73		89			
46										
48				RC16	54		100			
50				RC17	89		98			
52										
54	ZONES OF BROKEN RECOVERY 48.2m TO 48.8m 54.3m TO 54.9m			RC18	69		100			
56				RC19	91		97			
58	0.3 m ZONES UP TO 40% BY VOLUME VUGS AND CAVITIES 25 mm TO 76 mm IN SIZE 56.7 m TO 68.9 m. 1 TO 3 CAVITIES PER 1.5 m RUN. CALCITE CRYSTALS IN CAVITIES.									
60				RC20	76		100			

N VALUE: 10 20 30

WATER CONTENT %: 10 20 30

HYDRAULIC CONDUCTIVITY (LOG) (m / s): −10 −9 −8 −7 −6 −5 −4

Reference No.: 0-08203209 BH08-18.dwg

BOREHOLE NO. BH08-18

PROJECT NAME: MELANCTHON HYDROGEOLOGIC AND HYDROLOGIC ASSESSMENT **PROJECT NO.:** 0-082032.09

CLIENT: THE HIGHLAND COMPANIES **DATE:** MAY 15 - 20, 2008

BOREHOLE TYPE: 222 mm O.D. MUD ROTARY / PQ CORE **SUPERVISOR:** BTC

GROUND ELEVATION: 516.61 m ASL **REVIEWER:** KJF/JTB

DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATIGRAPHY	MONITOR DETAILS	SAMPLE TYPE	SAMPLE N / RQD VALUE	SAMPLE % WATER	SAMPLE % RECOVERY	N VALUE / HYDRAULIC CONDUCTIVITY (LOG) (m / s)	WATER CONTENT %	REMARKS
60								10 20 30 / −10 −9 −8 −7 −6 −5 −4	10 20 30	
	DOLOSTONE: CONTINUED.									MONITORING WELLS INSTALLED IN SEPARATE BOREHOLES.
62	ZONES OF BROKEN RECOVERY 60.9 m TO 61.6 m 69.1 m TO 69.3 m			RC21	77		94			
64										
				RC22	79		100			
66										
68										
				RC23	90		100			
70										
				RC24	95		100			
72										
74										
				RC25	80		96			
76										
78				RC26	90		100			
	THIN SHALEY PARTINGS BELOW 78.6 m.									
80										

BOREHOLE NO. BH08-18

PROJECT NAME: MELANCTHON HYDROGEOLOGIC AND HYDROLOGIC ASSESSMENT **PROJECT NO.:** 0-082032.09

CLIENT: THE HIGHLAND COMPANIES **DATE:** MAY 15 - 20, 2008

BOREHOLE TYPE: 222 mm O.D. MUD ROTARY / PQ CORE **SUPERVISOR:** BTC

GROUND ELEVATION: 516.61 m ASL **REVIEWER:** KJF/JTB

DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATIGRAPHY	MONITOR DETAILS	SAMPLE TYPE	SAMPLE N / RQD VALUE	SAMPLE % WATER	SAMPLE % RECOVERY	N VALUE / HYDRAULIC CONDUCTIVITY (LOG) (m / s)	WATER CONTENT %	REMARKS
80								10 20 30 / −10 −9 −8 −7 −6 −5 −4	10 20 30	
	DOLOSTONE: CONTINUED.			RC26	80		98			MONITORING WELLS INSTALLED IN SEPARATE BOREHOLES.
81.0	DOLOSTONE: GREYISH BROWN TO PINKISH GREY DOLOSTONE, FINE GRAINED, MEDIUM BEDDED, GOOD RQD, MODERATELY FRACTURED, HARD, SOME SHALEY PARTINGS UP TO 5 mm THICK, GREENISH GREY, 25 mm SHALE BED AT 82.9 m, MINOR PYRITE MINERALIZATION. SHARP LOWER CONTACT ON LOWEST DOLOSTONE BED.									
82										
83.0										
84	SHALE: GREENISH GREY CALCAREOUS SHALE, SOFT AT 83.0 m TO 83.2 m. REDDISH BROWN FOSSILIFEROUS DOLOMITIC SHALE BEDS UP TO 0.4 m THICK.			RC28	-		74			"-" INDICATES AN RQD NOT CALCULATED AS CORE RUN INCLUDES SHALE.
86										
				RC29	-		100			
88										
88.4	BOREHOLE TERMINATED AT 88.4 m IN SHALE.									
90										
92										
94										
96										
98										
100										

Reference No.: 0-08203209 BH08-18.dwg

BOREHOLE NO. BH08-19

PROJECT NAME: MELANCTHON HYDROGEOLOGIC AND HYDROLOGIC ASSESSMENT **PROJECT NO.:** 0-082032.09

CLIENT: THE HIGHLAND COMPANIES **DATE:** MAY 20, 2008

BOREHOLE TYPE: 222 mm O.D. MUD ROTARY / PQ CORE **SUPERVISOR:** BTC

GROUND ELEVATION: 506.33 m ASL **REVIEWER:** JTB

DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATIGRAPHY	MONITOR DETAILS	SAMPLE TYPE	SAMPLE N / RQD VALUE	SAMPLE % WATER	SAMPLE % RECOVERY	N VALUE / WATER CONTENT % / HYDRAULIC CONDUCTIVITY (LOG) (m / s)	REMARKS
0	SILTY SAND: BROWN SILTY SAND, SOME GRAVEL.			GS1				N VALUE 10 20 30; WATER CONTENT % 10 20 30; HYDRAULIC CONDUCTIVITY (LOG) (m / s) −10 −9 −8 −7 −6 −5 −4	
2									
2.7	COBBLES AND GRAVEL: BROWN CRUSHED COBBLES AND GRAVEL.								
3.0	SANDY SILT: BROWN SANDY SILT BECOMING CLAYEY SILT, TRACE GRAVEL.								
4									HYDRAULIC CONDUCTIVITY FOR INTERVAL BASED ON SLUG TEST.
6				GS2					
8									
9.4	DOLOSTONE: WEATHERED DOLOSTONE.			GS3					
10									
10.4	BOREHOLE TERMINATED AT 10.4 m IN DOLOSTONE.			GS4					CONTACT BASED ON FIELD OBSERVATIONS.
12									
14									
16									
18									
20									

Reference No.: 0-08203209 BH08-19.dwg

GENIVAR

BOREHOLE NO. BH08-24

PROJECT NAME: MELANCTHON HYDROGEOLOGIC AND HYDROLOGIC ASSESSMENT **PROJECT NO.:** 0-082032.13

CLIENT: THE HIGHLAND COMPANIES **DATE:** NOV. 25, 2008 to JAN. 28, 2009

BOREHOLE TYPE: 108 mm I.D. HOLLOW STEM AUGERS/PQ CORE **SUPERVISOR:** TAS/BTC/LJM

GROUND ELEVATION: 509.98 m ASL **REVIEWER:** KJF/JTB

DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATIGRAPHY	MONITOR DETAILS	SAMPLE TYPE	SAMPLE N / RQD VALUE	SAMPLE % WATER	SAMPLE % RECOVERY	N VALUE / HYDRAULIC CONDUCTIVITY (LOG) (m / s)	WATER CONTENT %	REMARKS
0			I II III					10 20 30 / −10 −9 −8 −7 −6 −5 −4	10 20 30	
0.3	**TOPSOIL:**			SS1	9	9	83			MONITORING WELLS INSTALLED IN SEPARATE BOREHOLES
	SAND: DARK BROWN SAND, SOME SILT, TRACE CLAY, MOIST, LOOSE. BOULDER FROM 2.5 m TO 2.6 m.			SS2	4	13	8			HYDRAULIC CONDUCTIVITY BASED ON PACKER TESTING UNLESS NOTED.
2				SS3	5	17	54			PARTICLE SIZE SAMPLE SS3 GRAVEL 0 % SAND 87 % SILT 11 % CLAY 2 %
2.6	**SILT AND SAND TILL TO SILTY SAND TILL:** BROWN SILT AND SAND TILL TO SILTY SAND TILL, MOIST BECOMING SATURATED AT 8.4 m, DENSE BECOMING COMPACT AT 3.8 m, BECOMING VERY DENSE AT 4.6 m.			SS4	38	15	50			
				SS5	45	22	17	45		
4				SS6	27	8	25			PARTICLE SIZE SAMPLE SS6 GRAVEL 16 % SAND 41 % SILT 34 % CLAY 9 %
				SS7	50 FOR 0.08 m	10	25	>50		
				SS8	50 FOR 0.10 m	8	21	>50		
6				SS9	50 FOR 0.08 m	8	13	>50		HYDRAULIC CONDUCTIVITY FOR INTERVAL BASED ON SLUG TEST.
				SS10	50 FOR 0.05 m	7	21	>50		
8				SS11	80 FOR 0.13 m	8	21	>80		
				SS12	63	10	25	63		HYDRAULIC CONDUTIVITY FOR FILTER PACK INTERVAL GREATER THAN 1 X 10^{-4} m/s BASED ON SLUG TEST ATTEMPT.
9.3	**DOLOSTONE:** TAN TO BUFF BROWN DOLOSTONE, BECOMING GREYISH BROWN TO LIGHT GREY AT 37.2 m, FINE TO MEDIUM GRAINED, THICKLY BEDDED, HARD. BROKEN RECOVERY WITH SUB-VERTICAL FRACTURES FROM 13.6 m TO 13.8 m, 40.4 m TO 40.6 m, AND 47.1 m TO 47.2 m. SLIGHTLY WEATHERED WITH RUSTY FRACTURE SURFACES TO 21.9 m. WEATHERED ZONE FROM 18.9 m TO 20.1 m. GOOD TO EXCELLENT RQD, MODERATELY FRACTURED TO 25.0 m, SLIGHTLY FRACTURED BELOW 25.0 m. FOSSILIFEROUS, ESPECIALLY BELOW 37.2 m, TYPICALLY 2% VUGS, UP TO 5% TO 10% VUGS WITH CALCITE FILLED 50 mm CAVITIES FROM 17.8 m TO 25.0 m AND 32.0 m TO 34.7 m. LESS THAN ONE STYLOLITE PER 0.3 m. NO VISIBLE CHERT. GRADATIONAL LOWER CONTACT AT CHANGE IN TEXTURE AT SHALE BED.			SS13	50 FOR 0.00 m	-	0	>50		
10										CONTACT BASED ON FIELD OBSERVATIONS.
										INTER REEFAL FACIES APPEARANCE
12				RC14	46		88			
14										
				RC15	93		100			
16										
				RC16	77		100			REEFAL FACIES APPEARANCE
18										
20										

Reference No.: 0-08203213-BH08-24.dwg

GENIVAR

BOREHOLE NO. BH08-24

PROJECT NAME: MELANCTHON HYDROGEOLOGIC AND HYDROLOGIC ASSESSMENT **PROJECT NO.:** 0-082032.13

CLIENT: THE HIGHLAND COMPANIES **DATE:** NOV. 25, 2008 to JAN. 28, 2009

BOREHOLE TYPE: 108 mm I.D. HOLLOW STEM AUGERS/PQ CORE **SUPERVISOR:** TAS/BTC/LJM

GROUND ELEVATION: 509.98 m ASL **REVIEWER:** KJF/JTB

DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATIGRAPHY	MONITOR DETAILS	SAMPLE TYPE	SAMPLE N / RQD VALUE	SAMPLE % WATER	SAMPLE % RECOVERY	N VALUE / WATER CONTENT % / HYDRAULIC CONDUCTIVITY (LOG) (m / s)	REMARKS
20	DOLOSTONE: CONTINUED.			RC17	98		90	N VALUE 10 20 30; WATER CONTENT % 10 20 30; HYDRAULIC CONDUCTIVITY (LOG) (m / s) −10 −9 −8 −7 −6 −5 −4	MONITORING WELLS INSTALLED IN SEPARATE BOREHOLES HYDRAULIC CONDUCTIVITY BASED ON PACKER TESTING UNLESS NOTED.
22									INTER REEFAL FACIES APPEARANCE
24				RC18	85		99		
26									
28				RC19	100		100		
30				RC20	92		100		
32									
34				RC21	98		100		
36				RC22	95		100		DASHED LINE INDICATES INFERRED MAXIMUM VALUE.
38									
40				RC23	97		100		

Reference No.: 0-08203213-BH08-24.dwg

BOREHOLE NO. BH08-24

PROJECT NAME: MELANCTHON HYDROGEOLOGIC AND HYDROLOGIC ASSESSMENT **PROJECT NO.:** 0-082032.13

CLIENT: THE HIGHLAND COMPANIES **DATE:** NOV. 25, 2008 to JAN. 28, 2009

BOREHOLE TYPE: 108 mm I.D. HOLLOW STEM AUGERS/PQ CORE **SUPERVISOR:** TAS/BTC/LJM

GROUND ELEVATION: 509.98 m ASL **REVIEWER:** KJF/JTB

DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATIGRAPHY	MONITOR DETAILS	SAMPLE TYPE	SAMPLE N / RQD VALUE	SAMPLE % WATER	SAMPLE % RECOVERY	N VALUE / WATER CONTENT % / HYDRAULIC CONDUCTIVITY (LOG) (m / s)	REMARKS
40								N VALUE 10 20 30; WATER CONTENT % 10 20 30; HYDRAULIC CONDUCTIVITY (LOG) (m / s) −10 −9 −8 −7 −6 −5 −4	
	DOLOSTONE: CONTINUED.								MONITORING WELLS INSTALLED IN SEPARATE BOREHOLES HYDRAULIC CONDUCTIVITY BASED ON PACKER TESTING UNLESS NOTED. DASHED LINE INDICATES INFERRED MAXIMUM VALUE. HYDRAULIC CONDUCTIVITY FOR INTERVAL BASED ON SLUG TEST.
42				RC24	89		100		
44				RC25	98		99		
46									
48				RC26	88		98		
50									
52				RC27	100		100		
54				RC28	98		100		
56									
58				RC29	96		100		
60									

BOREHOLE NO. BH08-24

PROJECT NAME: MELANCTHON HYDROGEOLOGIC AND HYDROLOGIC ASSESSMENT **PROJECT NO.:** 0-082032.13

CLIENT: THE HIGHLAND COMPANIES **DATE:** NOV. 25, 2008 to JAN. 28, 2009

BOREHOLE TYPE: 108 mm I.D. HOLLOW STEM AUGERS/PQ CORE **SUPERVISOR:** TAS/BTC/LJM

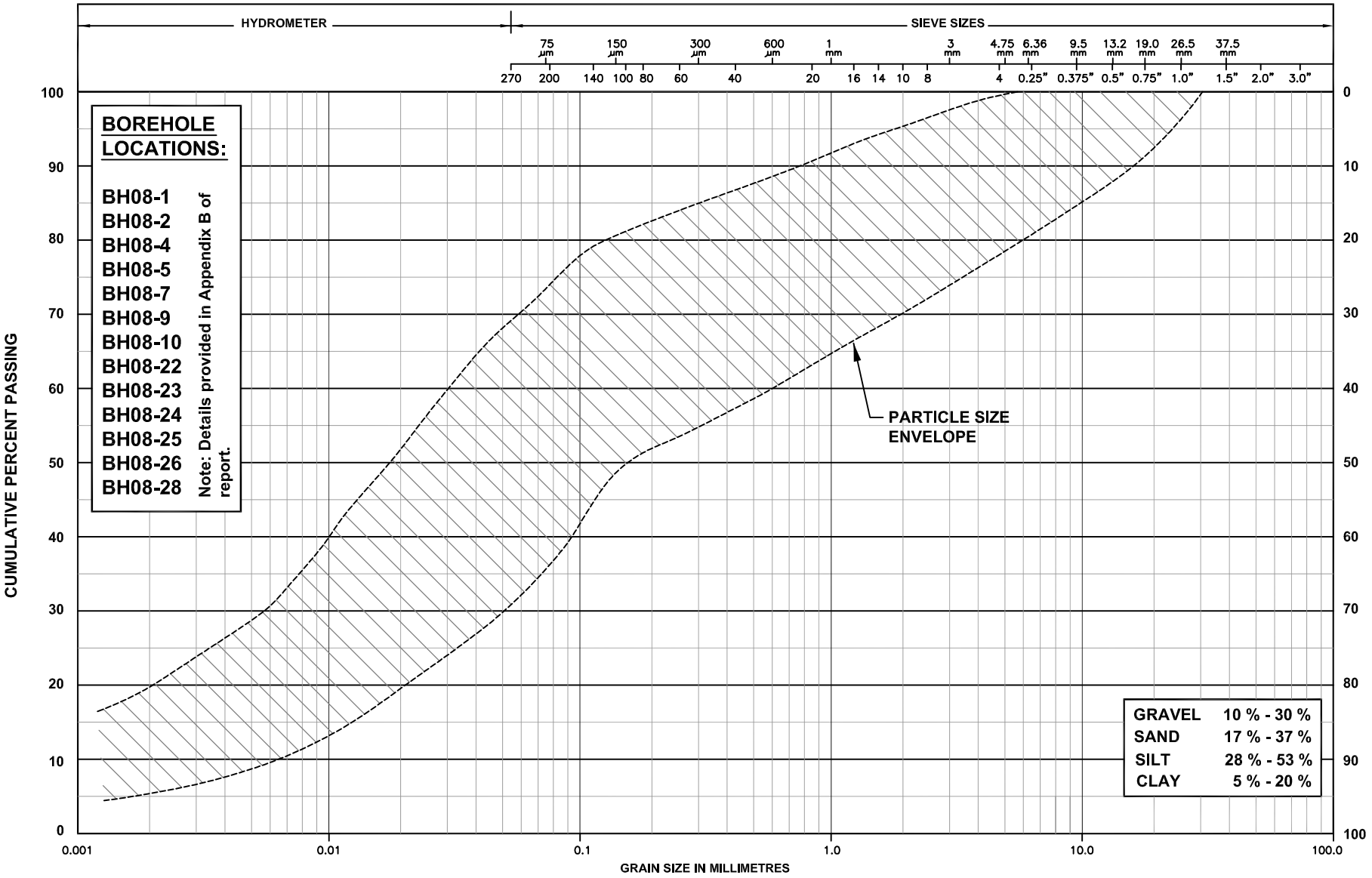
GROUND ELEVATION: 509.98 m ASL **REVIEWER:** KJF/JTB

DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATIGRAPHY	MONITOR DETAILS	SAMPLE TYPE	SAMPLE N / RQD VALUE	SAMPLE % WATER	SAMPLE % RECOVERY	N VALUE / WATER CONTENT % / HYDRAULIC CONDUCTIVITY (LOG) (m / s)	REMARKS
60								N VALUE 10 20 30; WATER CONTENT % 10 20 30; HYDRAULIC CONDUCTIVITY (LOG) (m / s) −10 −9 −8 −7 −6 −5 −4	
	DOLOSTONE: CONTINUED.			RC30	97		100		MONITORING WELLS INSTALLED IN SEPARATE BOREHOLES HYDRAULIC CONDUCTIVITY BASED ON PACKER TESTING UNLESS NOTED.
62									
64				RC31	95		100		
66									
				RC32	90		98		
68	DOLOSTONE: PINKISH BROWN DOLOSTONE, FINE TO MEDIUM GRAINED, MEDIUM BEDDED, HARD, GOOD TO EXCELLENT RQD, MODERATELY FRACTURED. SHALEY PARTINGS TYPICALLY 3 mm TO 5 mm THICK BUT UP TO 50 mm THICK, 5 TO 10 PER 0.3 m. MINOR PYRITE MINERALIZATION THROUGHOUT. SHARP LOWER CONTACT ON LOWEST DOLOSTONE BED.			RC33	-		97		"-" INDICATES AN RQD NOT CALCULATED AS CORE RUN INCLUDES SHALE.
67.8									
70	SHALE: GREENISH GREY CALCAREOUS SHALE, PLASTIC TO FRIABLE. REDDISH BROWN SANDY DOLOMITIC AND FOSSILIFEROUS BEDS UP TO 0.5 m THICK.								DASHED LINE INDICATES INFERRED MAXIMUM VALUE.
69.7									
72				RC34	-		83		
74	BOREHOLE TERMINATED AT 73.8 m IN SHALE.								
73.8									
76									
78									
80									

Reference No.: 0-08203213-BH08-24.dwg

GENIVAR

PARTICLE SIZE DISTRIBUTION



CLAY	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE	GRAVEL	COBBLES
	SILT			SAND				

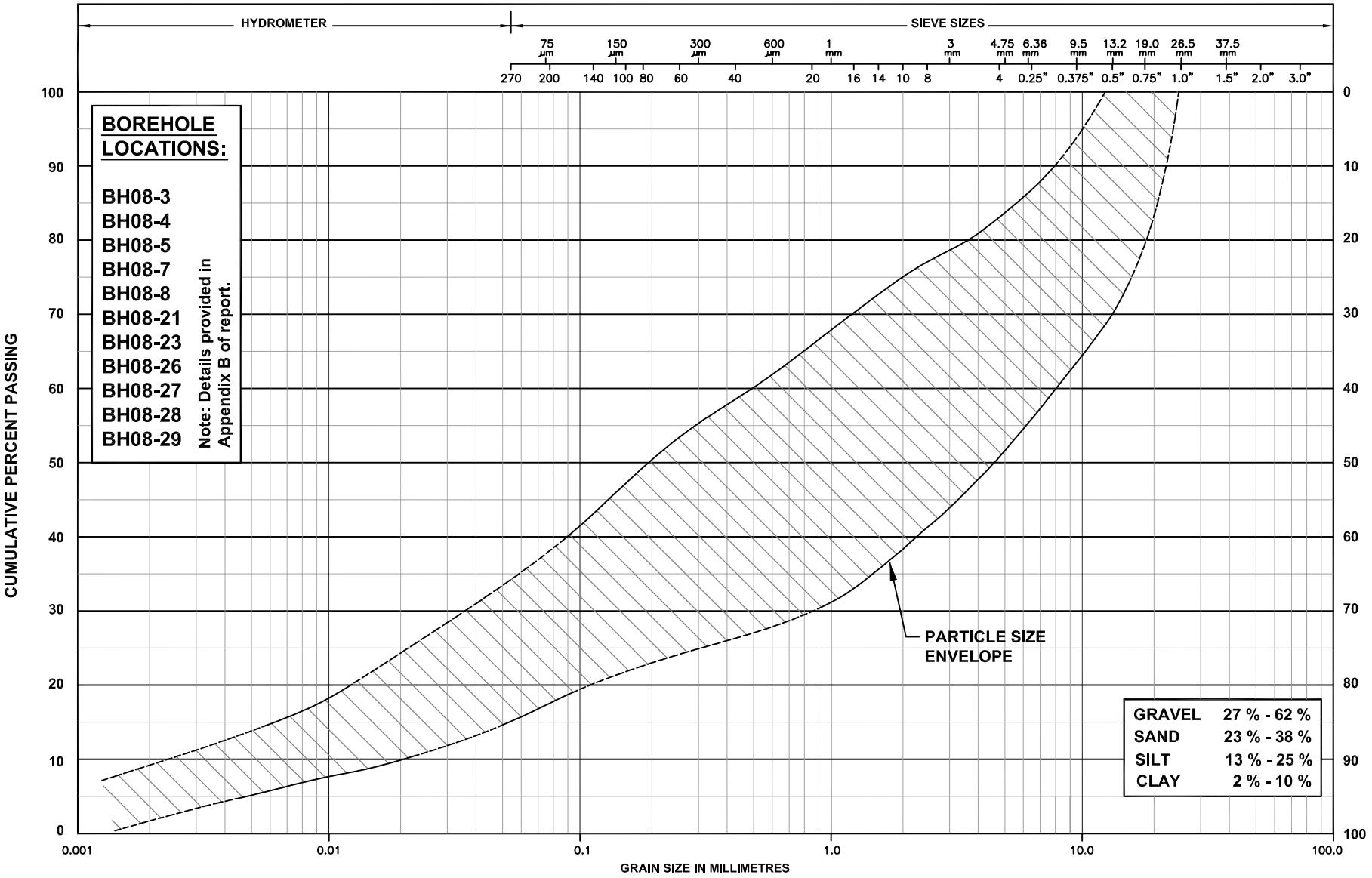
MIT SOIL CLASSIFICATION SYSTEM

PROJECT: MELANCTHON HYDROGEOLOGIC AND HYDROLOGIC ASSESSMENT PROJECT No: 0-082032.05 SAMPLE No: N/A

DEPTH: N/A REMARKS: Fine grained till FIGURE: 26

GENIVAR

PARTICLE SIZE DISTRIBUTION



CLAY	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE	GRAVEL	COBBLES
	SILT			SAND				

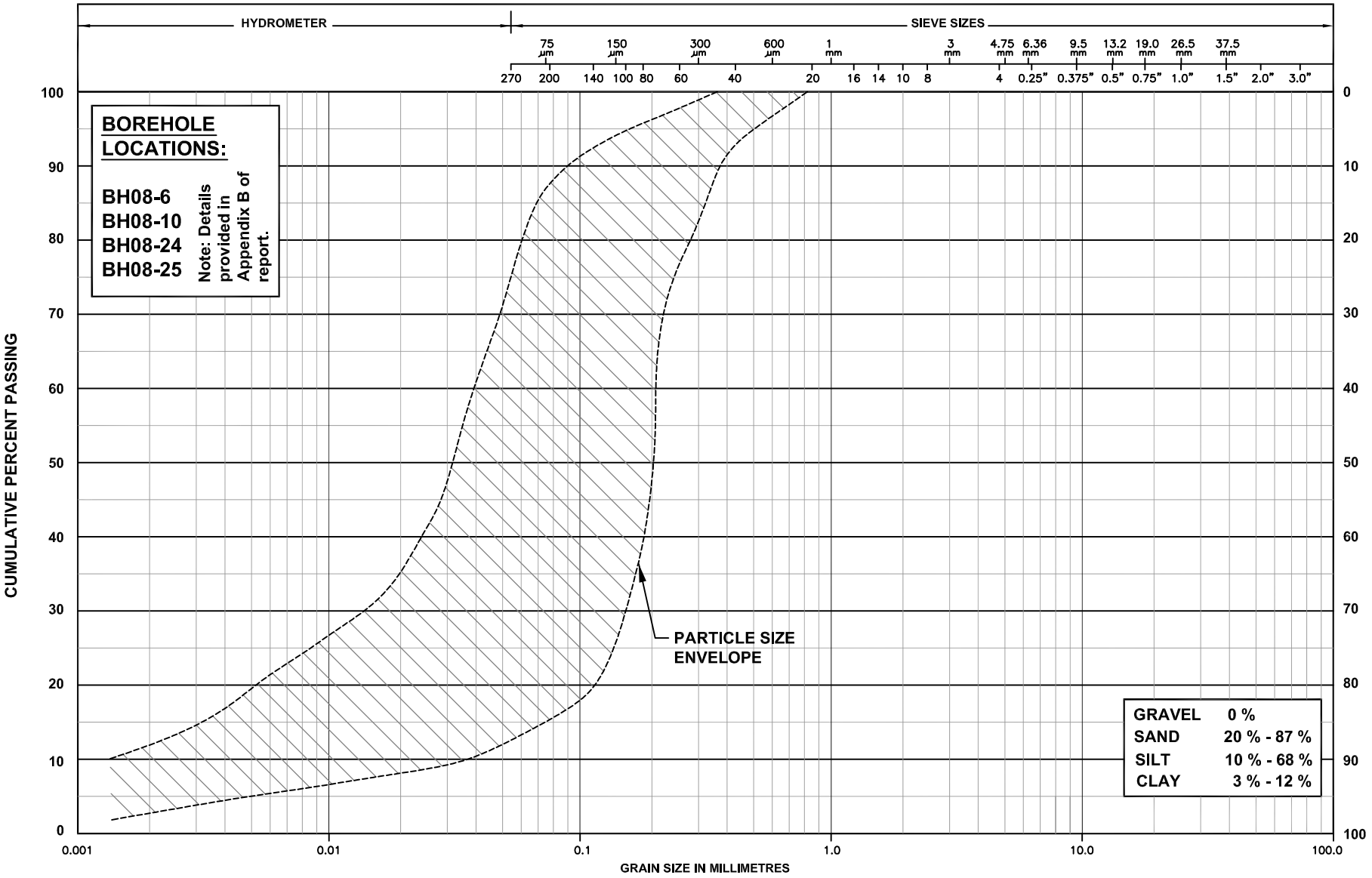
MIT SOIL CLASSIFICATION SYSTEM

PROJECT: MELANCTHON HYDROGEOLOGIC AND HYDROLOGIC ASSESSMENT PROJECT No: 0-082032.05 SAMPLE No: N/A

DEPTH: N/A REMARKS: Granular till FIGURE: 27

GENIVAR

PARTICLE SIZE DISTRIBUTION

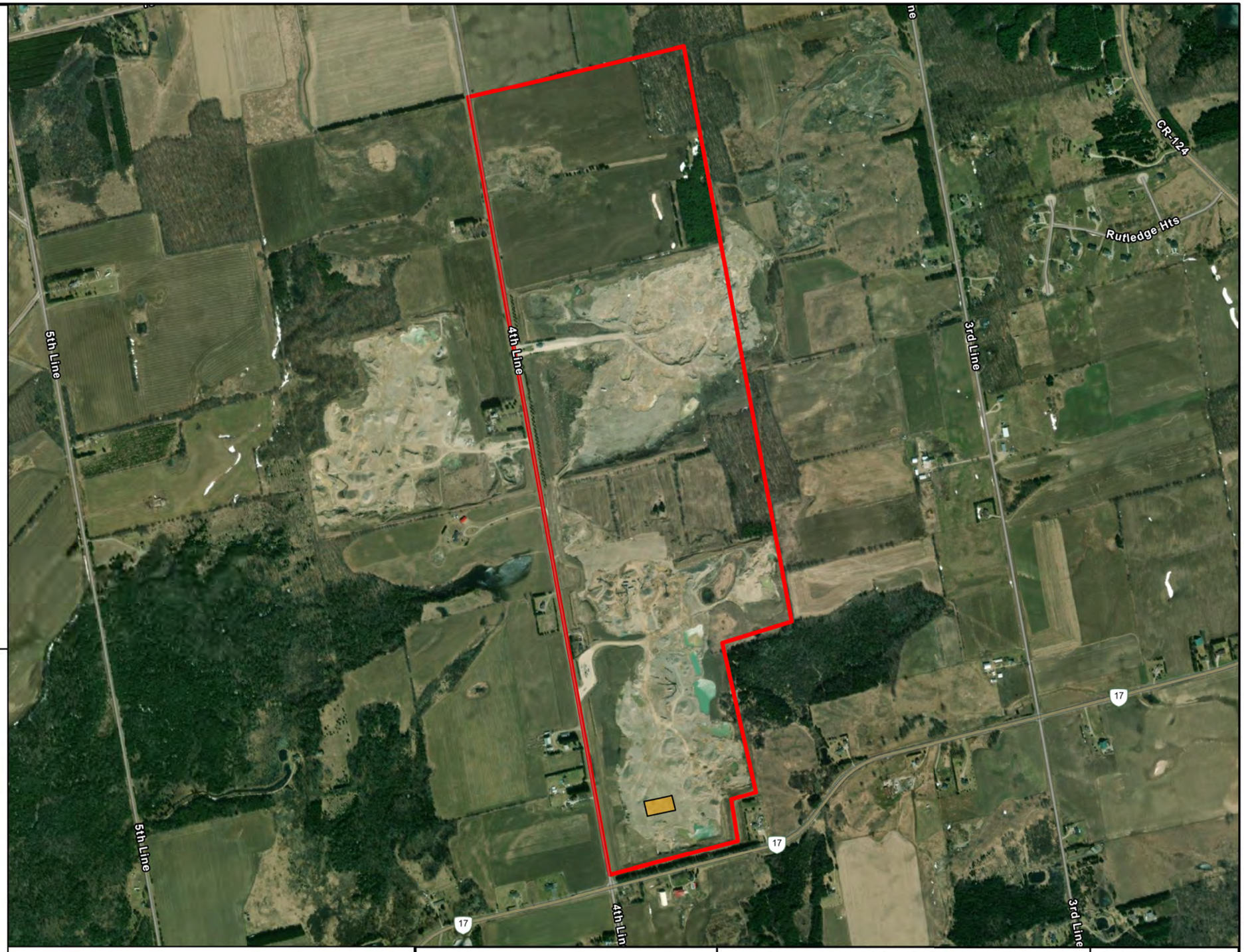


CLAY	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE	GRAVEL	COBBLES
	SILT			SAND				

MIT SOIL CLASSIFICATION SYSTEM

PROJECT: MELANCTHON HYDROGEOLOGIC AND HYDROLOGIC ASSESSMENT PROJECT No: 0-082032.05 SAMPLE No: N/A

DEPTH: N/A REMARKS: Sandy silt to silty sand FIGURE: 28



NOTES:
1. COORDINATE SYSTEM: NAD 1983 UTM ZONE 17N
2.CONTAINS INFORMATION LICENSED UNDER THE OPEN GOVERNMENT LICENSE – ONTARIO.

LEGEND

- SITE
- GUELPH PERMEAMETER TESTING LOCATIONS

0 200 400 800 METERS

TATHAM ENGINEERING

STRADA AGGREGATES PROPOSED SHELBURNE QUARRY INFILTRATION TESTING PROGRAM

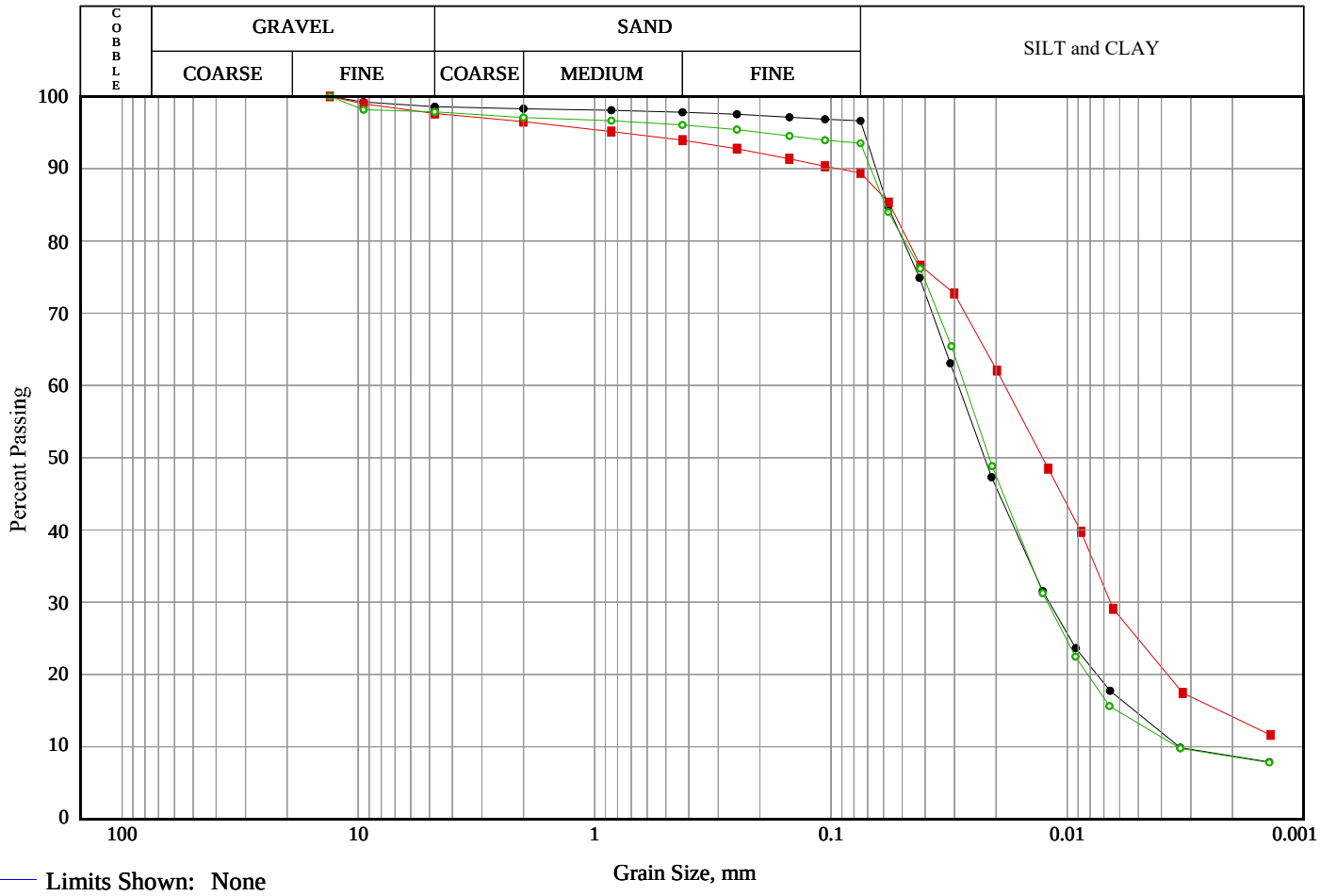
DWG. No. **FIG-1**

SCALE: 1:12,000 | DRAWN: AO | DATE: SEP. 2023 | JOB NO. 123016

I:\2023 Projects\123016 - Strada - Shelburne\04 - ARA Submission\GIS\Monitoring Locations - 123016\Monitoring Locations - 123016.aprx

