MORRISON HERSHFIELD

FINAL REPORT

Livingstone Trail Environmental Control Facility (LTECF) Hydrogeological Study

WHITEHORSE, YT

Presented to:

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EXECUTIVE SUMMARY

Morrison Hershfield Ltd. (MH), was retained by the City of Whitehorse (The 'City') to provide hydrogeological consulting services through the completion of this desk-top hydrogeological study for the Livingstone Trail Environmental Control Facility (LTECF). The facility is comprised of a series of primary wastewater lagoons, secondary lagoons, and a long-term water storage impoundment, set in a terraced glaciolacustrine setting, on the east side of the Yukon River. This study fulfills Condition 37 of The City's Water License MN18-059, which notes the requirement of an updated hydrogeological assessment.

The assessment involved compilation of existing hydrological and hydrogeological information, development of a water balance for the facility, identification of potential receiving environments, development of a conceptual hydrogeological model of the facility and surrounding area, creation of a three-dimensional groundwater flow model of same, and use of the model to quantify direction and rate of groundwater flow, travel times for potential contaminant pathways, and the impact of uncertainties/data gaps.

The water balance found that approximately 4.2 million cubic metres of wastewater flow into the facility each year, while approximately 3.5 million discharge. After accounting for precipitation, evaporation, and changes in storage, the rate of exfiltration (or loss to the groundwater system) was estimated as less than four percent of the total inflow, a small number within the range of uncertainty of the analysis.

The conceptual model was supported by the available digital elevation model, approximately 300 test pit logs, 70 borehole logs, 41 monitoring well records, 17 representative measured/ averaged groundwater elevations, and the construction details of the facility. The conceptual model was realized in maps and in a set of six (6) cross sections. The conceptual model identified the Yukon River as the primary receiving environment, the role of the surficial silt (grading to clay) upon which the facility is built, the importance of an ice-contact deposit of sand and gravel situated between the facility and the Yukon River to the south, and the probable importance of the bedrock as being more permeable than the overlying silt/clay.

The numerical model was constructed using nine-layers of 50 m by 50 m finite difference grid blocks, with variable thickness, to represent the overburden and the upper one kilometer of the bedrock. Constant head boundary conditions were applied to represent the fixed water elevation at the up-gradient boundaries of the model, at the lagoons, and at the Yukon River. "Inactive cells" were applied to eliminate the unsaturated zone, and groundwater outside of the groundwatershed. Constant flux was applied to the top of the model to represent recharge from precipitation. Model properties were applied to represent silt, clay, the ice-contact deposit, and the bedrock, with distribution based on the conceptual model. The model was calibrated by adjusting parameters, within reasonable ranges, so as to match the simulated groundwater elevations to the measured values.

The results of the modelling indicated that exfiltration from the lagoons travels vertically downward in the silt and clay for a few hundred years prior to discharge into the underlying bedrock and/or ice-contact deposit. The results suggest that all groundwater discharged to the bedrock is captured by the ice-contact deposit and, ultimately, by the Yukon River. Travel times in the bedrock vary depending on the length of the path, but are in the order of a few decades. Travel times across the ice-contact deposit (between the facility and the river) are also in the order of one to two decades. The key uncertainties are the possible presence of ice-contact deposit on the west side of the facility (due to a lack of deep boreholes there), and the degree of connectivity between the south end of the lagoons and the ice-contact deposit. A borehole drilling program involving the installation of monitoring wells is recommended to be implemented in an orderly, non-urgent manner, to better characterize the groundwater flow regime and to more effectively monitor potential impacts to groundwater quality downgradient of the LTECF.

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1. INTRODUCTION

Morrison Hershfield Ltd. (MH), was retained by the City of Whitehorse (The 'City') to provide hydrogeological consulting services through the completion of this desk-top hydrogeological study for the Livingstone Trail Environmental Control Facility (LTECF). This study fulfills *Condition 37* of The City's Water License MN18-059, which notes the requirement of a hydrogeological assessment.

1.1 Scope of Work

The scope of work for this study includes the following:

- Review, compile, and analyze related studies, reports, borehole logs, test pit logs, groundwater and surface water test results prior to development of the facility and since it has been in operation to the present.
- Determine the direction and rate of groundwater flow.
- Identify potential receiving environments.
- Assess travel times for potential contaminant pathways.
- Develop a hydrogeological ground water flow model, and interpret the modeling results.
- Provide recommendations for additional wells if they are found to be necessary to characterize the groundwater flow regime and/or to effectively monitor potential impacts to groundwater quality downgradient of the LTECF; and,
- Prepare of a report that address the items identified in the Water Use License (WUL), including any recommendations for additional data collection and/or subsurface investigations required to substantiate conclusions, define flow paths, impacts of probable seepage paths from the facility, etc.

1.2 Background Information Review

A number of background reports were provided by The City for review, as listed in **Table 1**, below. Overall, based on the available background documents, 293 known shallow test pits were previously completed in the area to depths ranging from 0.7 m to 11.7 m. Additionally, 69 boreholes were drilled to depths ranging from 4.5 m to 59.8 m, and 28 monitoring wells were installed in the area.