GEMTEC Consulting Engineers and Scientists	Client: Tatham Engineering Limited	Soils Grading LS-702/ASTM D-422
	Project: Laboratory Testing of Soil	
	Project #: 100876030	

Note: More information available upon request



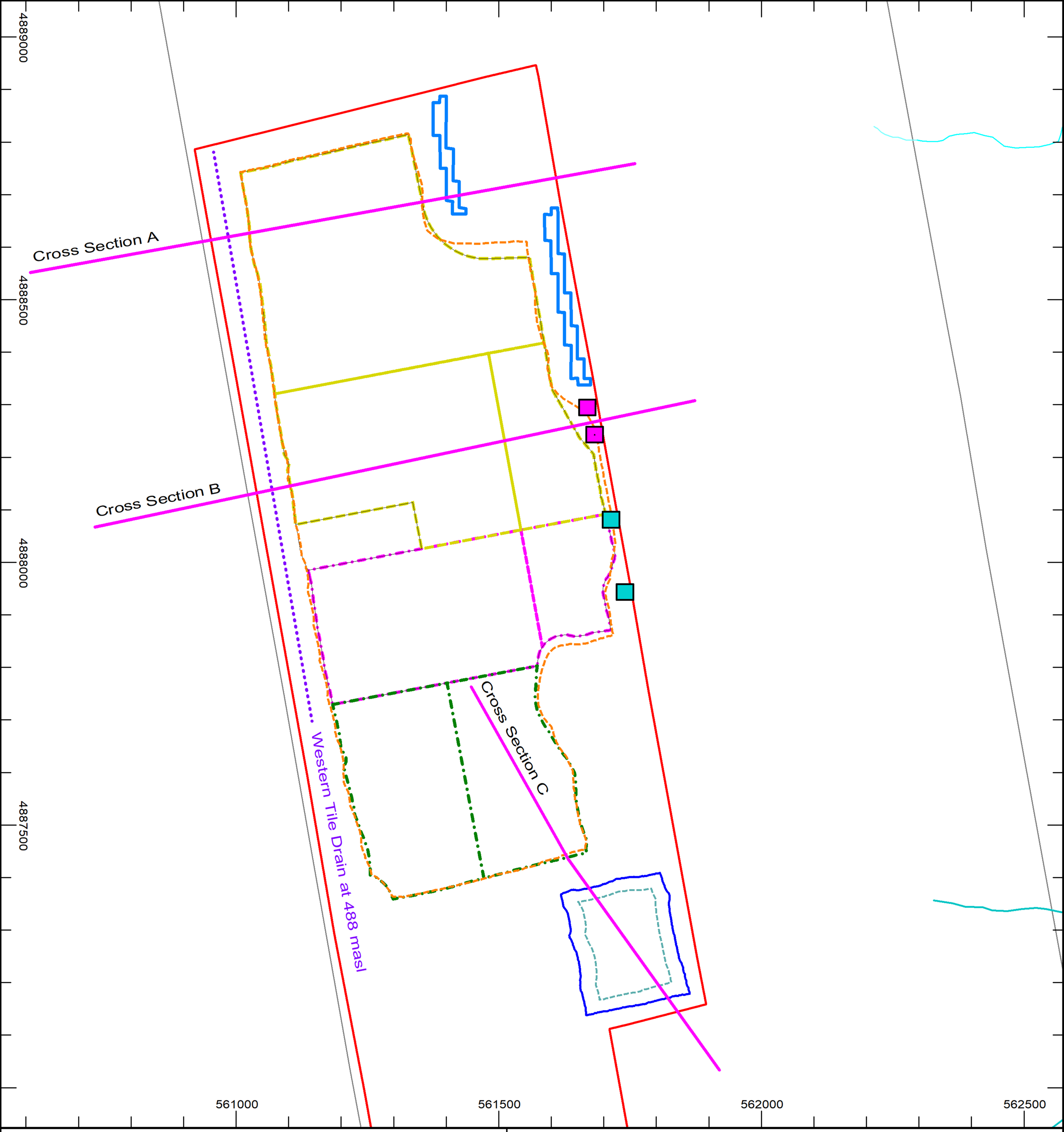
Limits Shown: None

Line Symbol	Sample	Borehole/ Test Pit	Sample Number	Depth	% Cob.+ Gravel	% Sand	% Silt and Clay
●	Client Reference No. 123016		GS-1		1.4	2.0	96.7
■			GS-2		2.4	8.2	89.5
○			GS-3		2.1	4.3	93.5

Line Symbol	CanFEM Classification	USCS Symbol	D_{10}	D_{15}	D_{30}	D_{50}	D_{60}	D_{85}	% 5-75µm
●	Silt , some clay , trace gravel, trace sand	N/A	0.00	0.01	0.01	0.02	0.03	0.06	82.1
■	Clayey silt , trace gravel, trace sand	N/A	---	0.00	0.01	0.01	0.02	0.06	64.6
○	Silt , some clay , trace gravel, trace sand	N/A	0.00	0.01	0.01	0.02	0.03	0.06	80.3

APPENDIX B

Proposed Cross Sections Provided by Client



Legend:

- Road
- Strada Property Limit
- Proposed Quarry Limit
- Extraction Phase 1A & 1B
- Extraction Phase 2 & 3
- Extraction Phase 4A & 4B
- Infiltration Well - Guelph Fm
- Infiltration Well - Gasport Fm
- Infiltration Feature
- Drain
- Stream
- Cross Section

0 200 400

Units: UTM NAD83 Zone 17

Data Sources:
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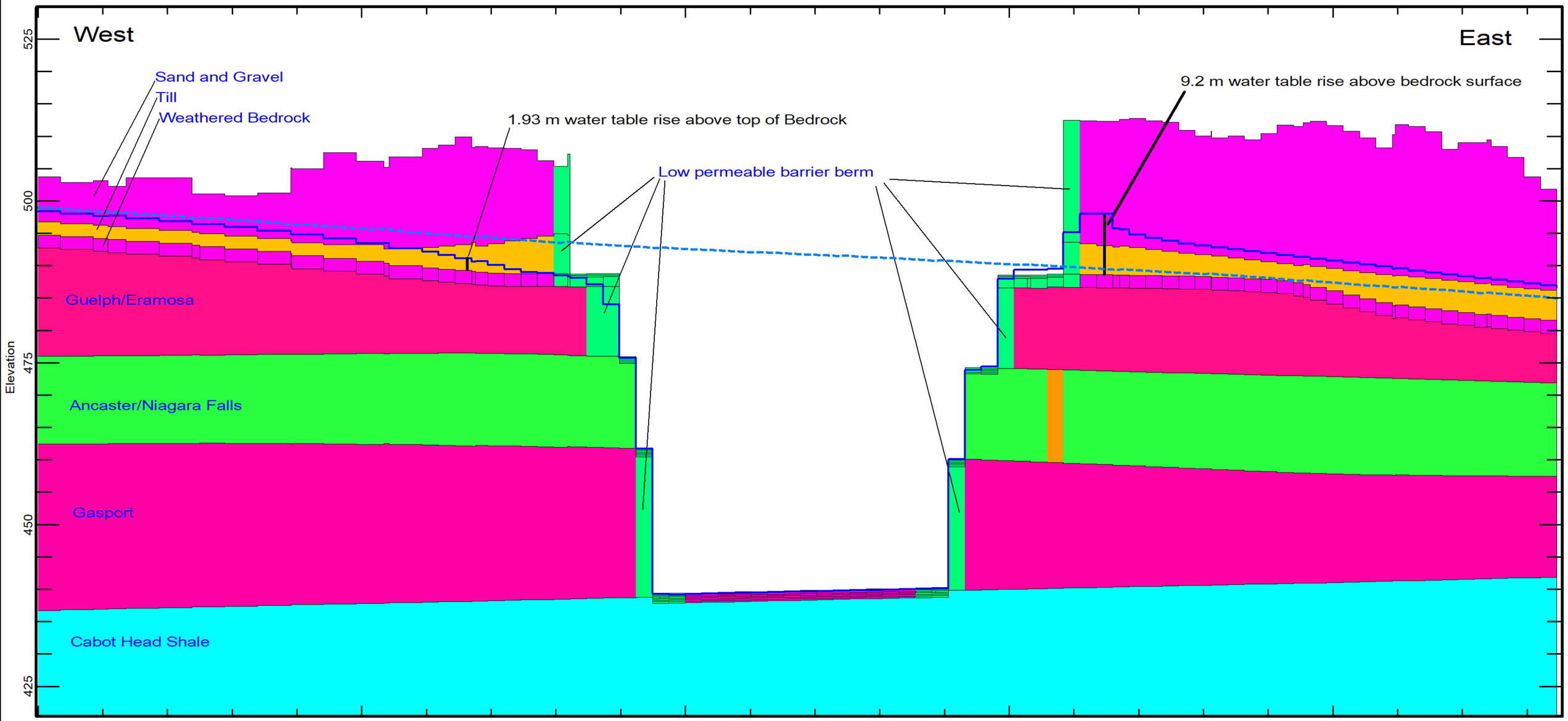
Strada Aggregates Proposed Shelburne Pit/Quarry

Geotechnical Cross Sections

STRADA

EARTHfx INCORPORATED

Drawing prepared 2024-10-11



---- Baseline Water Table - Pre-quarry (masl)

—— Water Table: Under Extraction with Infiltration (masl)

—— Hydraulic Conductivity (m/s)

Contours on section:

1E-08 0.0000001 0.000001 0.00001 0.0001

0 100 200

Units: UTM NAD83 Zone 17

Data Sources:
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Strada Aggregates Proposed Shelburne Pit/Quarry

West - East Cross Section A

Units: UTM NAD83 Zone 17
Section Distance in metres
Vertical elevation in mASL
Vertical Exaggeration: 5x
Borehole Offset Projection: 250 m

Drawing prepared by Earthfx 2024-09-23

STRADA

EARTHfx INCORPORATED

West

East

Sand and Gravel

Till

Weathered Bedrock

Low permeable barrier berm

Guelph/Eramosa

Tile Drain at 488 masl in Bedrock

Ancaster/Niagara Falls

Gasport

Cabot Head Shale

Elevation

525

500

475

450

250

500

750

1000

---- Baseline Water Table - Pre-quarry (masl)

—— Water Table: Under Extraction with Infiltration (masl)

—— Hydraulic Conductivity (m/s)

Contours on section:

1E-08 0.0000001 0.000001 0.00001 0.0001

0 100 200

Units: UTM NAD83 Zone 17

Data Sources:
Produced with information provided by the Ministry of Natural Resources,
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Units: UTM NAD83 Zone 17
Section Distance in metres
Vertical elevation in mASL
Vertical Exaggeration: 5x
Borehole Offset Projection: 250 m

Drawing prepared by Earthfx 2024-09-23

Strada Aggregates Proposed Shelburne Pit/Quarry

West - East Cross Section B

STRADA

EARTHfx INCORPORATED



---- Baseline Water Table - Pre-quarry (masl)

—— Water Table: Under Extraction with Infiltration (masl)

—— Hydraulic Conductivity (m/s)

Contours on section:

1E-08 0.0000001 0.000001 0.00001 0.0001

0 50 100 150

Units: UTM NAD83 Zone 17

Data Sources:
Produced with information provided by the Ministry of Natural Resources,
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Strada Aggregates Proposed Shelburne Pit/Quarry

North West - South East Cross Section C

Units: UTM NAD83 Zone 17
Section Distance in metres
Vertical elevation in mASL
Vertical Exaggeration: 5x
Borehole Offset Projection: 250 m

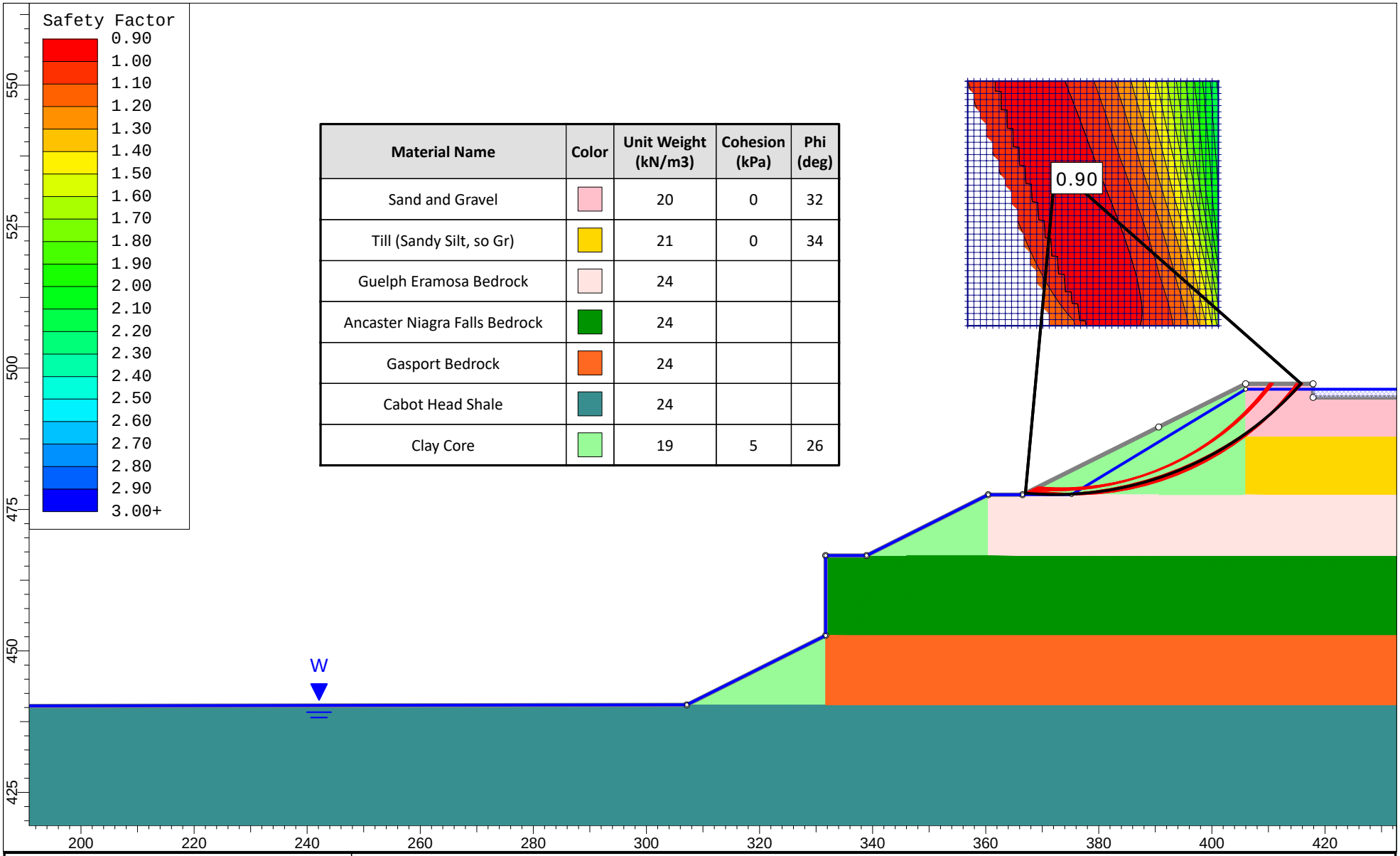
Drawing prepared by Earthfx 2024-09-23

STRADA

EARTHfx INCORPORATED

APPENDIX C

Global Slope Stability Analysis Results

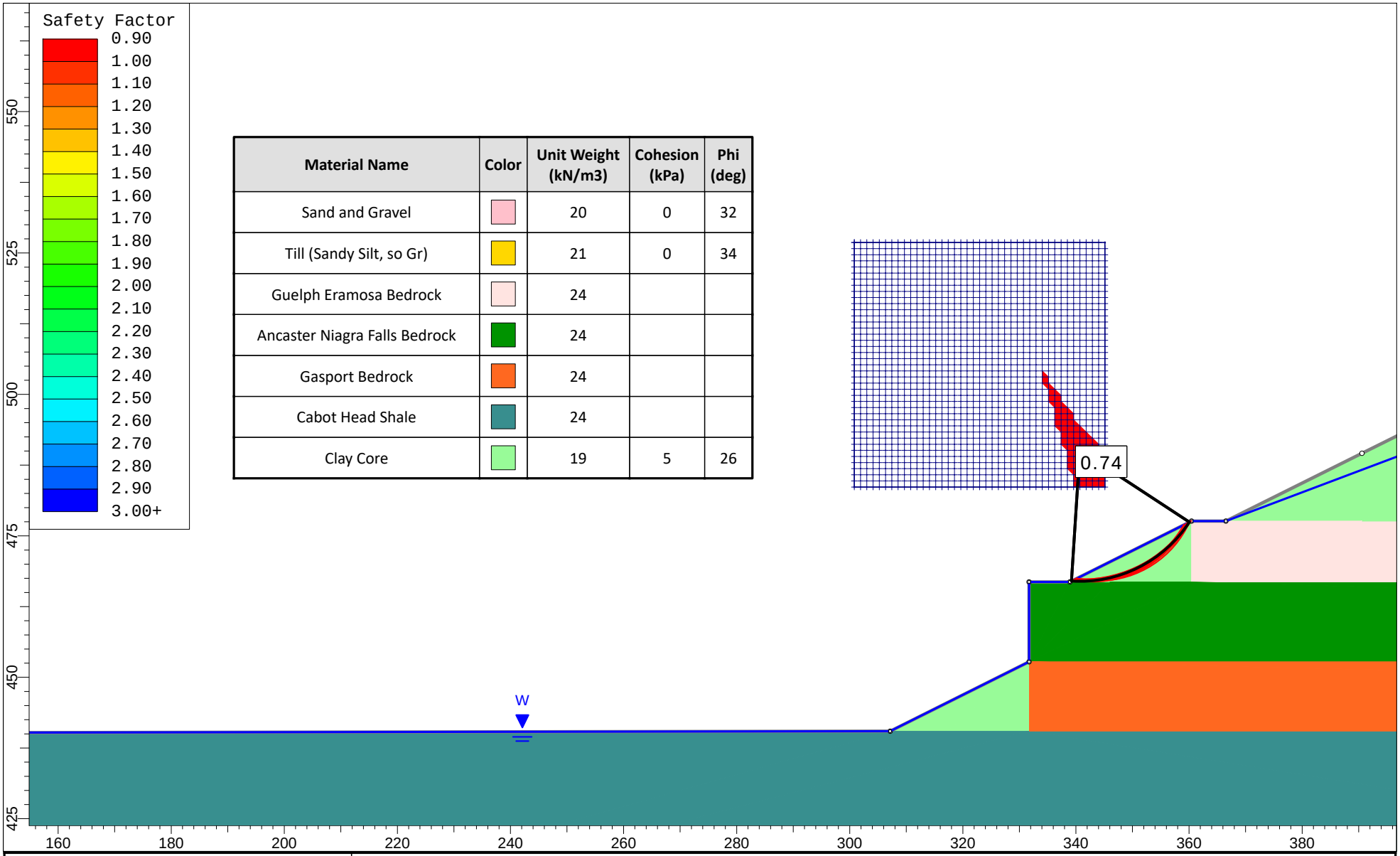


Material Name	Color	Unit Weight (kN/m3)	Cohesion (kPa)	Phi (deg)
Sand and Gravel		20	0	32
Till (Sandy Silt, so Gr)		21	0	34
Guelph Eramosa Bedrock		24		
Ancaster Niagra Falls Bedrock		24		
Gasport Bedrock		24		
Cabot Head Shale		24		
Clay Core		19	5	26