Table 1: Background Studies and Reports

	Report	Key Information Summary
A	July 1990 - Klohn Leonoff / NovaTec; Sewage Treatment Feasibility Study Phase I Brief	
B	August 1991 - Klohn Leonoff / NovaTec; Sewage Treatment Feasibility Study Phase II Report, Vol. 1 and 2	11 drill holes and 31 test pits; potentiometric map; three cross sections; summary of monitoring well installations.
C	April 1993 - Klohn Leonoff / NovaTec; Sewage Treatment Feasibility Study Phase III Report	Updated potentiometric map.
D	December 1992 - Klohn Leonoff / NovaTec; Sewage Treatment Feasibility Study; Selection of Final Treatment Option	Site plan of surface impoundment area.
E	June 1996 - Stanley/DNA; City of Whitehorse Sewage Treatment Project Treatment Lagoons and Long Term Impoundment Design Brief; including Geotechnical Embankment Design, Primary and Secondary Treatment Cells and Storage Impoundment Pond, Whitehorse Sewage Treatment Facility, Whitehorse, YT, EBA Project No. 0201-11482, April, 1995	Logs of 7 boreholes and 100 test pits; evaluation of the ice-contact deposits encountered in the vicinity of primary cell B; borehole and test pit location plan showing 1990 Klohn Leonoff, 1993 and 1995 EBA; updated potentiometric map showing flow patterns, extent of ice contact deposits, including outlier; hydraulic conductivities, seepage rates, travel times, and renovation of seepage quality.
F	March 1996 - Stanley; Preliminary Evaluation Pot Hole Lake Treated Sewerage Effluent Disposal	Detailed hydrogeological evaluation to determine whether the connection existed that would provide an option to discharge treated effluent from the retention pond to Pot Hole Lake, as opposed to a direct discharge to the river.
G	April 1999 - Stantec; Preliminary Report Trial Discharge of Treated Sewerage to the Pot Hole Lake	Monitoring wells drilled between Pot Hole Lake and the Yukon River and in the upper slopes of Pot Hole Lake; transmissivity estimates from pumping tests; calibrated groundwater simulation of trial discharge.
H	July 2000 - Stantec Trial Discharge Evaluation Report	Summary of findings from the discharges, including an updated groundwater model for the Pot Hole Lake area.
I	DNA 1996 - Sewage Treatment Project Porter Creek Effluent Transfer Design Brief	Geotechnical evaluation undertaken for the proposed alignment of the Porter Creek effluent transfer line to the new LTECF. It included tests pits and bore holes to determine soil conditions along the proposed alignment.
J	City of Whitehorse Water Use License MN18-059	Rationale for this project.
K	Water License water monitoring for the LTECF; '96 to present	
L	City of Whitehorse Water License Annual Reports; '96 to present	Maps, potentiometric data, groundwater flow/quality data.
M	March 2019 - Morrison Hershfield; Memo Report: Inspection and Replacement of Monitoring Well (GW4) at LTECF	
N	Geotechnical Evaluation, Proposed Sewage Treatment Facility, Whitehorse, Yukon, EBA Project No. 0201-11929	Logs of 17 boreholes and 157 test pits.
O	Monitoring data	Spreadsheets of groundwater monitoring data provided by the City of Whitehorse
P	Groundwater Inventory and maps, Gartner Lee, 2003	

1.3 Regional Setting

1.3.1 Physiography

The full extent of the Study Area is shown on **Figure 1, of Appendix A**. The dominant physiographic feature in the Study Area is the northwestward flowing Yukon River, located to the west and south of the LTECF.

Whitehorse lies at the transition zone between two Physiographic Regions; the Yukon Plateau, and the Coast Mountains (Wheeler, 1961). The Yukon River is bound both to the east and west by glacially rounded mountains. In general, the ground surface is highest (700 metres above sea level (mASL)) near the eastern boundary of the Study Area, and lowest at the eastern boundary (640 mASL) along the Yukon River.

The LTECF is within a terraced glaciolacustrine landscape setting (Gartner Lee, 2003). These terraces represent the bottom of an ancient lake which filled the Whitehorse Valley during deglaciation. The glaciolacustrine terraces are comprised of a thick sequence of fine sand, silt and clay and are frequently capped by a two to five meter layer of glacial outwash sand.

The LTECF is located within the Laberge Basin, which is bound in the west by the Yukon River and in the east the Salmon Range. The basin is bound by Croucher Creek to the south, and by Lake Laberge in the north.

1.3.2 Surficial Geology

The glaciolacustrine deposits consist of silts which gradually grade from non-plastic silt in the upper three to five metres to a medium plastic clayey silt at depth. The upper part of non-plastic silt has a blocky structure due to weathering and frost effects. In general, sand content increases closer to the source of the sediment, the ice front or incoming streams into the lake, and the clay content usually increases towards the deeper portion of the lake basin. These glaciolacustrine deposits have been observed to have fine horizontal lamination, and as a result, it is inferred that there is a strong preference for horizontal groundwater flow versus vertical seepage flow.

Coarse-grained ice-contact deposits also exist within the Whitehorse Valley (Gartner Lee, 2003). These ice contact deposits are glaciofluvial and are created either from direct contact with or in proximity to glacial ice. Boulder and cobble gravel with pockets of silty and sandy gravel are very common in these deposits. The ice contact deposits are characterized by a pitted and hummocky topography which represents the locations of buried ice blocks which have subsequently thawed and collapsed. The glaciolacustrine silt was formed after the ice contact deposits. The ice contact hills and ridges were initially deposited in mounds and hills likely extending to near the original valley bottom. Flooding by the subsequent glacial lake filled the valley with lacustrine silts which covered the lower elevations of the isolated ice contact hills. Glacial ice blocks were also buried or encapsulated by the lacustrine sediments. These ice blocks subsequently melted, resulting in intermittent depressions and small isolated lakes.

Some exposures where the ice contact materials were not entirely covered by the silt deposits were identified, forming gravel hills, with flanks buried in silt and clay. A large exposure of the ice contact deposit was observed in the southwest corner of the lagoon area, around the Pot Hole Lake area (see Stanley, 1996 and the horizontal extent of the deposit inferred from previous mapping, on **Figure 1 of Appendix A**). Ice contact deposits were also exposed at the Primary Lagoon Cell B, and the lagoon structure was over-excavated to a depth of approximately four metres in the vicinity of the granular deposits and replaced with compacted silt liner material. The ice contact deposit thickness can exceed 20 meters, and in the Hidden Lake area, the thickness of the ice contact deposit have been documented to be over 90 meters thick (Gartner Lee, 2003). These ice-contact deposits, being of coarser texture than the overlying silts and clays, are very important from a hydrogeological perspective, and this is described in more detail in Section 1.3.4.