GEMTEC
Consulting Engineers and Scientists

SLIDEINTERPRET 8.032

Project	10876.086 | Melancthon Quarry Slope Stability		
Analysis Description	Slope Stability - Section C-C' Upper Berm		
Drawn By Connor McCormick	*Scale* 1:950	*Company* GEMTEC Consulting Engineers and Scientists	
Date 2024-05-28		*File Name* 100876.086 Berm Stability.slmd	

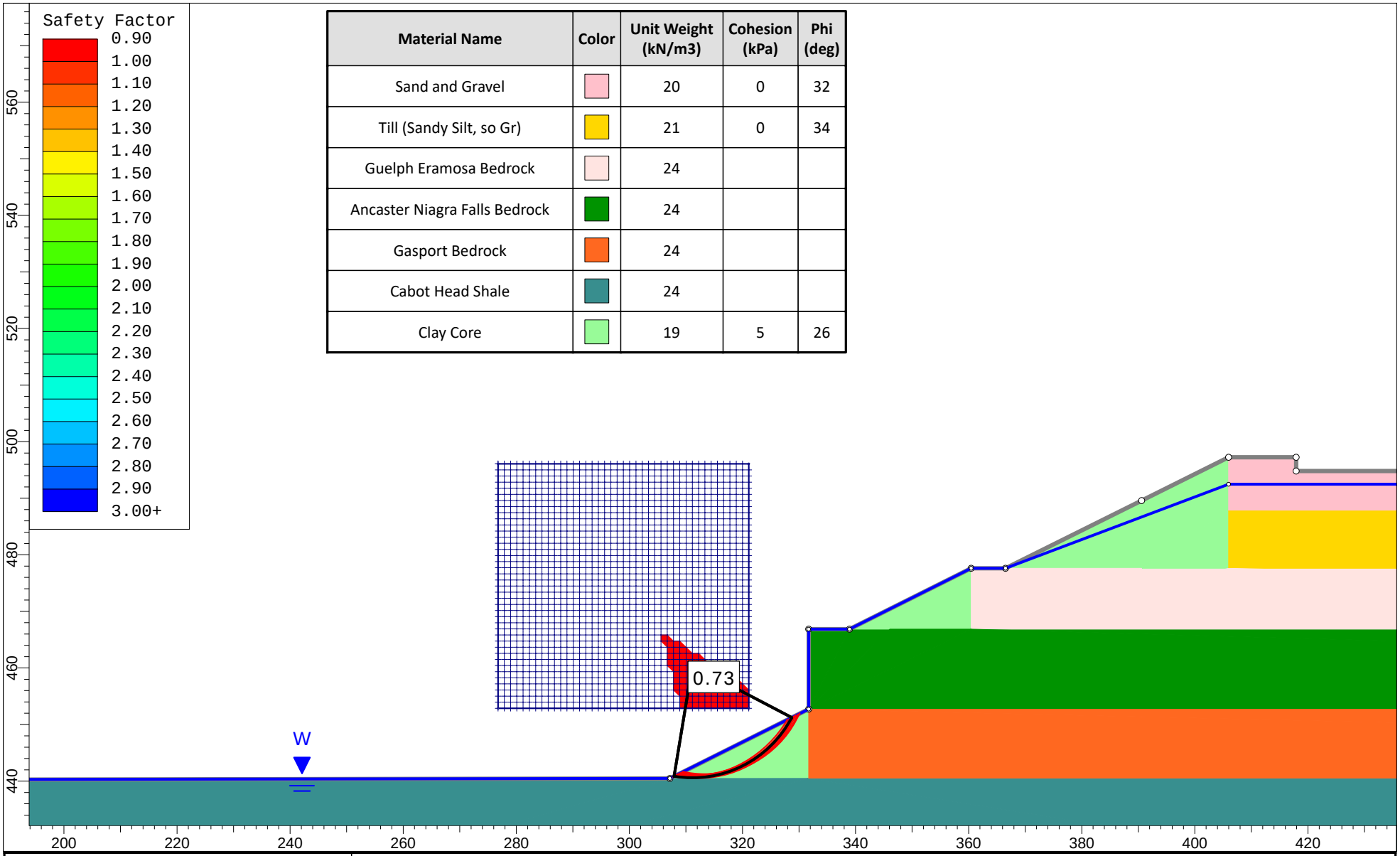


Material Name	Color	Unit Weight (kN/m3)	Cohesion (kPa)	Phi (deg)
Sand and Gravel		20	0	32
Till (Sandy Silt, so Gr)		21	0	34
Guelph Eramosa Bedrock		24		
Ancaster Niagra Falls Bedrock		24		
Gasport Bedrock		24		
Cabot Head Shale		24		
Clay Core		19	5	26

GEMTEC
Consulting Engineers and Scientists

SLIDEINTERPRET 8.032

Project	10876.086 | Melancthon Quarry Slope Stability		
Analysis Description	Slope Stability - Section C-C' Middle Berm		
Drawn By Connor McCormick	*Scale* 1:950	*Company* GEMTEC Consulting Engineers and Scientists	
Date 2024-05-28		*File Name* 100876.086 Berm Stability.slmd	

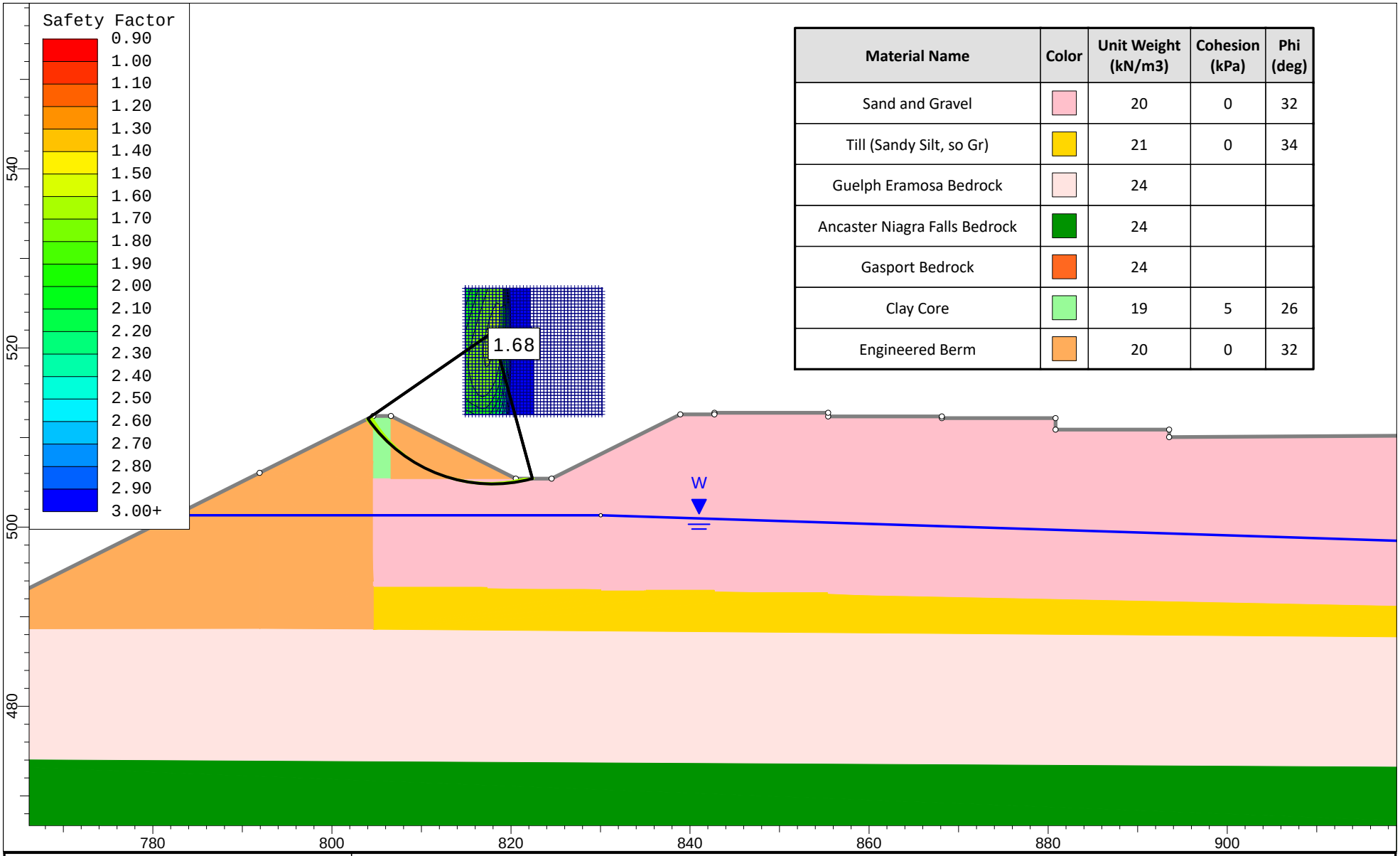


Material Name	Color	Unit Weight (kN/m3)	Cohesion (kPa)	Phi (deg)
Sand and Gravel		20	0	32
Till (Sandy Silt, so Gr)		21	0	34
Guelph Eramosa Bedrock		24		
Ancaster Niagra Falls Bedrock		24		
Gasport Bedrock		24		
Cabot Head Shale		24		
Clay Core		19	5	26

GEMTEC
Consulting Engineers and Scientists

SLIDEINTERPRET 8.032

Project	10876.086 | Melancthon Quarry Slope Stability		
Analysis Description	Slope Stability - Section C-C' Lower Berm		
Drawn By Connor McCormick	*Scale* 1:950	*Company* GEMTEC Consulting Engineers and Scientists	
Date 2024-05-28		*File Name* 100876.086 Berm Stability.slmd	

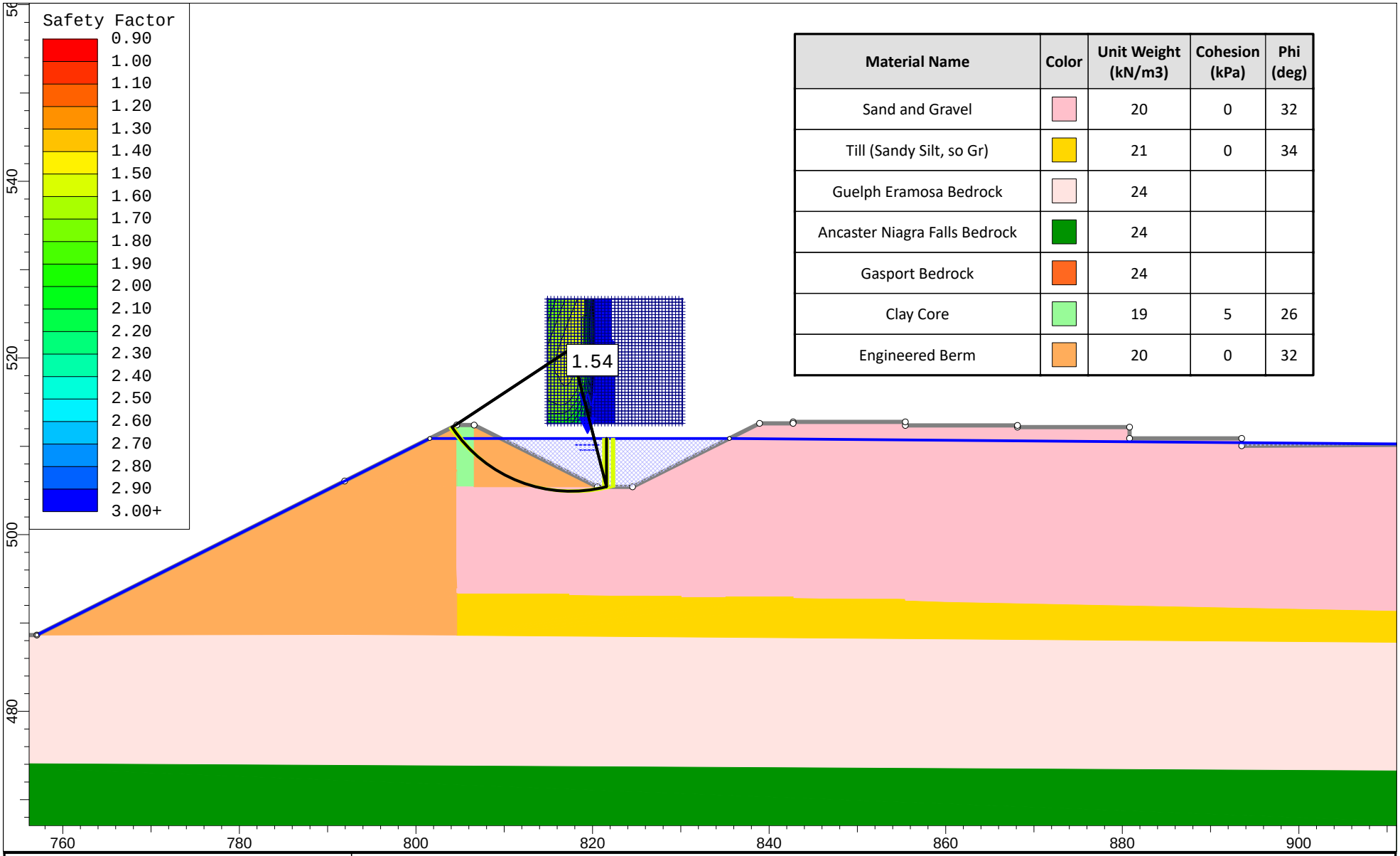


Material Name	Color	Unit Weight (kN/m3)	Cohesion (kPa)	Phi (deg)
Sand and Gravel		20	0	32
Till (Sandy Silt, so Gr)		21	0	34
Guelph Eramosa Bedrock		24		
Ancaster Niagra Falls Bedrock		24		
Gasport Bedrock		24		
Clay Core		19	5	26
Engineered Berm		20	0	32

GEMTEC
Consulting Engineers and Scientists

SLIDEINTERPRET 8.032

Project	10876.086 | Melancthon Quarry Slope Stability			
Analysis Description	Slope Stability - Section A-A' West Trench Wall, Dry			
Drawn By	Connor McCormick	*Scale*	1:600	*Company* GEMTEC Consulting Engineers and Scientists
Date	2024-05-28, 7:56:12 AM			*File Name* 100876.086 Trench Stability.slmd

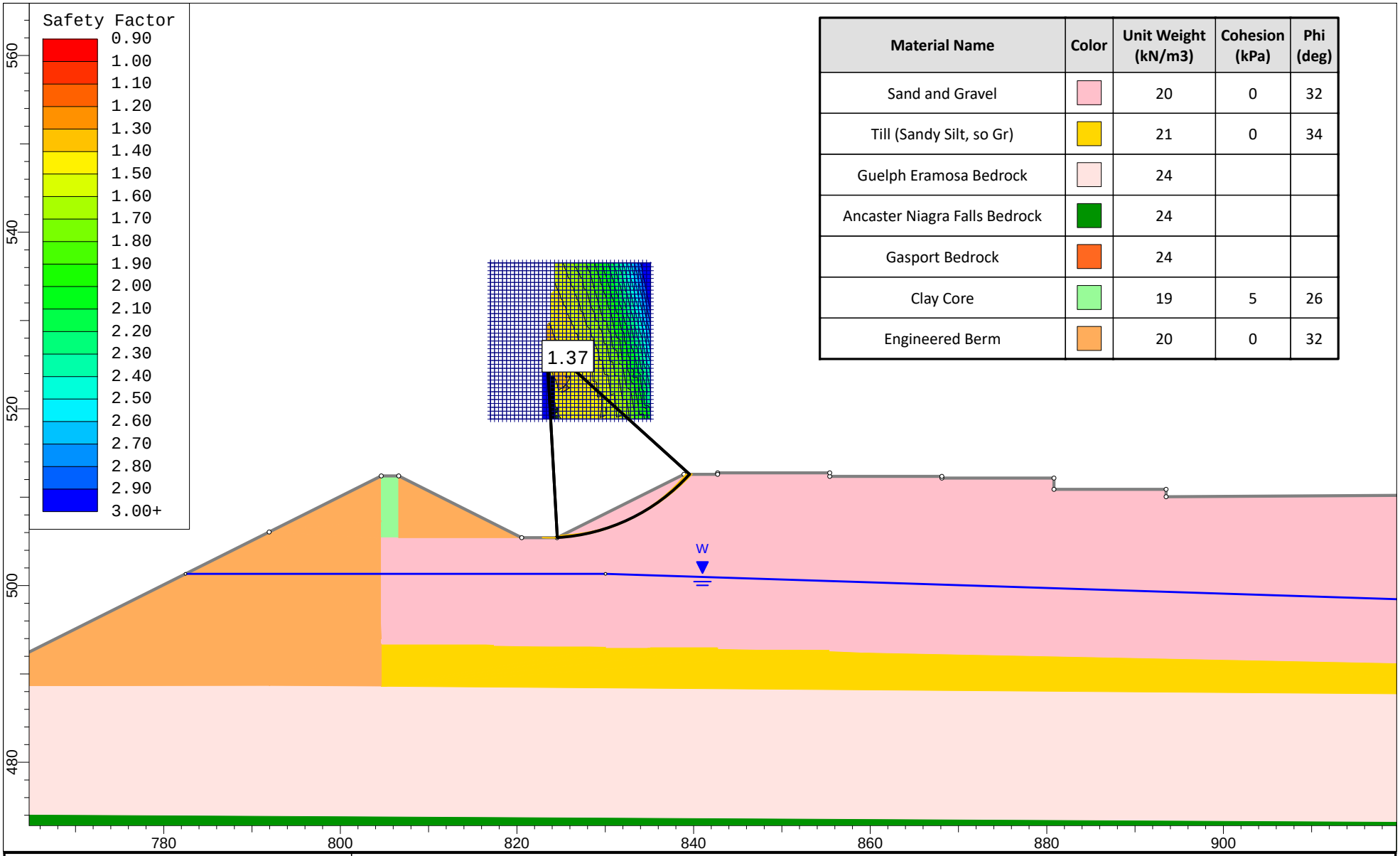


Material Name	Color	Unit Weight (kN/m3)	Cohesion (kPa)	Phi (deg)
Sand and Gravel		20	0	32
Till (Sandy Silt, so Gr)		21	0	34
Guelph Eramosa Bedrock		24		
Ancaster Niagra Falls Bedrock		24		
Gasport Bedrock		24		
Clay Core		19	5	26
Engineered Berm		20	0	32