North of the site is mapped as Whitehorse Dune Field with significant occurrence of aeolian deposits which consist of medium to fine sand and silt that is well sorted and non-compacted (EBA, 1995).

1.3.3 Bedrock Geology

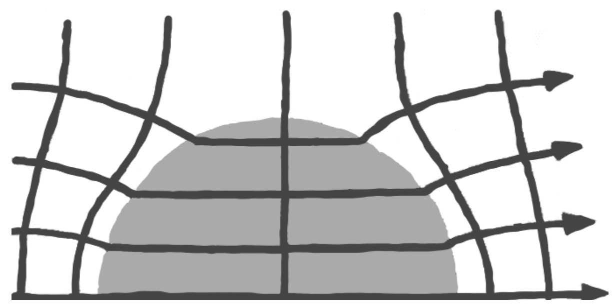
Bedrock was not encountered during the subsurface investigations in the Study Area. The bedrock beneath the Study Area is believed to consist of sandstone and shale strata belonging to the Laberge Formation (part of the Whitehorse Trough Supergroup). A Geophysical investigation conducted by Cosmic Ventures indicated the bedrock surface may be at an elevation of less than 600 mASL in this area (Stantec, 2000).

1.3.4 Hydrogeology

Regionally, the groundwater flow direction is to the west, away from the mountains and towards the Yukon River. Local surface water impoundments distributed irregularly throughout the basin appear to represent intermediate groundwater discharge points between the bedrock highlands (to the east) and the Yukon River. The river represents the regional groundwater discharge zone. The river level is known to vary seasonally, fluctuating approximately 2.5 m between the wet and dry season (City of Whitehorse, personal communication).

Generally, the glaciolacustrine silts and clays act as an aquitard. Previous testing has indicated the hydraulic conductivity of the silt to be in the order of $7x10^{-7}$ m/s (Klohn Krippen in Stanley, 1996).

The hydraulic conductivity of the ice-contact deposit, which is acknowledged as the main aquifer in the area, is known from pumping tests carried out during investigations for the use of Pot Hole Lake as effluent injection point (Stantec, 1996). The pumping tests and model calibration suggested a hydraulic conductivity for these sand and gravel deposits between $1x10^{-4}$ m/s and $7x10^{-4}$ m/s. This ice-contact deposit is very similar in its origin to the Selkirk aquifer, in the Riverdale part of the city. According to Gartner Lee (2003), the aquifer has a typical transmissivity of 2,000 m^2/day, a typical thickness of 50 m; translating to a typical hydraulic conductivity of $4x10^{-4}$ m/s.



The hydrogeological effect of high permeability inclusions in otherwise low-permeability porous media is sometimes called “flow focusing”. In short, the high permeability represents a path of least resistance, and groundwater is drawn into this path. That is, on the up-gradient side, horizontal gradients develop near the inclusion, and flow lines bend towards it. There is a refraction of flow lines at the inclusion edge, and groundwater flow directly across the inclusion within low hydraulic gradient but higher velocity. At the down-gradient side, the flow lines refract back outwards. The graphic within this paragraph shows this pattern of flow lines (lines with arrowheads) and equipotential lines (lines without arrowheads) at an inclusion of high permeability (the shaded area), adapted from West et al., 2003. Within the context of the Laberge Basin, the ice contact deposits represent such an inclusion. Generally, the ice-contact deposit acts as a groundwater sink, and conduit to the Yukon River, to which it appears to be directly attached. The lower hydraulic gradients and higher groundwater velocities documented down-stream of Pot Hole Lake (Stantec, 1996) are consistent with this interpretation.

The extent to which the bedrock represents the regional aquifer system is unknown. According to Gartner Lee (2003), there are very few documented water wells completed in the Whitehorse Trough Super Group. What few wells there are range in depth from 20 to 100 m and are typically low yield. Other bedrock packages are typically considered to contain aquifers of less than 100 m thickness, with transmissivity on the order of 1 m^2/day. This suggests a hydraulic conductivity on the order of $1x10^{-7}$ m/s.

1.4 LTECF Configuration and Operation

The LTECF was constructed in 1996 and the outlet structure to the impoundment was constructed later in 1997. In the following year, the discharge pipe connecting the impoundment to the Pot Hole Lake was built. In October 2009, the discharge line was completed by adding a conveyance section from the Pot Hole Lake junction to the Yukon River (City of Whitehorse, 2018).

The lagoon system, as shown on **Figure 1 of Appendix A**, consists of the following:

- Two 115,000 m^3 primary treatment cells (with depths of 6.1 m and a combined retention time of 20 days);

- Four 293,000 m^3 secondary cells (with depths of 2.5 m and a combined retention time of 100 days); and,

- One 5,813,000 m^3 long term water storage pond (also referred to as the impoundment), with varying depth based on the original topography, with approximately one year of retention time.

For the normal lagoon operation, wastewater flows through all treatment cells in series, from Primary B to Primary A and to Secondary 1 to Secondary 4 by gravity, and finally to the long term storage impoundment. Information about the treatment cells is summarized in **Table 2**, below:

Table 2: Treatment Cells and Configurations

Cell Number	Cell Bottom Elevation	Effluent Level Elevation
Primary Cell A	674.7	680.9
Primary Cell B	674.7	680.9
Secondary 1	677.6	680.1
Secondary 2	675.9	678.4
Secondary 3	674.9	677.4
Secondary 4	674.2	676.7
Storage Impoundment	Variable	Variable

The storage impoundment is a natural depression with a low dyke closing the west end of the impoundment. The ground elevation is between 655 m and 670 m. After initial filling, the water level will varies between 665 m following the fall drawdown, and 670 m immediately prior to the fall drawdown.

From 1998 to 2009, the discharge of the treated effluent was directed to Pot Hole Lake during the three months of August to October. Over time, a layer of material (fines, bacterial mat, etc.) accumulated at the bottom of PHL which reduced its ability to exfiltrate the effluent water, and, from 2009 to 2016, the treated effluent was directed to the Yukon River. Discharge was reverted back to Pot Hole Lake following a discharge line failure in 2016, but this situation is now corrected. More details on the discharge amounts and schedule is provided in **Appendix B**.

2. METHODS

2.1 Water Balance

A water balance analysis was conducted using standard methods, as described in the Water Balance Memo, provided in **Appendix B**.

2.2 Conceptual Modelling

2.2.1 Borehole/Piezometer Database Compilation and Process

A database was populated in Microsoft Excel, which included information for each known test pit and borehole, such as: point identifier (ID), coordinate location, elevations of ground surface, piezometer top and bottom; groundwater level (by date), and bottom of stratigraphic unit.

In-house software called MOEWW (because it was originally designed to process Ontario Ministry of the Environment Water Well information) was used to process the borehole/piezometer information. This software reads header information, geologic data (tops and bottoms of the stratigraphic units, each of which are tagged with a code), hydrogeological data (in “open hole mode”, the software reads the elevation of one or more “water found” and a single groundwater elevation; in “monitoring well mode”, the software reads the top and bottom elevations of one or more monitoring well screens and one or more associated groundwater elevations), and an optional surface file (typically a digital elevation model (DEM)). Depending on instructions in the header, the software combines stratigraphic units into a smaller number of “formations”, calculates various statistics on the borehole information, projects the formations, the hydrogeological information, and the optional surface elevations on a set of one or more cross-sections chosen by the analyst, and writes out the map and cross-section information to an AutoCAD-compatible file. The software also prepared input files for later use in Visual MODFLOW Flex (mainly calibration targets from groundwater elevations). The analyst then brought the cross-section output into AutoCAD and post processed to produce high quality drawings to-scale.

2.2.2 Conceptual Groundwater Modelling

A conceptual hydrogeological model was developed based on careful interpretation of the available information, specifically the surficial geological mapping and the cross-sections. The conceptual model is a written description of the hydrogeological system, accompanied by maps and subsurface cross-sections. It explains the major patterns of groundwater (recharge, flow, and discharge); the major aquifers and aquitards (i.e., a list of hydrostratigraphic units defined by name, lithology, hydraulic conductivity, and porosity); the typical horizontal and vertical groundwater velocities;

groundwater geochemistry and age; and, the anthropogenic and ecological interactions and dependencies.

2.3 Groundwater Flow Simulation using MODFLOW

After the conceptual model of groundwater flow, a three-dimensional numerical model was developed using Visual MODFLOW Flex. The step by step process for this conversion is:

1. Prepare the hydrostratigraphy as a set of surfaces; discretize the model domain horizontally (potentially with refinement around the LTECF itself to account for higher velocities, more complex geometry and the need for special boundary conditions), and vertically to account for the hydrostratigraphy from surface to the practical bottom of the flow system;

2. Apply best estimate properties of the hydrostratigraphy; apply recharge to the upper surface; assign other surface boundary conditions (e.g., constant head boundary conditions at the Yukon River, chosen representation of the hydraulics of the LTECF);

3. Assign lateral boundary conditions (e.g., no-flows beneath the centreline of the Yukon River, general head or constant head at the up-gradient sides); and,

4. Set up the zone budgets (for assessing the accuracy of the flow rates) and the calibration targets (for assessing the accuracy of the simulated groundwater elevations).

The model was run using MODFLOW-2005, Version 1.12.00 2/03/2017, which is resident in Visual MODFLOW Flex. The model was run in steady-state mode with the choice of confined or unconfined layers being decided as part of the model development (see the results section for more information on why we chose to eliminate the unsaturated zone from the model, and run all layers a fully confined/saturated). To calibrate the model, its parameters were adjusted within the estimated ranges so as to best match the simulated flows and groundwater elevations to the measured or estimated values. If a reasonable match was not achieved through this adjustment process, then the conceptual model was revisited and the model construction and calibration process started anew (i.e., all modelling is an iterative process, and the purpose of all modelling is to investigate and learn).

2.4 Water Balance Check using ‘ZONEBUDGET’

‘ZoneBudget’ is a program developed by the U.S. Geological Survey to assess the flow of water between different zones in a model and how water enter and exists the groundwater system within the model boundary. This program was used to complete a check on the water balance, and to understand the magnitude of the flows within different parts of the hydrogeological system.

2.5 Travel Time Analysis using 'MODPATH'

'MODPATH' is a particle-tracking post-processing software package that was developed to compute three-dimensional flow paths using output from steady-state or transient ground-water flow simulations by MODFLOW. 'MODPATH' uses a semi-analytical particle tracking scheme that allows an analytical expression of the particle's flow path to be obtained within each finite-difference grid cell.

'MODPATH' calculates pathlines and travel times of groundwater flow (and solutes dissolved in groundwater). Particle tracking can be used to draw flow nets, determine recharge zones and/or capture zones, and to estimate travel times of conservative contaminants of concern.

'MODPATH' is the most common particle tracking code in the groundwater industry. It is useful as a visualization tool to help understand flow patterns in simulated ground-water flow systems. It is useful for delineating sources of water to discharge sites and aquifers in systems simulated with MODFLOW.

Once the numerical model was calibrated, we used 'MODPATH' to determine the flow lines and the travel times. One particle was released in the centroid of each lagoon, one particle in the north part of the long-term water storage impoundment, and one particle in the south part, and one particle was released at Pot Hole Lake.

2.6 Uncertainty Analysis

Uncertainty analysis is an assessment of the degree to which the characteristics of the hydrogeological system are uncertain, and the degree to which this uncertainty affects the conclusions of the study. Typically in modelling projects, uncertainty is assessed by identifying both a best estimate of parameters as well as ranges of possible values. The model parameters can then be adjusted to quantify the difference in model output due to the differences in input.

See the results section for more information on how we assessed uncertainty.