GEMTEC
Consulting Engineers and Scientists

SLIDEINTERPRET 8.032

Project	10876.086 | Melancthon Quarry Slope Stability		
Analysis Description	Slope Stability - Section A-A' West Trench Wall		
Drawn By	Connor McCormick	*Scale* 1:608	*Company* GEMTEC Consulting Engineers and Scientists
Date	2024-05-28, 7:56:12 AM		*File Name* 100876.086 Trench Stability.slmd

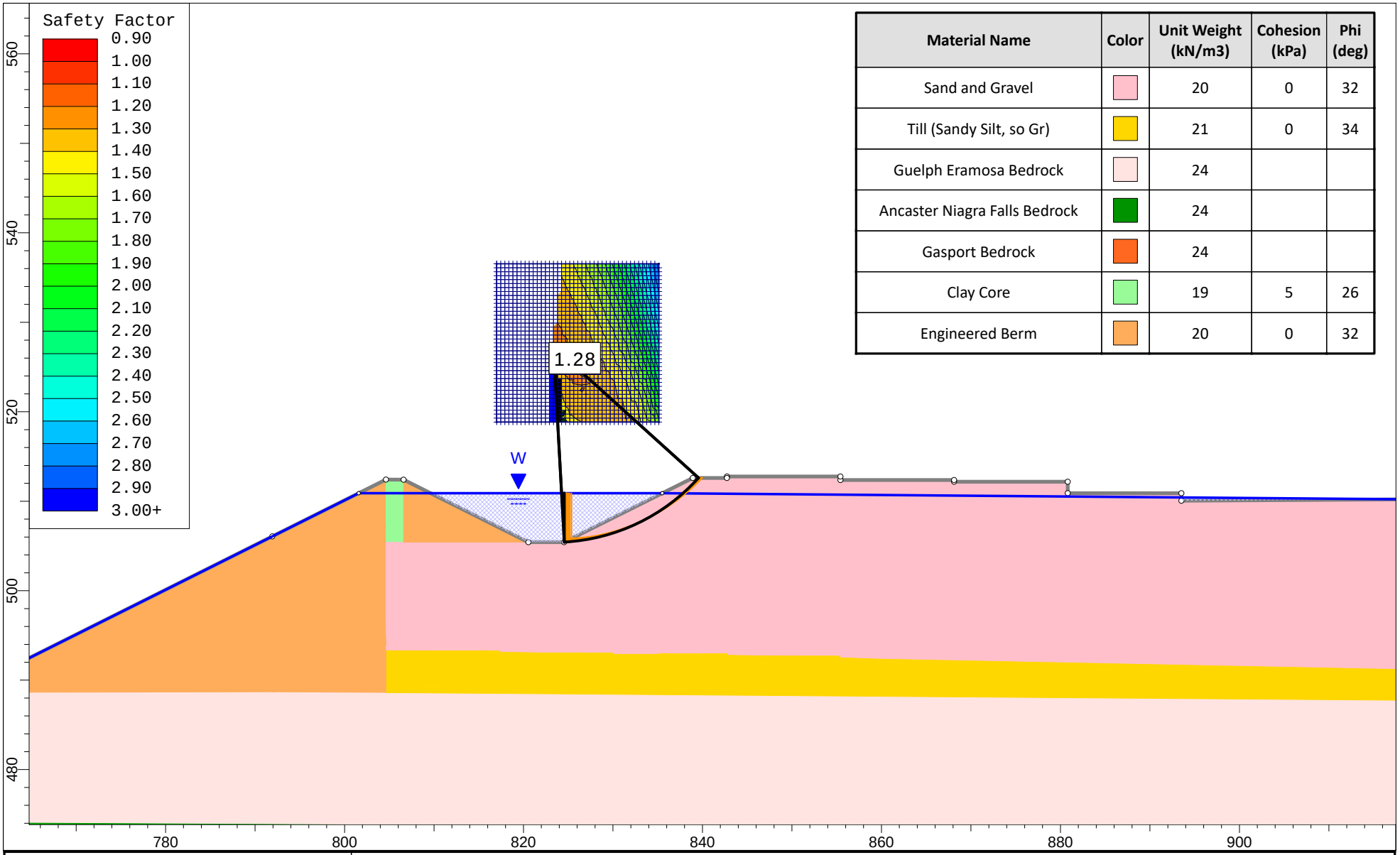


Material Name	Color	Unit Weight (kN/m3)	Cohesion (kPa)	Phi (deg)
Sand and Gravel		20	0	32
Till (Sandy Silt, so Gr)		21	0	34
Guelph Eramosa Bedrock		24		
Ancaster Niagra Falls Bedrock		24		
Gasport Bedrock		24		
Clay Core		19	5	26
Engineered Berm		20	0	32

GEMTEC
Consulting Engineers and Scientists

SLIDEINTERPRET 8.032

Project	10876.086 | Melancthon Quarry Slope Stability			
Analysis Description	Slope Stability - Section A-A' East Trench Wall, Dry			
Drawn By	Connor McCormick	Scale	1:608	Company: GEMTEC Consulting Engineers and Scientists
Date	2024-05-28, 7:56:12 AM			File Name: 100876.086 Trench Stability.slmd

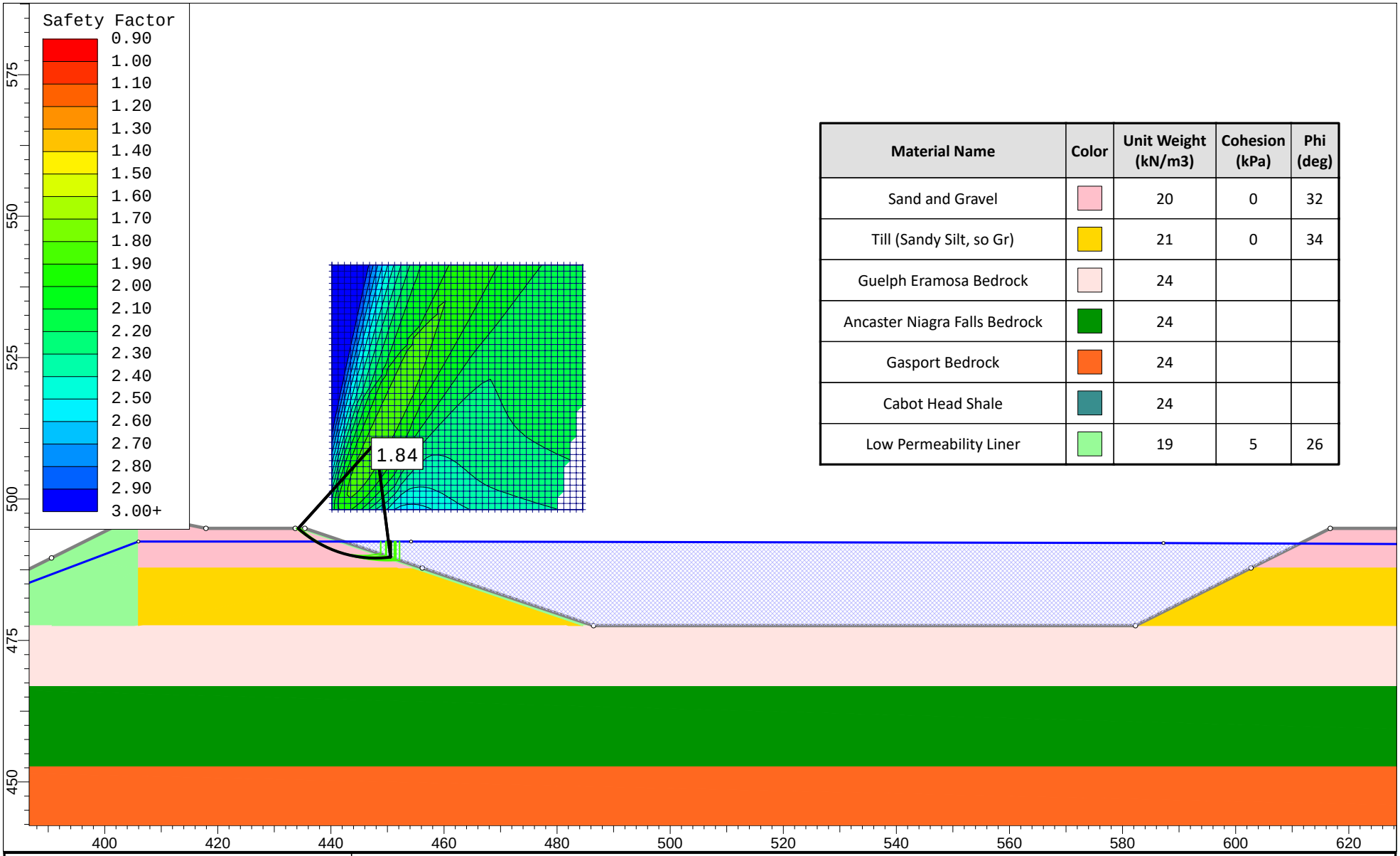


Material Name	Color	Unit Weight (kN/m3)	Cohesion (kPa)	Phi (deg)
Sand and Gravel		20	0	32
Till (Sandy Silt, so Gr)		21	0	34
Guelph Eramosa Bedrock		24		
Ancaster Niagra Falls Bedrock		24		
Gasport Bedrock		24		
Clay Core		19	5	26
Engineered Berm		20	0	32

GEMTEC
Consulting Engineers and Scientists

SLIDEINTERPRET 8.032

Project	10876.086 | Melancthon Quarry Slope Stability			
Analysis Description	Slope Stability - Section A-A' East Trench Wall			
Drawn By	Connor McCormick	*Scale*	1:600	*Company* GEMTEC Consulting Engineers and Scientists
Date	2024-05-28, 7:56:12 AM			*File Name* 100876.086 Trench Stability.slmd

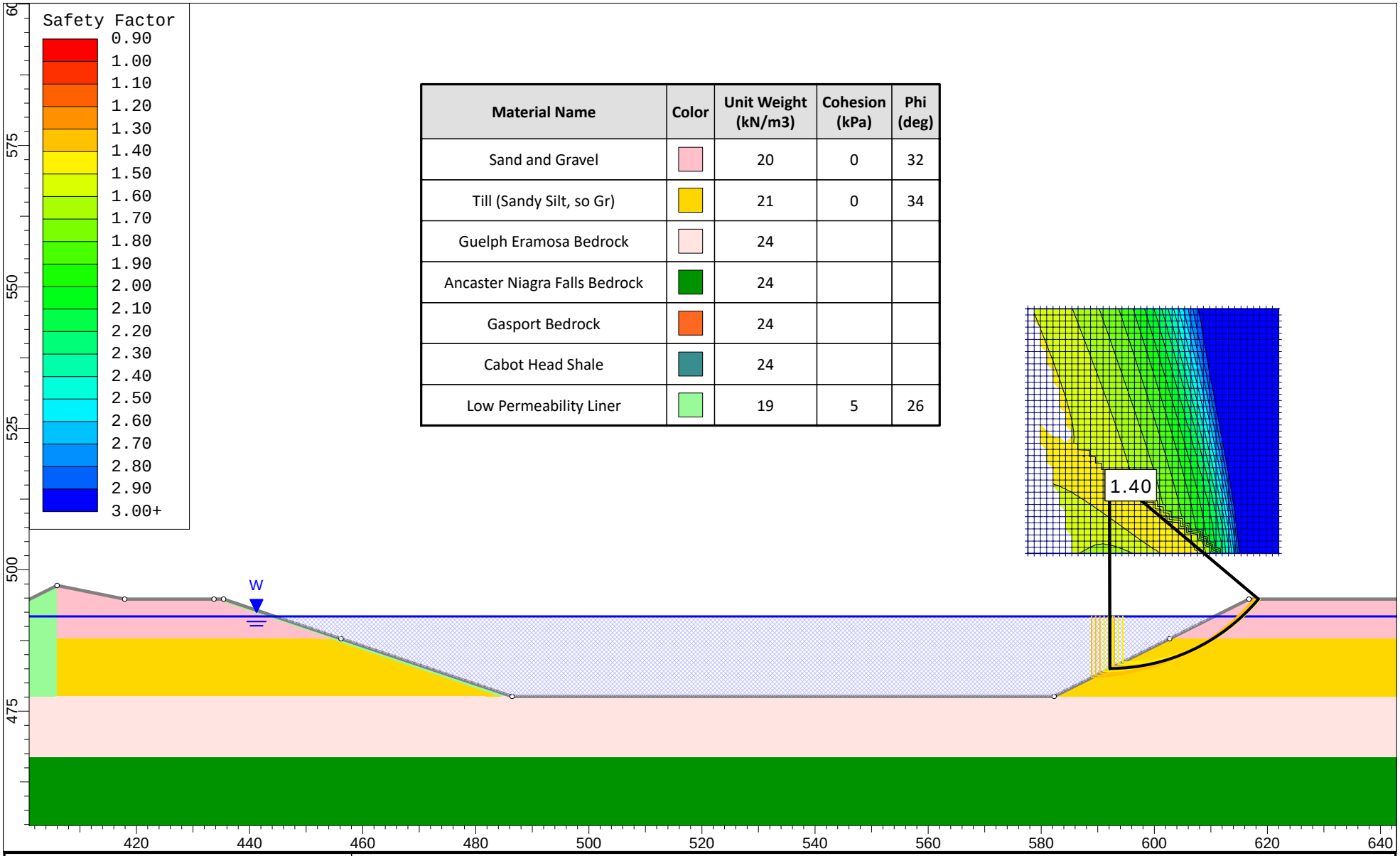


Material Name	Color	Unit Weight (kN/m3)	Cohesion (kPa)	Phi (deg)
Sand and Gravel		20	0	32
Till (Sandy Silt, so Gr)		21	0	34
Guelph Eramosa Bedrock		24		
Ancaster Niagra Falls Bedrock		24		
Gasport Bedrock		24		
Cabot Head Shale		24		
Low Permeability Liner		19	5	26

GEMTEC
Consulting Engineers and Scientists

SLIDEINTERPRET 8.032

Project	10876.086 | Melancthon Quarry Slope Stability		
Analysis Description	Slope Stability - Section C-C' North Pond Wall		
Drawn By Connor McCormick	*Scale* 1:950	*Company* GEMTEC Consulting Engineers and Scientists	
Date 2024-05-28		*File Name* 100876.086 Infiltration Pond Stability.slmd	



Material Name	Color	Unit Weight (kN/m3)	Cohesion (kPa)	Phi (deg)
Sand and Gravel		20	0	32
Till (Sandy Silt, so Gr)		21	0	34
Guelph Eramosa Bedrock		24		
Ancaster Niagra Falls Bedrock		24		
Gasport Bedrock		24		
Cabot Head Shale		24		
Low Permeability Liner		19	5	26

GEMTEC
Consulting Engineers and Scientists

SLIDEINTERPRET 8.032

Project	10876.086 | Melancthon Quarry Slope Stability		
Analysis Description	Slope Stability - Section C-C' South Pond Wall		
Drawn By Connor McCormick	*Scale* 1:950	*Company* GEMTEC Consulting Engineers and Scientists	
Date 2024-05-28		*File Name* 100876.086 Infiltration Pond Stability.slmd	

Appendix F: CVs

TATHAM ENGINEERING

Daniel Twigger, P.Eng.
Manager – Water Resources

Career Highlights

Daniel specializes in the field of water resources engineering. He has completed many studies related to stormwater management and is skilled in stormwater management design, bridge and culvert replacements, natural hazard (flood and erosion) assessments, hydrologic and hydraulic analysis, surface water monitoring and water balance calculations. Daniel has been involved in the preparation of Master Drainage Plans, Environmental Assessments, and Comprehensive Stormwater Management Master Plans and is highly knowledgeable about water resources regulatory requirements.

Daniel has completed natural channel designs, site plans in support of Aggregate Resource Act licence applications, and stormwater retrofit designs. Daniel has advanced projects from inception to completion, participating in preliminary designs, securing approvals, preparing final designs, conducting construction inspection and contract administration.

Detailed Experience

Modelling Capabilities

Daniel is proficient with several hydrologic and hydraulic computational models including VISUAL OTTHYMO, SWMHYMO, PCSWMM, GAWSER and HEC-RAS. He has completed advanced hydraulic and hydrologic modeling courses in HEC-RAS, GAWSER and PCSWMM.

Hydrologic & Hydraulic Studies

Involved in hydrologic and hydraulic investigations undertaken in conjunction with planning and proposed development activity. These studies have evaluated existing sewer capacities, hydraulics, replacement requirements and priority, determined floodplain or fill limits, culvert and bridge sizing, preliminary stormwater management constraints and assessed pond and dam works.

Daniel has participated in such studies for:

- Simcoe Road 21 Phase 1, County of Simcoe
- Big Bay Point Drive Road Improvements, Barrie
- Duckworth Street Road Improvements, Barrie
- Innisfil Various Roads Drainage Improvements Project
- Gravenhurst Master Storm Sewer Study
- The Blue Mountains TRIP SWM Needs Study
- Barrie City Wide Minor/Major SWM Model Development Project
- 27th/28th Sideroad Road Improvements Project
- Poplar Sideroad Road Improvements Project
- Tenth Line Road Improvements Project
- Lackies Bush Pond Hydraulic Analysis
- Kidd's Creek Hydraulic Analysis
- Little Lake Sub-Watershed Drainage System Analysis
- Hewitt's Creek Hydraulic Analysis
- Simcoe County North River Bridge Hydraulic Analysis

Qualifications

2005 Bachelor of Science in Engineering (Water Resources)
University of Guelph
Guelph, ON

Professional Designations, Licences, Registrations

- Professional Engineers Ontario

Professional Experience

2005 to Present Tatham Engineering Limited /C.C. Tatham & Associates Ltd.
Collingwood, ON

- Ramara Township Concession Road 1 Bridge Hydraulic Analysis
- Municipality of Arran Christie Bridge Replacement
- Municipality of Arran Proud Bridge Replacement
- Summerhaven Windfarm Hydrologic/Hydraulic Analysis
- Town of Bracebridge McCutcheon Bridge Hydraulic Analysis
- North Bay Lakeshore Drive Bridge Replacement
- Huron Haven Village Storm Outfall Hydraulic Analysis
- Lora Bay Drainage Improvements Project
- Township of Oro-Medonte, various drainage improvement projects

Stormwater Management Plans

Involved in the design of preliminary and detailed stormwater management plans for a variety of development scenarios including residential subdivisions, industrial and commercial sites and highway development. Specific duties have included the development of hydrologic models, water balance calculations, hydraulic grade line analysis, design of stormwater management facilities and report preparation.

Projects Daniel has participated in extensively include:

- Burlington Quarry, Region of Halton
- Blue Vista, The Blue Mountains
- Plateau East, The Blue Mountains
- Second Nature, The Blue Mountains
- Windfall Development, The Blue Mountains
- Founder's Village Subdivision, Wasaga Beach
- Osprey Quarry, Grey Highlands
- Mair Mills Village Subdivision, Collingwood
- New England Village Development, Wasaga Beach
- Springwater Meadows Subdivision, Springwater Township
- Richvale Athletic Field, Richmond Hill
- Stonebridge on the Bay Development, Wasaga Beach
- Windrose Valley Estates Subdivision, Clearview Township
- 11 Bay Street Condominium Development, The Blue Mountains
- MacDonald Street Self Storage Development, Collingwood
- Trillium Forest North Development, Wasaga Beach
- Barrie BMW/Mini Dealership, Barrie
- River's Edge Subdivision, Wasaga Beach
- Wolf Steel Warehouse Facility, Oro-Medonte
- Welland Retirement Centre, Welland
- Wyldewood Trailside Condos, Collingwood
- Wyldewood Cove, Collingwood
- Huron Have Village, Goderich

Master Drainage Plans, Environmental Assessments and Comprehensive Master Plans

These technical Guidance Documents provide municipalities an opportunity to establish short and long-term strategies for effective stormwater management within existing and expanding settlement areas. The documents provide an opportunity to identify, prioritize and implement SWM improvements within existing settlement areas and SWM requirements for planned developments.

Projects Daniel has participated in extensively include:

- Gravenhurst Master Storm Sewer Study
- Whiskey Creek at Minets Point Class EA, Barrie
- City of Barrie Drainage Master Plan
- Town of The Blue Mountains Drainage Master Plan
- Town of Wasaga Beach Drainage Master Plan
- Huronia Road ESR Drainage Update
- Sophia Creek Watershed and Mulcaster Drainage Area EA Update, Barrie
- Thornbury West Drainage Master Plan, The Blue Mountains
- Osler Bluff Secondary Plan, The Blue Mountains
- Airport Heights SWM Pond Class EA, North Bay
- Sophia Creek West Branch Drainage and Infrastructure Improvements Class EA, Barrie
- Sophia Creek Master Drainage Plan Class EA Update, Barrie
- Leslie Street Extension Environmental Assessment, Innisfil
- Lovers Creek, Hewitts Creek and Annexation Lands Study Area CSWM Master Plan, Barrie
- Barrie Creeks Study Area CSWM Master Plan, Barrie

Water Quality/Quantity Monitoring

Involved in water quality/quantity monitoring for the purpose of Permit to Take Water, Certificate of Approval compliance, I/I studies and hydrologic/hydraulic model calibration. Daniel has undertaken the specific responsibilities of field investigations and sample collection, stream gauging, data logger installation/maintenance, water quality data collection, statistical analysis and interpretation of results, technical support and reporting.

Projects Daniel has participated in extensively include:

- TOBM Streamflow Monitoring Program
- Collingwood Sanitary Sewer Renewal Program
- Devil's Glen PTTW Compliance Monitoring
- Osler Bluff Ski Club PTTW Compliance Monitoring
- OslerBrook Golf and Country Club PTTW Compliance Monitoring
- Castle Glen Development Area
- Blue Mountain Resorts PTTW/ECA Compliance Monitoring
- Osprey Quarry ECA Compliance Monitoring
- Reeb Quarry ECA Compliance Monitoring
- Hewitt Quarry ECA Compliance Monitoring
- Barrie Creek Flow Monitoring
- Alliston Aggregates Sand and Gravel Pit, Surface Water Monitoring
- Beaver Valley Ski Club, Surface Water Monitoring
- Burlington Quarry Expansion Surface Water Monitoring
- Hockley Valley Ski Club, PTTW
- Nelson Aggregates, Burlington Quarry, PTTW Compliance Monitoring

PTTW, ECA and ARA License Applications

Daniel has completed the following Permit to Take Water (PTTW), Environmental Compliance Approval (ECA), and Aggregate Resources Act (ARA) applications in support of agricultural, commercial and industrial developments:

- Botden Orchard PTTW
- Devil's Glen Ski Club PTTW
- Osler Bluff Ski Club PTTW
- Quality Sod Farm PTTW
- Thornbury Horse Park PTTW
- Sutherland Quarry Expansion ECA
- Blue Mountain Resorts ECA
- Nelson Waynco Wash Pond ECA
- Hamilton Brothers Works Yard ECA
- Georgian Triangle Anglers Association PTTW
- Alliston Aggregates Sand and Gravel Pit ARA License
- Osprey Quarry ECA/PTTW and ARA License
- Nelson Aggregates Burlington Quarry PTTW and ARA License
- Beaver Valley Ski Club PTTW

Natural Hazard Assessments

Natural hazard assessments undertaken in conjunction with planning and proposed development activity generally establish the flood hazard, meander belt width, and/or erosion hazards and consequently the allowable development limits on a property.

Projects Daniel has participated in extensively include:

- Lake St. Johns Floodplain Mapping Project
- Huron Haven Village Gully Erosion Hazard Assessment
- Huron Park Flood and Erosion Hazard Assessment
- Violet Hill Pit Erosion Hazard Assessment
- Devil's Glen Escarpment Brow Delineation
- Windfall Flood and Erosion Hazard Assessment
- Alliston Aggregates Flood and Erosion Assessment
- Sunnidale Trails Flood and Erosion Hazard Assessment
- Monterra Phase 2 Natural Hazard Assessment
- Nelson Aggregates Burlington Quarry Expansion Natural Hazards Assessment

Natural Channel Designs

Involved in the planning and detailed design of watercourse improvements, watercourse realignments and natural channel designs in support of municipal infrastructure improvements and proposed development activity. Specific duties include development of hydrologic and hydraulic models, detailed natural channel design, securing permits and approvals, coordinating with ecologists and landscape architects, tendering, construction inspection and contract administration.

Projects Daniel has participated in extensively include:

- Sandy Cove Creek Realignment, Barrie

- Taylors Creek Channelization, Collingwood
- Bear Creek Watercourse Improvements, Barrie
- Townline Creek Relocation, The Blue Mountains
- Underwood Creek Realignment, Collingwood
- Silver Creek Tributary Realignment, The Blue Mountains
- Little Beaver River Tributary Realignment, The Blue Mountains

Peer Review Services

Daniel has provided peer review services for planning and development engineering confirming applications and designs conform to provincial, municipal and conservation authority guidelines and standards and best engineering practices for the following:

- Kawartha Conservation Flood Mapping Peer Reviews
- Oro-Medonte SWM Peer Reviews
- TOBM SWM and Drainage Peer Reviews
- Meaford SWM Peer Reviews
- Cramahe SWM Peer Reviews
- Ramara SWM Peer Reviews

Dirk Kassenaar, M.Sc., P.Eng.

President, Senior Hydrogeologist

BIOGRAPHY

Dirk Kassenaar, M.Sc., P.Eng. is a senior hydrogeologist and President of Earthfx. Dirk founded Earthfx in 1998 with the goal of integrating environmental simulation and advanced data management. Earthfx is a world leader in the integrated simulation of groundwater and surface water systems, with a particular specialization with the USGS GSFLOW Model. As founder and President, Dirk has technically directed and managed projects for large water management agencies, land developers, mining and oil sand companies and nuclear power stations. In addition to managing projects and operations at Earthfx, Dirk is the key architect of VIEWLOG, overseeing its development into the premier 4-dimensional modeling system interface to the USGS GSFLOW integrated SW/GW model. Dirk has also acted as an expert witness in the fields of geophysics, hydrogeology and engineering in numerous Canadian and US legal and land development hearings.

EDUCATION

- B.A.Sc. Geological Engineering, University of Waterloo (1986)
- M.Sc. Earth Science, University of Waterloo (1989)

PROFESSIONAL EXPERIENCE

President/ Senior Hydrogeologist, Earthfx Inc. ***1998 - Present***

At Earthfx, Dirk provides senior consulting expertise in geologic and hydrogeologic modeling, geophysical interpretation, hydrogeology and geological engineering. As President, Mr. Kassenaar is responsible for all aspects of project development, budgeting, technical analysis and quality control/quality assurance. He is also responsible for product development, code design, and marketing of the VIEWLOG and SiteFX products. Recent projects include:

- Development of a large scale fully integrated GSFLOW model of the City of Toronto and Region of York for water budget analysis, permitting, and drought impact assessment.
- Interpreted the geology in the six-county Southwest Florida Feasibility Study area to create hydrostratigraphic model layers for the new regional simulation model.
- Assessment and optimization of low impact urban design facilities to mitigate the impact of the development of the proposed Town of Seaton.
- Analysis, using a fully integrated GW/SW GSFLOW model, of the interconnection between the Milton wellfield and Kelso Lake reservoir.
- Development of a web interface to the St. John's River WMD VIEWLOG database.
- Development of a comprehensive water management database, geologic and regional scale MODFLOW model of the Oak Ridges Moraine
- Numerical assessment of surface water recharge and groundwater impacts of the proposed Darlington Nuclear Power Station expansion.

Hydrogeologist/ Geophysicist, Gartner Lee Limited ***1989 - 1995***

As Project Manager and Engineer, Mr. Kassenaar's responsibilities included:

- Managed field investigations, modeling and remediation of a multi-component DNAPL spill in fractured dolostone. Reduced contaminant concentrations in nearby private wells from 1000's of ppb to less than the drinking water limits.
- Designed and assessed over 20 landfill systems and monitoring projects across Canada and the USA. Tasks included modelling of caps and leachate collection systems, geophysical and hydrogeologic assessment of contaminant plumes, and management and analysis of water quality monitoring studies.
- Managed dozens of groundwater modeling projects, including simulations of municipal and hazardous waste landfills, contaminant spills, low-level radioactive waste and ground water supply and WHPA studies.
- Completed water supply capture zone analysis for a major bottled water company.

Logging Scientist, International Ocean Drilling Program ***Fall 1987***

Completed 3 months of downhole geophysical testing using advanced nuclear and geochemical logging probes aboard the research ship JOIDES Resolution. Testing identified significant titanium deposits in gabbros on the flanks of a 6000 m deep submarine canyon in the Southwest Indian Ocean. Results published in Nature v. 333, Issue 6169.

Highwall Geologist and Research Engineer, Syncrude Canada Ltd. ***1983 - 1984***

Performed daily highwall mapping of oil sand deposits under dragline operations at the Syncrude mine site in Fort McMurray, Alberta. Supervised drilling investigations for ore grade reserve calculations. Promoted to the Research Department in Edmonton to assess the correlations between core measurements and downhole geophysical logs.

SELECT TECHNICAL PAPERS (FULL BIBLIOGRAPHY AVAILABLE ON REQUEST)

Wexler, E.J., and Kassenaar, Dirk, 2024. Simulation of Recharge and Groundwater Flow in the Extreme Arid Environment of the Najd, Sultanate of Oman. Modflow and More 2024, Princeton NJ.

Kassenaar, Dirk. 2022 Integrated model analysis of wetland water budget and hydroperiod for quarry development. Washington Hydrogeology Symposium, May, 2022, Tacoma, WA

Kassenaar, D. and Wexler, E.J. 2022. Integrated modelling of fractured rock: Process complexity versus parameterization. Modflow and More, June 2022, Princeton, NJ

Kassenaar, Dirk. 2021 Integrated model analysis of wetland water budget. IAH Conference, Niagara Falls, ON. 2021

Kassenaar, D. and Wexler, E.J. 2020. Integrated Surface Water and Groundwater Modeling for Streamflow Restoration and Climate Change Assessment in a Mountain Basin Watershed in Eastern Washington State. Calgary GeoConvention, 2020

Hermanson, Mike, Kassenaar, D. and Wexler, E.J. 2019. Use of a Coupled Ground and Surface Water Model (GSFLOW) in the WRIA 55 RCW 90.94 Watershed Plan Update, 12th

Washington Hydrogeology Symposium, Tacoma, WA 2019

Kassenaar, D. and Wexler, E.J. 2019. Integrated modelling of mine and quarry development impacts. Modflow and More, June 2019, Golden, CO

Kassenaar, Dirk. 2018. Engineering scale integrated modelling within a watershed context, Resources for Future Generations, Vancouver, BC. 2018

Kassenaar, D. and Wexler, E.J. 2017. Assessing the Cumulative Effects of Groundwater Withdrawals for Oils Sands Production on a Watershed Scale. Modflow and More, June 2017, Golden, CO

Kassenaar, Dirk. 2017. Long-Term Monitoring Network Design with an Integrated Model. Watertech, Banff, AB. 2017

Kassenaar, D. and Wexler, E.J. 2016. Incorporating a Dynamic Irrigation Demand Module into an Integrated Surface Water/Groundwater Model to Assess Drought Response, Toward Sustainable Groundwater in Agriculture, San Fransisco, CA. 2016

Kassenaar, D. and Wexler, E.J. 2016. Integrated Groundwater/Surface Water Modelling to Assess Irrigation Demand and Drought Response in a Southwestern Ontario Watershed. CWRA Canadian Committee on Irrigation and Drainage (CANCID), Montreal, QC 2016

Wexler, E.J., and Kassenaar, Dirk. 2016. Applications of Integrated Models to Watershed and Sub-Watershed Scale Analysis: A Canadian Context. XXI International Conference Computational Methods in Water Resources, Toronto, June 2016

Kassenaar, D. and Wexler, E.J. 2016. Assessing irrigation demand under drought conditions with the USGS GSFLOW model. Groundwater Resources Association of California, Concord, CA 2016

Kassenaar, D. and Wexler, E.J. 2016. Seasonal and Inter-Annual Water Budget Modelling with Integrated Models. Groundwater Resources Association of California, Concord, CA 2016

Kassenaar, D. and Wexler, E.J. 2015. Issues and Strategies for Integrated Model Calibration. IAH Conference, Waterloo, ON 2015

Wexler, E.J. and Kassenaar, D., 2015. Analysis of Groundwater/Surface Water Interaction at the Site Scale Babcock Ranch Community Development, Lee County, Florida. IAH Conference, Waterloo, ON 2015

Kassenaar, D. and Wexler, E.J. 2015. Assessing Cumulative Effects of SAGD Operations with an Integrated Model. CWRA Conference, Edmonton, AB 2015

Kassenaar, J.D.C. Integrated Modelling as a Tool for Assessing Groundwater Sustainability under Future Development and Drought in York Region, Ontario, Canada. Proceedings of the Canadian Water Resource Conference, Hamilton, Ontario, June, 2014

Wexler, E.J., Thompson, P.J., Takeda, M.G.S., Howson, K.N., Cuddy, S.E., Kassenaar, J.D.C., Simulating climate change and extremes with an integrated surface water-groundwater model to assess hydrologic response in the Lake Simcoe watershed. Proceedings of the Canadian Water Resources Conference, Hamilton, Ontario, June, 2014

Kassenaar, D., Wexler, Data Management and Calibration Strategies for Integrated Modelling. In Proceedings of the Watertech Conference, Banff, Alberta, April, 2014

Kassenaar, D., Marchildon, M., Wexler, E.J.. Rethinking Recharge. in Proceedings of the Conference "Modflow and More 2013" IGWMC, Golden, CO. May, 2013

Kassenaar, D., Wexler, E.J., Marchildon, M., Thompson, P.J. Integrated Modelling of

Groundwater Interaction with Channels, Wetlands and Lakes in GSFLOW. In Proceedings of the Watertech Conference, Banff, Alberta, April, 2013

Li, Q., Unger, A.J., Sudicky, E.A., Kassenaar, J.D., Wexler, E.J., and Shikaze, S., 2008, Simulating the multi-seasonal response of a large-scale watershed with a 3-D physically-based hydrologic model: J. of Hydrology, v. 357, no. 3-4.

Kassenaar, J.D.C., 1988. "Ocean Drilling Program: Plutonic Rocks in Fracture Zones", Leg 118 Shipboard Scientific Party. Nature v. 333, Issue 6169, 12 May, 1988.

SELECT TECHNICAL REPORTS (FULL BIBLIOGRAPHY AVAILABLE ON REQUEST)

Earthfx Incorporated, 2022, Updated wellhead protection area delineation, vulnerability scoring, and threats assessment for the Town of Shelburne, Ontario: prepared for S. Burnett and Associates and the Lake Erie Source Protection Region, August 2022, 311p.

Earthfx Incorporated, 2020, Level 1 and Level 2 Hydrogeological and Hydrological Impact Assessment Report for the proposed Burlington Quarry Extension: prepared for the Nelson Aggregates Co., April 2020, 461 p.