3. RESULTS

3.1 Conceptual Model

3.1.1 Hydrogeologic Units

The test pit and borehole locations (with useful subsurface data) are shown on **Figure 1, of Appendix A**. There were approximately 300 useful test pit logs and approximately 70 useful borehole logs. Test pits ranged in depth from 0.7 m to 11.7 m, with a 4.3 m average. Boreholes ranged in depth from 4.5 m to 59.8 m, with a 15.7 m average. Stratigraphic descriptions included silt (43% of entries), fine sand (23% of entries), topsoil (16% of entries), medium sand (7% of entries), clay (5% of entries), gravel (5% of entries), coarse sand (1% of entries) and till (1% of entries). The dominance of the silt and fine sand in the statistics relates to the higher proportion of shallow test pits in the sample than deeper boreholes. For the purposes of presenting the information on the cross-sections, the various stratigraphic descriptions were lumped into the following categories, from finest to coarsest: clay, silt, sand, and gravel. The depth range of these categorized soils are shown on cross-sections A through F, as shown on **Figures 3a-f, of Appendix A**.

Based on the classified and projected stratigraphic information, and on the surficial geology of (**Figure 2, of Appendix A**), a conceptualized geological layer-cake model was drawn onto the cross-sections, as shown. The oldest unit in the model is the “ice-contact deposit”, overlain by glaciolacustrine clays, transitioning upwards to silts. Generally, five to ten or more metres of silt is present. The uppermost unit is sand, where present, with a significant thickness (greater than 20 m), especially in the north of the Study Area where sand dunes exist. The shape of the ice-contact deposit was inferred based on assumed depositional history, and it was assumed to extend to bedrock. Approximately 100 m of overburden was assumed based on the background information, and bedrock was assumed present at 580 mASL.

3.1.2 Groundwater Flow

The locations of monitoring wells with useful groundwater elevation data are shown on **Figure 1, of Appendix A**. Forty-one monitoring well logs were found, with corresponding water levels measured at various dates. The monitoring wells ranged in depth from a few metres to almost 40 m, with a 14 m average. Seventeen of the 41 wells were dry, leaving 24 measured groundwater elevations. Within the Study Area, four (4) groundwater elevations were found representing pre-lagoon conditions, and eleven (11) were found representing post-lagoon conditions when discharge was not being directed to to Pot Hole Lake (because discharge to Pot Hole Lake was not included in the modelling scenario). Those groundwater elevations that were used as “calibration targets” in the model are summarized in **Table 3**, below. The screened intervals and measured groundwater elevation are shown on cross-sections A through F, as shown on **Figure 3a-f, in Appendix A**.

Table 3: Groundwater Elevation Calibration Targets

Well Name	Bottom of Well Elevation (mASL)	Groundwater Elevation (mASL)	Date of Measurement
93-BH-02	651.1	655.93	11/23/1993
93-BH-03	659.1	659.2	11/23/1993
93-BH-04	658.62	662.22	11/23/1993
93-BH-06	669.6	670.4	11/23/1993
PH1	624.2	632.36	7/1/2001[1]
PH3	623.63	631.87	7/1/2001[1]
PH2	614.36	631.14	7/1/2001[1]
MW4A	624.65	628.91	5/1/2003[2]
12025-MW1	626.493	630.33	5/1/2003[2]
12025-MW2	624.505	629.67	5/1/2003[2]
12025-MW3	621	628.66	5/1/2003[2]
12025-MW4	616.948	629.37	5/1/2003[2]
GW1	661.9	666.5	8/15/2018
GW2	652.4	664.6	8/15/2018
GW3	654.9	663.63	8/15/2018

[1]Average of monitoring between September 1999 and July 2001.
[2]Average of monitoring between September 1999 and May 2003.

The regional groundwater flow condition was adopted from the existing studies. That is, the majority of recharge is assumed to originate from the uplands on the eastern boundary of the Laberge Basin (i.e. from just east of the model domain), flowing westward and radially towards the Yukon River. Considering the low hydraulic conductivity of the glaciolacustrine sediments, it is important to note that the majority of the regional groundwater is assumed to be flowing in the bedrock, and that such water surplus that exists within the basin travels vertically downwards to the bedrock. The exception to this rule is that the high hydraulic conductivity of the ice-contact deposit represents the most permeable feature within the Study Area, and a place where groundwater flow is predominantly horizontal.

3.2 Numerical Groundwater Model

3.2.1 Model Domain and Discretization

The origin of the finite difference grid was set at UTM NAD83 coordinates of 490,400 easting and 6,739,000 northing, and was divided into 102 east-west oriented rows and 128 vertical north-south oriented columns, each with 50 m dimension (that is, the grid had dimensions 6,400 m and 5,100 m in the east-west and north-south directions, respectively). The numerical model was discretized into 9 layers of grid blocks of constant thickness: Layer 1 from 680 to 670 mASL, Layer 2 to 650 mASL, Layer 3 to 630 mASL, Layer 4 to 610 mASL, and Layer 5 to 580 mASL, the assumed top of bedrock. Layers 6, 7, 8, and 9 were given an even thickness to represent a one kilometer total thickness of bedrock. The layer top and bottom elevations were chosen strategically, to allow properties and boundary conditions to be assigned. The model layers are shown on cross-sections A through F, as shown on **Figure 3a-f, of Appendix A**.

3.2.2 Boundary Conditions

No-flow boundary conditions were assigned below the centerline of the Yukon River, where groundwater is assumed to be vertically upwards, and at certain edges of the flow system, where the horizontal flow direction was assumed perpendicular to the Yukon River. Where the no-flow boundary was internal to the finite difference grid, "inactive cells" were assigned to the zone outside of the model domain. The model domain is shown in plan-view in **Figure 1**, and on cross-sections A through F, as shown on **Figure 3a-f, of Appendix A**.