Earthfx Incorporated, 2020, Wellhead protection area and vulnerability assessment update for the Freelton Water Supply, City of Hamilton, Ontario, prepared for the City of Hamilton Public Works Department, April 2020, 126 p.

Earthfx Incorporated, 2018, Whitemans Creek Tier Three Local Area Water Budget and Risk Assessment: prepared for the Grand River Conservation Authority, 171 p.

Earthfx Incorporated, 2016, Phase 2 Review of potential cumulative effects to surface water and groundwater from in-situ oil sands operations, focusing on the Mackay River Watershed: prepared for the CEMA – Water Working Group, January 2016, 416 p.

Earthfx Incorporated, 2015, Thermal impact assessment of below-water-table aggregate extraction, Strada Aggregates Hillsburgh Pit: prepared for Strada Aggregates Incorporated, March 2015, 115 p.

Earthfx Incorporated, 2014, Tier 3 Water Budget and Local Area Risk Assessment for the Region of York Municipal Systems – Risk Assessment Report: prepared for the Regional Municipality of York Transportation and Works Department, March 2014.

Earthfx Incorporated, 2014, Tier 3 Water Budget and Local Area Risk Assessment for the Kelso and Campbellville Groundwater Municipal Systems - Phase 2 Risk Assessment Report: prepared for the Halton Region Conservation Authority, February 2014.

Earthfx Incorporated, 2014, Ecologically Significant Groundwater Recharge Area Delineation in the Central Lake Ontario Conservation Authority Area: prepared for the Central Lake Ontario Conservation Authority, May 2014.

Earthfx Incorporated, 2012, Simulation of Groundwater Flow and Saltwater Movement in the vicinity of the Atlantic Civil Property South Miami-Dade County, FL:

Earthfx Incorporated, 2010, Tier 2 water budget analysis and water quantity stress assessment for Lake Ontario Subwatersheds 1 and 3 in the Brighton and Colborne area: prepared for the Trent Conservation Coalition Source Protection Region - Lower Trent Conservation, April 2010.

Earthfx Incorporated, 2010, Vulnerability Assessment and Scoring of Wellhead Protection Areas: prepared for the City of Hamilton Public Works Department, April 2010, 162 p.

Earthfx Incorporated, 2010, Vulnerability analysis for the Georgetown and Acton wellfields, Regional Municipality of Halton, Ontario: prepared for the Regional Municipality of Halton, February 2010, 110 p.

Earthfx Incorporated, 2010, Vulnerability analysis for the Milton and Campbellville Wellfields, Regional Municipality of Halton, Ontario: prepared for the Regional Municipality of Halton, April 2010, 134 p.

Earthfx Incorporated, 2009: Updated vulnerability assessment and scoring of wellhead protection areas, Regional Municipality of York: prepared for the Regional Municipality of York, Environmental Services, November 2009.

Earthfx Incorporated, 2008, Appendix L: Simulation of groundwater flow in the vicinity of the proposed Southeast Collector trunk sewer -- Southeast Collector Trunk Sewer Environmental Assessment: Prepared for Conestoga-Rovers and Associates, the Regional Municipality of York, and the Regional Municipality of Durham, March 2008

Earthfx Incorporated, 2008, Simulation of groundwater flow in the vicinity of the New Nuclear-Darlington project -- Geology and Hydrogeology Effects Assessment: Prepared for CH2M Hill Canada Limited and Ontario Power Generation Inc., December 2008.

Earthfx Incorporated, 2007, Wellhead protection area study for municipal residential groundwater systems located within the Toronto and Region Conservation Authority watersheds -- Caledon East Wells 2, 3, and 4 and Palgrave Wells 2 and 3: prepared for the Regional Municipality of Peel, May 2007.

Earthfx Incorporated, 2007, Vulnerability assessment and scoring of wellhead protection areas -- Regional Municipality of York: prepared for the: Regional Municipality of York Transportation and Works Department, Water and Wastewater Branch, Sept. 2007.

Earthfx Incorporated and Geo Kamp Limited, 2020, Peel Water Resources Management Model 2019: prepared for the Regional Municipality of Peel, December 2020, 275 p.

Earthfx Incorporated, Greg Rawl, P.G., and Dean M. Mades (HSW Engineering Inc.), 2012, An integrated surface-water/groundwater modeling analysis of infiltration and stormwater runoff from the Babcock Ranch Community Development, Charlotte and Lee Counties, Florida: Prepared for Babcock Property Holdings, LLC, July 2012.

E. J. Wexler, M.Sc., M.S.E., P.Eng.

Vice-President and Director of Modeling Services

BIOGRAPHY

E.J. Wexler is Vice-President and Director of Modeling Services at Earth*fx* and has over 35 years of experience in groundwater modeling, contaminant hydrogeology, geostatistical analysis, and model code development. He has taught graduate courses in groundwater at universities in Canada, FL, and NY. He worked as a research hydrologist and groundwater modeling specialist for the USGS in Reston, VA, Long Island, NY, and Miami, FL. Mr. Wexler is a licensed engineer in the Province of Ontario, Canada.

EDUCATION

- B.E. Civil Engineering, City University of New York (1977)
- M.S.E. Civil Engineering, Princeton University (1978)
- M.Sc. Earth Science, University of Waterloo (1988)

PROFESSIONAL EXPERIENCE

Director of Modeling Services, Earthfx Inc., Toronto, ON 2002 - Present

Mr. Wexler is the Director of Modeling Services at Earth*fx* where he leads a team of surface and groundwater modelers. Mr. Wexler's experience at Earth*fx* includes:

- Directing groundwater flow and contaminant transport studies, with an emphasis on integrated groundwater/surface water modeling using GSFLOW.
- Technical Manager for Source Water Protection studies in southern Ontario. This included regional groundwater flow modeling studies for aquifer and wellhead vulnerability assessment and hydrologic modeling for water quality and water quantity risk assessment.
- Developed an integrated GW/SW model for the Little Spokane River, WA watershed.
- Technical Manager for Lake Simcoe Protection Plan studies in southern Ontario; subwatershed studies assessed regional groundwater flow, delineated ecologically significant groundwater recharge areas, and quantified the impact of land development, drought, and climate change on watershed function.
- Project Manager for an Integrated Catchment Management Plan for Northern Oman.
- Member of Scientific Peer Review team for evaluating the Tampa Bay Water/SWFWMD North Tampa Bay integrated model.
- Conducted integrated GW/SW modeling study for a large-scale development in Ft. Meyers, FL and a study of the FW/SW interface movement in the Homestead, FL area.
- Project Manager for hydrogeologic data analyses in South Florida related to the Comprehensive Everglades Restoration Program (CERP)
- Developed geostatistical analysis codes (3-D kriging and variogram analysis) for VIEWLOG, advanced water quality analysis modules for SiteFX, and graphical user interfaces for PRMS/GSFLOW (VL-GSFLOW and MC-Analyst) and PEST (VL-PEST).

Hydrogeologist/Hydrologist, Gartner Lee Limited, Markham, ON 1990 - 2002

As a senior hydrogeologist at Gartner Lee, Mr. Wexler directed groundwater modeling, groundwater resources management and contaminant hydrogeology studies in Canada, Florida and the Middle East. Selected projects where he was principal investigator include:

- Development of a groundwater flow and contaminant transport model for a low-level radioactive waste disposal site and evaluation of remedial measures.
- Development of a groundwater flow model for St. Thomas, U.S. Virgin Islands used to investigate the source of volatile organic compounds affecting water supply wells.
- Development of surface water and groundwater models to assess the impact of artificial recharge on the water balance, groundwater flow patterns and salt water intrusion in the arid coastal regions of Northern Oman.
- Co-development of MODNET, a surface water and groundwater model based on the USGS MODFLOW model and the USACE UNET surface water model for SFWMD.

Research Hydrologist, U.S. Geological Survey, Miami, FL ***1986 - 1990***

Mr. Wexler researched and developed models for simulating groundwater/surface water interaction. He also investigated the effects of density-dependent groundwater flow and solute transport on the feasibility of freshwater storage and recovery in saline aquifers (ASR) at Cape Coral, FL. He developed a coupled, regional-scale/fine-scale flow and transport model for simulating leachate migration at landfills in West Palm Beach, FL. He served as the Groundwater Discipline Specialist and Digital Modeling Specialist and was responsible for technical review and quality control for other surface water and groundwater modeling investigations.

Hydrologist, U.S. Geological Survey, Long Island, NY ***1981 - 1985***

Mr. Wexler was the Project Chief of a groundwater contaminant transport study at a sanitary landfill site. He investigated the local hydrogeology and studied the physical and geochemical controls on the transport of groundwater solutes. He developed flow and transport models for the study area and simulated long-term contaminant migration.

Research Hydrologist, U.S. Geological Survey, Reston, VA ***1979 - 1981***

Mr. Wexler was responsible for developing and testing finite-element models for simulating groundwater flow, solute transport and parameter estimation. E.J. consulted on field application of these models to sites in Maine, Kansas, and California.

SELECT TECHNICAL PAPERS (FULL BIBLIOGRAPHY AVAILABLE ON REQUEST)

Earthfx Incorporated, 2022, Updated wellhead protection area delineation, vulnerability scoring, and threats assessment for the Town of Shelburne, Ontario: prepared for S. Burnett and Associates and the Lake Erie Source Protection Region, August 2022, 311p.

Earthfx Incorporated, 2020, Level 1 and Level 2 Hydrogeological and Hydrological Impact Assessment Report for the proposed Burlington Quarry Extension: prepared for the Nelson Aggregates Co., April 2020, 461 p.

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Earthfx Incorporated, 2015, Thermal impact assessment of below-water-table aggregate extraction, Strada Aggregates Hillsburgh Pit: prepared for Strada Aggregates Incorporated, March 2015, 115 p.

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Earthfx Incorporated, 2014, Tier 3 Water Budget and Local Area Risk Assessment for the Kelso and Campbellville Groundwater Municipal Systems - Phase 2 Risk Assessment Report: prepared for the Halton Region Conservation Authority, February 2014.

Earthfx Incorporated, 2014, Ecologically Significant Groundwater Recharge Area Delineation in the Central Lake Ontario Conservation Authority Area: prepared for the Central Lake Ontario Conservation Authority, May 2014.

Earthfx Incorporated, 2012, Simulation of Groundwater Flow and Saltwater Movement in the vicinity of the Atlantic Civil Property South Miami-Dade County, FL:

Earthfx Incorporated, 2010, Tier 2 water budget analysis and water quantity stress assessment for Lake Ontario Subwatersheds 1 and 3 in the Brighton and Colborne area: prepared for the Trent Conservation Coalition Source Protection Region - Lower Trent Conservation, April 2010.

Earthfx Incorporated, 2010, Vulnerability Assessment and Scoring of Wellhead Protection Areas: prepared for the City of Hamilton Public Works Department, April 2010, 162 p.

Earthfx Incorporated, 2010, Vulnerability analysis for the Georgetown and Acton wellfields, Regional Municipality of Halton, Ontario: prepared for the Regional Municipality of Halton, February 2010, 110 p.

Earthfx Incorporated, 2010, Vulnerability analysis for the Milton and Campbellville Wellfields, Regional Municipality of Halton, Ontario: prepared for the Regional Municipality of Halton, April 2010, 134 p.

Earthfx Incorporated, 2009: Updated vulnerability assessment and scoring of wellhead protection areas, Regional Municipality of York: prepared for the Regional Municipality of York, Environmental Services, November 2009.

Earthfx Incorporated, 2008, Appendix L: Simulation of groundwater flow in the vicinity of the proposed Southeast Collector trunk sewer -- Southeast Collector Trunk Sewer Environmental Assessment: Prepared for Conestoga-Rovers and Associates, the Regional Municipality of York, and the Regional Municipality of Durham, March 2008

Earthfx Incorporated, 2008, Simulation of groundwater flow in the vicinity of the New Nuclear-Darlington project -- Geology and Hydrogeology Effects Assessment: Prepared for CH2M Hill Canada Limited and Ontario Power Generation Inc., December 2008.

Earthfx Incorporated, 2007, Wellhead protection area study for municipal residential groundwater systems located within the Toronto and Region Conservation Authority watersheds -- Caledon East Wells 2, 3, and 4 and Palgrave Wells 2 and 3: prepared for the Regional Municipality of Peel, May 2007.

Earthfx Incorporated, 2007, Vulnerability assessment and scoring of wellhead protection areas -- Regional Municipality of York: prepared for the: Regional Municipality of York Transportation and Works Department, Water and Wastewater Branch, Sept. 2007.

Earthfx Incorporated and Geo Kamp Limited, 2020, Peel Water Resources Management Model 2019: prepared for the Regional Municipality of Peel, December 2020, 275 p.

Earthfx Incorporated, Greg Rawl, P.G., and Dean M. Mades (HSW Engineering Inc.), 2012, An integrated surface-water/groundwater modeling analysis of infiltration and stormwater runoff from the Babcock Ranch Community Development, Charlotte and Lee Counties, Florida: Prepared for Babcock Property Holdings, LLC, July 2012.

Fernandes, R., Simic, A., Wang, S., Holysh, S. and Wexler, E.J., 2004, Assessing the effect of land cover and climate variability on supplying the water table through application of point source hydrological models in the Oak Ridges Moraine, Greater Toronto Region: Paper presented at the 57th CWRA Annual National Conference, June 16-18, 2004

Gartner Lee Limited, 1992, Surface and subsurface hydrology of the Credit River Escarpment Tributary headwaters area - Subwatershed 12: Prepared for the Credit Valley Conservation Authority, November 1992.

Gartner Lee Limited (Woerns, N. and Wexler, E.J.), 1996, Long-term water supply for the Regional Municipality of York – Groundwater resources:, Prepared for the York Region/Consumer Utilities/ Public-Private Partnership, October 1996. 68 p.

Gartner Lee Limited (Funk, G. and Wexler, E.J.), 1999, Simulation of regional groundwater flow in the City of Guelph, Ontario: 78 p.

Gerber, R., Wexler, E.J., Kassenaar, D., and Holysh, S., 2004, Regional numerical groundwater flow modelling and preliminary local-scale water budget analysis, Holland River Watershed, Ontario: in Proceedings IAH Annual Conference, Quebec City, Oct. 24.

Kassenaar, J.D.C. and Wexler, E.J., 2006, Groundwater modelling of the Oak Ridges Moraine Area: CAMC/YPDT Technical Report Number 01-06 -- York Peel Durham Toronto (YPDT) - Conservation Authorities Moraine Coalition (CAMC), 265 p.

Kassenaar, J.D.C., Wexler, E.J., Marchildon, M., Qing Li, 2011, GSFLOW Modeling of Surface Water And Groundwater Flow for Source Water Protection, Regional Municipality of York, Ontario, Canada: presented at MODFLOW and More, June 2011.

Li, Q., Unger, A.J., Sudicky, E.A., Kassenaar, J.D., Wexler, E.J., and Shikaze, S., 2008: Simulating the multi-seasonal response of a large-scale watershed with a 3-D physically-based hydrologic model: J. of Hydrology, v. 357, no. 3-4.

Thompson, P.J., Wexler, E.J., Takeda, M.G.S., and Kassenaar, D., 2015, Integrated surface water/groundwater modelling to simulate drought and climate change impacts from the reach to the watershed scale: paper presented at the IAH-CNC Conference, Waterloo, Ontario, November 2015.

WEST Consultants Inc. and Earthfx Incorporated, 2018, Integrated Groundwater/Surface Water Model for the Little Spokane Watershed – Water Bank Modeling and Decision Support Tool - Model Development and Application Report:, prepared for Department of Water Resources, Spokane County, 274 p.

Wexler, E.J., Strakowski, J., Kassenaar, D., Marchildon, M., Thompson, P.J., 2013, Using GSFLOW to Simulate Wellfield/Reservoir Interaction in a Re-Entrant Valley: presented at MODFLOW and More, June 2013

Wexler, E.J., Thompson, P.J., Kassenaar, J.D.C., and Takeda, M.G.S., 2016, Applications of integrated models to watershed and sub-watershed scale analysis -- A Canadian context: XXI International Conference Computational Methods in Water Resources, June 2016, Waterloo, Ontario.

Wexler, E.J., Thompson, P.J., Takeda, M.G.S., Howson, K.N., Cuddy, S.E., and Kassenaar, J.D.C., 2014, Simulating climate change and extremes with an integrated surface water-groundwater model to assess hydrologic response in the Lake Simcoe watershed: Canadian Water Resources Association Conference, Hamilton, ON, June 2014.

Gabriel F. Bacca-Cortes, PhD, P.E.

Intermediate Hydrogeologist

BIOGRAPHY

Gabriel is a hydrogeologist/water resources engineer experienced with the development of groundwater (HGS, MODFLOW, FEFLOW), surface water (SWMM 2-D), water quality (HSPF, WAM), and geochemical (PHREEQC) models. He also has considerable professional experience conducting water resources conceptual plans, rainfall space-time variability analysis, and the design of sewer collection systems.

EDUCATION

- **PhD Earth Science Department, University of Waterloo**. Advisor: Dr. Philippe Van Cappellen. Gabriel's research was in the development of a methodology for a multicomponent reactive transport model coupled with a travel time approach for multi-scale groundwater basin analysis.
- **Master of Science in Civil Engineering, Water Resources Program.** University of New Hampshire, Durham, NH, USA, December, 2004. Thesis: *"The Influence of Land Use upon the Characteristics of Groundwater Inputs to Great Bay Estuary, New Hampshire*" Analysis coupled groundwater dating tracers, stable isotopes and flow pattern analysis to identify the 'age' and degree of mixing of anthropogenic nitrate sources. Presented at the 2004 AGU Conference. Identified septic tank use in residential areas as source of high nitrate-bearing groundwater discharging to the Great Bay Estuary. (Advisor: Dr. Thomas Ballestero).
- **Bachelor of Science, Environmental Engineering**, December 1999. Universidad del Valle, Cali-Valle, Colombia.. Thesis: *"Streamflow multi-regressive prediction models in rivers from El Alto Cauca using macro-climatic variables associated to the ENSO (El Nino-Southern Oscillation) phenomena"*. (Advisor Dr. Yesid Carvajal).