Constant head boundary conditions were assigned at certain exterior boundaries representing regional recharge from the upland areas to the east (at 680 mASL) and in Layer 4 at the Yukon River (at 628 mASL), representing regional groundwater discharge. A constant value for the Yukon River was chosen, despite the seasonal fluctuation, to avoid the use of a transient flow model, which is not warranted considering the multi-decadal timeframe for operation of the LTECF, and the relatively stable monitoring data. The impact of variation in the river level was assessed as part of the sensitivity analysis.

To simplify and stabilize the model from a numerical convergence perspective, model layers were set to be fully saturated. The unsaturated parts of the upper three layers (generally, the sand dunes at the northwest end of the model, and the unsaturated part of the ice-contact deposit) were removed from the model domain by assigning inactive cells.

The lagoons and the long-term water storage impoundment were simulated as constant head boundary conditions, set to 680 mASL and 670 mASL, respectively.

The distribution of the boundary conditions by model layer and through a typical north-south cross-section is shown in **Figure 4, of Appendix A**.

3.2.3 Model Properties

Model properties (hydraulic conductivity for the flow solution, and porosity for the particle tracking) were assigned by blocking the conceptual geological model, as shown on cross-sections A through F, shown on **Figure 3a-f, of Appendix A**. Four types of geological media were included: silt, clay, ice-contact deposit, and bedrock. The hydraulic conductivity of the three overburden units was assumed, by default, to be $7x10^{-7}$ m/s for the silt, $1x10^{-8}$ m/s for the clay, $3x10^{-4}$ m/s for the ice-contact deposit, subject to adjustment during model calibration. The hydraulic conductivity of the bedrock was set to be $1x10^{-6}$ m/s, lacking any information to the contrary, and assuming that the bedrock is more permeable than the overlying glaciolacustrine deposits. The number falls within the upper range for limestones and sandstones provided by Domenico and Schwartz (1997).

The porosity of the overburden and the bedrock was set to 0.3 and 0.005, respectively. These are typical values for porous unconsolidated deposits and for fractured bedrock, respectively (Domenico and Schwartz, 1997).

3.2.4 Recharge and Evapotranspiration

The recharge rate was acknowledged to be difficult to estimate, and best set as part of model calibration. However, a preference for up to 25 mm of recharge was acknowledged, considering the known water balance in this part of Canada (see Water Balance, Appendix B).

3.2.5 Model Calibration

Model calibration consisted of making adjustments to the hydraulic conductivity and recharge, so as to minimize the error between calculated and observed groundwater elevations. Recharge, being the most uncertain parameter was chosen first to provide a broad agreement between simulated groundwater elevation and observed conditions (that is to best simulate the regional groundwater flow conditions, as well documented in the background reports). Then adjustments were made to the magnitude of the hydraulic conductivity of the three overburden units, to achieve finer agreement between simulated and observed groundwater elevation. Generally, the silt and clay values were considered more certain and were thus kept within tighter ranges, while the ice-contact deposit value was considered less certain, and subject to a larger acceptable range. Finally, adjustments to the distribution of the overburden units were made to attempt to correct the most-obvious miss-matches between simulated and observed groundwater elevation at individual observation wells.

The distribution of the hydraulic conductivities by model layer and in a typical north-south cross-section is shown in **Figure 4, of Appendix A**. The values of the adjusted parameters were as shown in **Table 4,** below.

Table 4: Parameters Used in the Calibrated Model

Parameter	Value in the Calibrated Model
Silt hydraulic conductivity	$7x10^{-7}$ m/s
Clay hydraulic conductivity	$1x10^{-8}$ m/s
Ice contact deposit hydraulic conductivity	$3x10^{-4}$ m/s
Recharge	10 mm/year

The calibration residuals are shown on **Figure 5, of Appendix A**. The challenge that remains apparent in the calibration is that simulated groundwater elevations are approximately 12 m lower than observed at monitoring wells GW1 and GW2. These wells are very close to the south end of the lagoons, and, according to the conceptual model, are underlain by ice-contact deposit. The high water levels at these wells may reflect the presence of very impermeable layers of clay, causing a perched water table, which is not adequately represented in the model. To minimize these residuals, the northern extent of the ice-contact deposit distribution was pulled back and down, away from these (relatively shallow) wells. Despite, this adjustment, the discrepancy remains, but is considered acceptable in light of other model uncertainties.

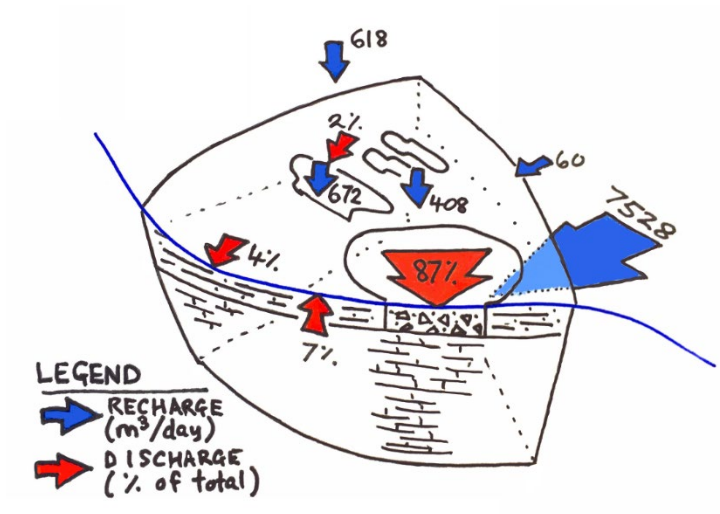
3.3 Simulated Heads, Flowlines, and Travel Times

Simulated heads are shown in plan-view on **Figure 5, of Appendix A**. These groundwater elevations were extracted from Layer 5 of the model, which is the bottom-most overburden layer. They show the influence of the ice-contact deposit, which is to lower the groundwater elevation south of the lagoons and impoundment below levels that would be expected in its absence.