AWARDS

- 2013 Farvolden Scholarship

PROFESSIONAL EXPERIENCE

***Senior Hydrologist/Integrated Modelling Specialist,* Earthfx Incorporated 2019-present**

- Project Manager, Town of Shelburne WHPA update. Developed and calibrated a PRMS hydrologic model for the area surrounding the Town of Shelburne and updating the previous MODFLOW groundwater model to account for new geologic and aquifer property data. Updated the wellhead protection area delineation and vulnerability assessment to reflect pumping from newly installed well.
- Project Manager, Peel Water Resources Management Model (PWRMM19) study. Developed and calibrated an integrated surface water/groundwater model using GSFLOW for the Regional Municipality of Peel, a 2692 km^2 area and a population of .1.4 million. Responsible for interpretation of hydrogeology, construction of a three-dimensional numerical MODFLOW model and a fine-scale (15-m cell size) distributed hydrologic model for Peel Region and the surrounding watersheds.
- Project Manager for a water budget study of the Whitewater watershed in the Sudbury, Ontario area. Applied USGS PRMS hydrologic model for highly responsive catchments on low-permeability soils on the Canadian Shield draining into Whitewater Lake. Model applied to better manage urban development and industrial practices in the basin.

***Senior Hydrologist/Modelling Specialist,* Chen Moore & Associates (CMA) 2011-2012**

- Project Engineer, Pompano Beach Stormwater Master Plan. Developed a 2-D Hydraulic Model using SWMM for the City including groundwater components and a calibration of open channel conveyance systems.

***Senior Hydrologist/Modelling Specialist,* Camp Dresser and McKee (CDM) 2005 – 2011**

- Project Engineer, Fort Lauderdale Executive Airport (FXE) Stormwater Drainage Study, 2011. Participated in the development of a stormwater management model (SWMM 2-D modeling) for the FXE airport to evaluate alternative scenarios needed for the improvement of drainage inside and in the vicinity of the airport.
- Project Engineer, City of New Orleans Stormwater Master Plan, 2009 to 2011. Coordinated development of 15 SWMM (2-D) models to define Capital Improvement Projects (CIP) for the City. Responsibilities included data collection and processing, development of hydrologic and hydraulic models, and coordinated the work of two junior modelers. Models entailed 10,530 hydrologic units, 16,000 junctions, 37,800 conduits, and 23 pump stations.
- Project Engineer, City of Miami Beach Stormwater Master Plan, June 2010 to June 2011. Conducted tasks including SWMM (2-D) alternative scenarios for Flamingo-Lummus neighborhood, rainfall analysis, the use of NetSTORM to estimate pump capacities, and development of a water quality model for the entire City to determine expected pollutant loadings from this highly urbanized area using the Watershed Management Model (WMM).
- Project Engineer, Development of a Water Quality Model for TMDL Implementation in the Indian River Lagoon Watershed (870 mi^2), 2008. Responsible for data collection, and HSPF model implementation and calibration of the North, Main, and South Canals in the Indian River Lagoon watershed. Compiled BMP (urban and agricultural) GIS coverages, MS4 program information, and point source monitoring data. Modeling tasks included updating the existing HSPF model with newer land use, and hydrology and water quality calibration.
- Project Engineer, City of Jacksonville's MSMP Update, 2009. Participated in the SWMM 2-D modeling task of two subbasins (Oldfield Creek) and (Cormorant Branch) and reviewed/updated the model for another two subbasins (Dunn Creek and Williamson Creek). Also participated in the modeling-mapping task of water level stages estimated by the model following specific standards to comply with FEMA Floodplain delineations.
- Project Engineer, Stormwater Master Plan for the City of Fort Lauderdale, 2007 to 2009. Completed the data collection, and the regional water quality (with WMM) and water quantity (with SWMM) evaluations for the Study Area. Responsibilities included collection of all pertinent data for the City-wide water quality and water quantity evaluations Modeling tasks included the development of a regional WMM model and the development of a local SWMM 2-D model at the Progresso Neighborhood (~500 ac).

SOFTWARE

- Integrated (groundwater/surface water) modeling : GSFLOW (USGS) and Hydrogeosphere (HGS). • Groundwater modeling: MODFLOW (USGS), Hydrogeosphere (HGS), FEFLOW (DHI), PHAST (USGS), PHT3D. • Surface water modeling: Storm Water Management Model (SWMM), HEC-RAS. • Watershed modeling: PRMS (USGS), HSPF, Watershed Assessment Model (WAM). • Other codes: Octave, Python, MATLAB, ArcGIS, EPANET, NetSTORM, Eagle Point (Sanitary Sewer), AquaCHEM, AutoCAD, SigmaPlot, OriginPro7.

CERTIFICATE

Professional Engineering (PE) License in the USA, received in June, 2012.

TATHAM ENGINEERING

Alicia Kimberley, MSc, P.Geo
Manager

Career Highlights

Alicia is a geoscientist, specifically practicing in the fields of hydrogeology and geoenvironmental sciences. Alicia's hydrogeological experience includes local and regional scale groundwater assessments, source water protection planning and implementation, well feasibility studies, water budgets, construction dewatering plan development and review, supervising the installation, development, sampling and decommissioning of monitoring wells, in-situ borehole permeability testing, design and execution of aquifer tests for water supply, determination of groundwater flow characteristics, assessment of groundwater-surface water interactions, and preparation of hydrogeological reports and compliance monitoring programs. Her geoenvironmental experience includes Phase One and Two Environmental Site Assessments, soil and groundwater sampling, near surface permeability testing, supervision of site cleanup/remediation, and external laboratory co-ordination. With respect to O.Reg.406/19, Ms. Kimberley meets the Qualified Persons requirements and has successfully executed several fill management projects including the preparation of the Past Use Assessments, completion of the required soil sampling and chemical testing, and preparation of the Soil Characterization Report. Ms. Kimberley has also coordinated and carried out several fill tracking programs as part of various fill management programs.

Detailed Experience

Alicia has provided senior hydrogeological and geoenvironmental input and review for various projects pertaining to site servicing, linear infrastructure, land development, source water protection, and/or excess soils.

Alicia's experience extends to the following:

- Detailed knowledge of the provincial legislation, regulations, and requirements pertaining to Water Takings, Private Septic and Water Wells, Large Subsurface Disposal Systems, Environmental Site Assessments, Excess Soil, and Well Construction.
- Extensive knowledge of the requirements and procedures of local municipalities and conservation authorities with respect to hydrogeological assessments in support of land development.
- Administration of various field assignments including hydrogeological and/or geoenvironmental drilling, monitoring well installation, development and decommissioning, groundwater and surface water sampling, borehole permeability testing, test-pitting, pump tests, and Guelph Permeameter testing.
- Collection, managing, analyzing, and presenting field data for use in technical reports.
- Preparation of the hydrogeological supporting technical reports in support of:
  - Water Taking (both Permit-To-Take-Water (PTTW) applications and Environmental Activity and Sector Registry (EASR) registration
  - Private Water Well and Septic Systems (MECP D-5-5 and D-5-4)
  - Reasonable Use Assessment for Large Subsurface Disposal Systems (LSSDS)
  - D-4 Land Use On or Near Landfills and Dumps
  - Submissions for new/proposed expansions of pits/quarries through the Aggregate Resources Act
  - PTTW and Environmental Compliance Approval (ECA) compliance reporting

Qualifications

2015 Master of Science
University of Waterloo
Waterloo, Ontario

2011 Bachelor of Science
McMaster University
Hamilton, Ontario

Professional Designations, Licences, Registrations

- Professional Geoscientists of Ontario

Professional Experience

2022 to Present — Tatham Engineering Limited
Barrie, ON
Group Leader

2021 to 2022 — GEI Consultants
Barrie, ON
Geoenvironmental and Hydrogeological Practice Lead

2016 to 2021 — Peto MacCallum Ltd.
Barrie, ON
Associate, Manager, Geoenvironmental and Hydrogeological Services

2013 to 2016 — Golder Associates Ltd.
Barrie, ON
Junior Hydrogeologist

- Preparation of the Phase One and Two Environmental Site Assessments, and Record of Site Condition submissions.
- Technical and budgetary aspects of hydrogeological consulting projects.

Previous Project Experience

Hydrogeological Investigations

MECP D-5-4: Individual On-Site Sewage Systems: Water Quality Impact Risk Assessment - Various projects throughout Ontario
Carried out test pitting and/or borehole drilling programs, groundwater sampling, and desktop background reviews in support of the MECP D-5-4 Guideline for both individual and multi-lot subdivisions. Assessed off-site impacts and determined potential nitrate loading associated with the proposed development.

MECP D-5-5: Private Wells: Water Supply Assessment - Various projects throughout Ontario
Carried out borehole drilling and monitoring well installation programs, groundwater sampling with respect Ontario Drinking Water Quality Standards, completed constant rate pumping tests, and desktop background reviews in accordance with the MECP D-5-5 Guideline for both individual and multi-lot subdivisions. Assessed available water supply with respect to both water quality and quantity, and potential off-site impacts.

Large Subsurface Disposal Systems - Various projects throughout Ontario
Carried out borehole drilling and monitoring well installation program, groundwater sampling and desktop background review in support of the MECPs Hydrogeological Investigation required for LSSDS. Assessed potential off-site impacts to downgradient water well users, surface water and ecologically sensitive receivers. Liaised with the MECP and septic designer through the MECP review and approval process.

Water Supply Assessment (Pump Test) - Various projects throughout Ontario
Following installation of a test hole and/or proposed water supply well, both short and long-term constant rate pump tests (2 to 72 hours) were carried out to confirm well yield. Water level monitoring was carried out in on-site monitoring wells, nearby private water supply wells, and test well(s) to confirm yield and potential impacts. Groundwater sampling was carried out to confirm compliance with the Ontario Drinking Water Quality Standards. Water level monitoring data was then assess to determine aquifer properties such as hydraulic conductivity, transmissivity and available storage. Prior to carrying out the proposed pumping tests all applicable MECP water taking permitting were obtained including either EASR registration or a MECP Category 3 PTTW.

Construction Dewatering – Various sites throughout Ontario
Collected and utilized hydrogeological/hydrological data from groundwater sampling, in-situ borehole permeability testing and surface water monitoring to assess the groundwater flow characteristics as part of a Hydrogeological Site Assessment in support of a Category 3 PTTW and/or EASR. Designed a MECP approved monitoring program for groundwater, surface water and settlement to be followed during construction dewatering to ensure not only compliance with the applicable municipal discharge criteria but to also monitor contaminant plumes in the vicinity of the site, and to continually assess potential dewatering induced settlement. Orchestrated and supervised the approved monitoring program through construction dewatering.

D-4 Land Use On or Near Landfills and Dumps - Various projects throughout Ontario
In accordance with the MECP D-4 Guidelines, a D-4 assessment was completed for the properties where a landfill was identified within 500 m of the subject property. Completed an exhaustive review of all available historical background information, annual monitoring reports for the source landfill, aerial photographs and geological maps were completed. Both the D-4 property and the source landfill were visited to document the features such as landfill configuration, slopes, drainage and/or vegetation as well as land use and drainage features between the D-4 property and the source landfill. To assess the potential on-site impacts from the source landfill a borehole drilling and monitoring well installation program was completed to facilitate a groundwater sampling and gas monitoring. Reporting in accordance with the MECP and local municipal requirements was completed.

Low-Impact Development Features and Water Balances – Lake Simcoe Regional Conservation Authority/ Nottawasaga Valley Conservation Authority
Coordinated and orchestrated borehole drilling and monitoring well installations, test pitting, Guelph Permeameter testing, groundwater sampling, and desktop background review in support of a hydrogeological investigation in accordance with both LSRCA, and NVCA requirements. Results of the field program and desktop review were utilized in the pre and post construction water balance calculations, assessment of the feasibility of implementing various LID features, and evaluation of potential off-site impacts as a result of the proposed development

Fill Management

Fill Management (Prior to O.Reg.406/19) – Various sites throughout southern, central and northern Ontario

Fill imported started in 2020 and with the expectation of O.Reg.406/19 being implemented in January 2021 was provided with respect to fill management ensuring compliance with the upcoming regulations. Qualified Persons (QP) services was provided where all imported soil was reviewed and approved prior to import to site. Part-time tracking of soil and confirmatory soil sampling and chemical testing during import was carried out ensuring the quality and quantity of imported soil was correct. In the event that the confirmatory soil sampling and chemical testing completed indicated that the imported soils did not meet the applicable Site Condition Standards guidance was provided with respect to a removals program, where all unsuitable soil would be removed from the site.

Fill Management (O.Reg.406/19) – Various sites throughout southern, central and northern Ontario

In response to the implementation of O.Reg.406/19 previous geotechnical projects were re-evaluated to ensure compliance with the new excess soil rules, as such an Assessment of Past Use, Soil Sampling and Analysis Plan, and Soil Characterization Report were developed. Further consulting services during Tender preparation ensuring sufficient details were provided to the bidding contractors

Environmental Investigations

Phase One and Two Environmental Site Assessments, and Record of Site Condition (RSC) Submissions – various sites throughout southern, central and northern Ontario

Facilitated the completion of Phase One and Phase Two Environmental Assessments in accordance with O.Reg. 153/04 in conjunction with concurrent geotechnical and hydrogeological investigations. Where environmental impact was noted recommendations regarding remediation and/or the completion of a Risk Assessment were provided. Liaised with MECP and subcontracted Risk Accessors (RA) throughout the iterative MECP Risk Assessment and/or RSC review and approval process

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PRESENTATIONS

Ontario Sand, Stone and Gravel Association Conference, February 2023

Title: Excess Soil: How to utilize collaboration partnerships to develop efficiencies and cost savings.

The goal of the presentation was to emphasize the importance of early planning to establish collaborative approaches and efficiencies during rehabilitation processes to ensure compliance with the new excess soil requirements.

Excess Soil – Compliance with the newly implements O.Reg.406/19 – various municipalities in Southern and Central Ontario

Provided technical support pertaining to new requirements outlined O.Reg.406/19 and coordinated interactive lunch and learns with the local municipalities to help educate staff on the new rules and requirements.

Asoka Kodippili, B.Sc., P.Geo.

Hydrogeologist/ Data Analyst

BIOGRAPHY

Mr. Asoka Kodippili is a Professional Geologist who works as a hydrogeologist and data analyst at Earthfx. Asoka has more than twenty years of experience as a professional hydrogeologist in Canada and other countries. In Ontario, he has worked on projects under the Ontario Geological Survey funded Groundwater Resources Inventory Program (GRIP) at Conservation Halton and Hamilton Conservation and as a regional hydrogeologist with the Ministry of Environment in Thunder Bay. His international experience includes work in Sri Lanka, where he managed a groundwater development program for the National Water Supply and Drainage Board and worked as a consultant hydrogeologist for Australia-based Water Resources Consulting Services. He has a strong background in GIS (including a GIS degree from Sir Sandford Fleming College) and extensive experience with modern database management systems.

EDUCATION

- B.Sc. Geology, University of Peradeniya, Sri Lanka (1979)
- Post Graduate Diploma, GIS Application Specialist, Sir Sandford Fleming College (2003)

PROFESSIONAL EXPERIENCE

Hydrogeologist, Earthfx Inc. ***2007 - Present***

- Managed, analyzed and processed large SQLServer databases for the Halton-Hamilton, GRCA, ORM and LSRCA Source Protection Regions. Prepared and analyzed datasets for numerous large GSFLOW projects for Source Water Protection.
- Utilized VIEWLOG to constructed hydrostratigraphic model surfaces for the Osmington GSFLOW model.
- Database Manager, Region of Durham Earthfx Hosted Database: Upgraded and applied QA/QC processing to the database for the three years it was hosted at Earthfx.
- Managed a large-scale aquifer vulnerability study for the Lake Erie Source Protection Region which covered Norfolk and Brant Counties and the Catfish Creek and Kettle Point watersheds.
- Conducted a wellhead protection area delineation study for Halton Region that analyzed potential contamination of wells under the direct influence of surface water.
- Analyzed and assessed hydrologic data for Halton Region and York Region source water protection studies to assess aquifer properties, analyze transient groundwater and surface water response, and characterize regional water demand.
- Developed environmental databases in support of regional groundwater modeling studies on the Oak Ridges Moraine and for numerous source water protection investigations.
- Manages all Earthfx and hosted environmental databases. Directed the conversion/upgrade of large MS ACCESS databases to the SQL Server environment.

Hydrogeologist, Halton Conservation Authority ***2006***

- Managed a Groundwater Resources Inventory Program (GRIP) study funded by the Ontario Geological Survey.

- Reviewed technical reports; gathered geological, hydrogeological, chemical and geophysical data.
- Compiled data and produced maps and reports.
- Participated in Source Water Protection planning workshops and discussions.

Hydrogeologist, Ontario Ministry of the Environment ***2005 - 2006***

- Reviewed technical reports to ensure compliance with Ontario legislation.
- Provided technical support to find an alternative water source for Hearst Township.
- Assisted in the geophysical delineation of a leachate plume at a landfill site.
- Developed a GIS system to enable the Provincial Permit to Take Water program to identify existing takings by watershed.

Hydrogeologist, Hamilton Conservation Authority ***2004 - 2005***

- Designed an MS ACCESS database and developed forms for manual data entry and analyzed data to produce groundwater vulnerability maps and derive parameters for groundwater models.
- Developed a two-dimensional hydrogeological model, which included the integration of geology, hydraulic properties, groundwater vulnerability and aquifer potentials.
- Tabulated historical groundwater and surface water flows to identify threshold values for low-water response criteria.
- Provided expertise to HCA staff to complete studies on source water protection.

GIS/GPS Technician, Eastern Ontario Trail Alliance ***2003 - 2004***

- Involved in the design of a geodatabase and the production of Trail Mapping.
- Initiated and developed a graphical-user interface (GUI) in ArcView.

Manager – Groundwater Investigation ***1998 - 2001***
National Water Supply and Drainage Board, Sri Lanka

- Supervised and managed the groundwater investigation section.
- Conducted numerical modelling for regional groundwater assessment.
- Coordinated the preparation of data standards and data transfer protocols.
- Performed aquifer delineation studies to identify vulnerable groundwater areas.
- Presented technical papers, reviewed consultants' reports and published reports.

Consulting Hydrogeologist ***1996 - 1998***
Water Resources Consulting Services, Australia

- Produced hydrologic schema of five river basins in the western province of Sri Lanka.
- Inventoried industrial and municipal waste disposal sites and their impacts on groundwater resources.
- Defined well-head protection areas for municipal water supply wells.
- Conducted numerical modelling to assess impacts on groundwater resources and calculated water budgets.

Well Site Hydrogeologist, Ministry of Water Resources, Oman ***1993 - 1995***

- Participated in a water-well drilling program to assess potable groundwater.
- Logged boreholes, pumping tests, designed wells and produced technical reports.