Also shown on **Figure 5 (of Appendix A)** are the particle traces calculated using 'MODPATH'. These show that all water recharged at the lagoons and the impoundment travels to the Yukon River by way of the ice-contact deposit. This is an important finding, as it confirms that the ice-contact deposit is the primary conduit for treated effluent to reach the Yukon River. Analysis of the particle traces indicates that where the lagoons and impoundment are set back from the ice-contact deposit, water recharged in the facility travels vertically downward to the bedrock, taking few hundred years to penetrate the thick silts and clays. Once in the bedrock, the groundwater moves much more rapidly and horizontally towards the south, spending approximately 20 years therein (i.e., within the bedrock), before discharging upwards again into the clay, silt, and, ultimately, the ice-contact deposit. Travel time from the bedrock through these overburden deposits to the Yukon River is in the order of 40 years. That is, the total travel time from the base of clay/top of rock at the north end of the impoundment to the Yukon River is in the order of 60 years. Travel time, entirely within the ice-contact deposit, from Pot Hole Lake to the Yukon River is in the order of 20 years.

At the south end of the facility, especially at the primary cells where the ice-contact deposit is not far below, the travel times are much shorter, and are dependent on the thickness of clay making underlying the cell. The pathlines in the calibrated model, with hydraulic conductivity adjusted (effectively adding more clay below GW1 to increase the head at GW1, as discussed above), show 100 years of vertical downwards travel, followed by the 40 years of horizontal flow in the ice-contact deposit. Uncertainty is significant in this part of the model, and the implications of this uncertainty are discussed further below.

3.4 Results of Water Balance



The calibrated model had a daily throughput of approximately 9,286 m^3, 618 m^3 of which originated as recharge (i.e., precipitation), while the remaining 8,668 m^3 originated at a constant head boundary condition. The input from the constant head boundary conditions was 60 m^3 laterally from groundwater into the silt and clay, 408 m^3 downwards from surface water in the lagoons, 672 m^3 downwards from surface water in the impoundment, and 7,528 laterally from groundwater in the bedrock. The output from the model was eighty-seven percent (87%) from the ice-contact deposit directly to the (constant head boundary condition representing the) Yukon River; seven percent (7%) from the bedrock directly to the Yukon River; four percent (4%) from the silt and clay directly to the Yukon River; and two percent (2%) from the silt and clay to the constant head boundary condition representing the impoundment.

The fact that 87% of all water input into the model travelled through the ice-contact deposit on its way to discharge at the Yukon River is an important finding. Like the results from the particle tracking, it indicates the importance of monitoring the ice-contact deposit as it is, notwithstanding the many attenuating mechanisms affecting and reducing their concentrations, the primary conduit for contaminants to reach the Yukon River.

The daily input of 1,080 m^3 from the lagoons and impoundment compares favourably with the annualized findings of the water balance. The amount (394,200 m^3 per year), which represents “exfiltration” in the water balance, represents less than 10% of the average wastewater inflow, less than half the total precipitation captured by the lagoons, and about one third of the water lost to evaporation. Following the logic of the water balance, this amount suggests that the discharge, estimated using a volume estimation curve, may be overestimated by approximately 10%.

3.5 Uncertainty Analysis and Justification

The key uncertainties, how they were explored, and their implication are summarized below.

The extent of the ice-contact deposit was inferred from the borehole data. The extent is clearly important, because, where it exists, it’s very high permeability ensures it is the single-most important conduit for groundwater flow, effectively drawing water from above, below and all around. The lack of deep borehole data west of the LTECF (note the lack of deep boreholes in cross-sections A and B) provides no assurance that the deposit does not exist in this area. No additional model simulations were performed to assess the impact of the possible presence of the deposit in this area, because, given the lack of borehole and monitoring well data in the area, it would have been difficult to assess the validity of the simulation, and because the results would have been self-evident. That is, if an ice-contact deposit connected the north end of the lagoons and/or impoundment to the Yukon River, then groundwater would certainly take this route, rather than travelling the longer distance to the south. The recommendation of installing monitoring wells in this area would aid in resolving the uncertainties regarding the geological conditions in this area.

The extent of the ice-contact deposit was confirmed at the base of Primary Cell 2 (where it was discovered during excavation of the cell), and the borehole data are fairly conclusive that it extents this far north (see the yellow and red lines beneath the cells in cross-section E, being **Figure 3e of Appendix A**). However the degree of connectivity between the south end of the lagoons and the deposit remains quite uncertain. A model simulation was run with less clay separating the bottom of the lagoons and the top of the deposit, and the results indicated much shorter travel times between the lagoons and the river (eliminating the vertical travel time in the silt and clay reduced the travel time from hundreds of years to about four decades).

The hydraulic conductivity of the ice-contact deposit ($3x10^{-4}$ m/s) was inferred from a pumping test performed in in BH4A during the investigations of Pot Hole Lake (Report G, of **Table 1**), and was further chosen to match the very low hydraulic gradients between the Yukon River and Pot Hole Lake. This hydraulic conductivity is clearly important because it controls the extent to which the ice-contact deposit draws groundwater from all around (being the "path of least resistance"). Our challenges getting the model to match the relatively high groundwater elevations in GW1 and GW2 (immediately south of the primary cells) calls into question whether the ice-contact deposit is uniformly as permeable as it is near Pot Hole Lake. During model calibration, we adjusted the hydraulic conductivity down by a factor of ten, which caused a commensurate (an unrealistic) increase in the hydraulic gradient between the Yukon River and the south end of the lagoons. Even at this lower value, however, the ice-contact deposit still captured all of the exfiltration from the lagoons and impoundment.

To further assess the impact of this parameter on the key model outputs, two additional simulations were performed, one with the hydraulic conductivity increased by half an order of magnitude ($\sqrt{10}$) and one with the hydraulic conductivity decreased by the same amount. The results of this analysis indicated that the higher hydraulic conductivity resulted in an approximately five percent (5%) decrease in typical travel time between the facility and the river, and an approximately seven percent (7%) increase in the proportion of water captured by the ice-contact deposit prior to its discharge to the river. Conversely, the lower hydraulic conductivity resulted in an approximately fifteen percent (15%) increase in typical travel time, and a seven percent (7%) decrease in the proportion of water captured by the ice-contact deposit. Together, these results indicate that the key findings are not unduly sensitive to the ice-contact deposit hydraulic conductivity, when it is adjusted within a reasonable range.

The hydraulic conductivity of silt (modelled at 7×10^{-7} m/s) and clay (1×10^{-8} m/s), especially in the vertical direction is important, as it controls the exfiltration from the lagoons, and the extent to which a shallow perched water table can exist overlying the ice-contact deposit. Extreme low vertical permeability of silt and clay at very specific locations within the model would have been required to match the high groundwater elevations at GW1 and GW2, so long as the ice-contact deposit was left beneath these wells. As noted above, we backed the silt and clay away from the base of these wells as a strategy to calibrate the model. During model calibration, we adjusted the hydraulic conductivity of the clay down by a factor of ten, which caused an unrealistic mounding of groundwater in the north end of the model domain. The downwards vertical travel times increased commensurate with the decrease in hydraulic conductivity, but, realistically, it is not important whether the exfiltration spends hundreds of years or thousands of years in the part of the flow path.

The lack of a deep (down to river level) boreholes and monitoring wells between the primary lagoons and the Yukon River limits our ability to validate the model in this important area. The model suggests that the majority of all seepage from the lagoons travels to the river through this area, and yet there is limited monitoring infrastructure in place within it (i.e., the monitoring infrastructure is mainly between Pot Hole Lake and the River, which is a little further to the west than the area described in this paragraph).

Another uncertainty is the hydraulic conductivity and porosity of the bedrock. The hydraulic conductivity is unlikely to be higher than the 1×10^{-6} m/s assumed in this study, and a relatively high value was chosen to be conservative. This value encourages exfiltration from the lagoons and impoundment to travel downwards to the bedrock, where it can traverse greater distances in shorter times than remaining within the silt and clay. The bedrock portion of the travel time is proportional to bedrock porosity. That is, $t = \frac{d}{v} = \frac{d}{\frac{q}{\theta}} = \frac{d\theta}{Ki}$, where t is the travel time, v is the average linear groundwater velocity, q is the groundwater flux, θ is the porosity, and i is the hydraulic gradient. In $\theta = 0.005$, we chose a conservative (relatively low) value.

The recharge rate (modelled as 10 mm per year) is uncertain, but the model performance relative to this (specifically, the regional flow patterns) proved highly non-unique. That is, adjustments to recharge rate, clay hydraulic conductivity, and bedrock hydraulic conductivity all had similar, offsetting effects on the match between simulated and observed groundwater elevations. Given the uncertainty in the latter two parameters, it was decided to accept the 10 mm/year recharge rate as reasonable.

The river elevation is acknowledged to fluctuate seasonally by approximately 2.5 m. To assess the impact of this fluctuation on the key model outputs, two additional simulations were performed, one with the river level set 2.5 m lower and one with the river level set 2.5 m higher than in the calibrated model. The results of this analysis indicated that the lower river level resulted in an approximately five percent (5%) decrease in typical travel time between the facility and the river, and an approximately five percent (5%) increase in the proportion of water captured by the ice-contact deposit prior to its discharge to the river. Conversely, the higher river level resulted in an approximately ten percent (10%) increase in typical travel time, and no change in the proportion of water captured by the ice-contact deposit. Together, these results validate the use of the steady state flow model, and indicate that river level is not a key factor in the overall performance of the LTECF.

Other than in carrying out simulations to understand the sensitivity of the results to the various parameters, an important method to account for uncertainty is to report the results with an appropriate level of precision. For this reason, we present travel times using ranges and reference to years, decades, or hundreds of years.

4. CONCLUSIONS

The conclusions of this study are as follows:

- The glaciolacustrine silts and clays of the Whitehorse valley support the operation of the LTECF lagoons and long-term water storage impoundment by limiting exfiltration. The exfiltration number calculated by the model (394,000 m^3/year) is consistent with the findings of a water balance performed on the lagoons, and represents a very small to insignificant leakage rate.

- The Yukon River is the ultimate receiver of groundwater from beneath the facility, however the average travel time between the two is estimated in the order of a few hundred years, the majority of which is spent in vertical travel within the silt and clay layer/deposits.

- The connectivity between the lagoons and the ice-contact deposit is the single-biggest uncertainty in the model. The available groundwater elevation information (relatively high heads in the monitoring wells closest to the lagoons) and water balance (which suggests that exfiltration is small) suggests that the connection is not strong (that is, that there is a significant amount of clay beneath the lagoons, or that the ice-contact deposit is not continuous or permeable within this area). However, if there is leakage from the lagoons directly to the ice-contact deposit, the travel times between lagoon and river are more likely in the order of decades rather than hundreds of years.

- The ice-contact deposit is, by far, the single most permeable feature in the landscape and the conduit for area groundwater to the Yukon River. The groundwater velocity within this deposit is estimated at approximately 70 metres per year. Between the Primary Cells and the Yukon River, this translates to a travel time in the order of 15 years. Between Pot Hole Lake and Yukon River, this translates to a travel time in the order of 10 years. When discharge is made to Pot Hole Lake, which raises the hydraulic gradient significantly, these travel times may be much shorter.

- In the modelling, we conservatively assumed that the bedrock was the second-most permeable feature, with the lowest porosity (bedrock typically supplies more water than silt and clay, and from a network of fractures which makes up a very small proportion of the rock mass). Although it is acknowledged that key model output such as the exfiltration rate and the overall travel time from the lagoons to the river are influenced by the actual permeability and porosity of the bedrock, it is stressed that testing of the bedrock, and resolution of uncertainty in its properties is not necessary. This is because of the aforementioned effectiveness of the silts and clays to ensure long travel times, and because of the dominance of the ice-contact deposit as the conduit for flow the river (generally, even bedrock water is drawn into the ice-contact deposit). Exploration of the bedrock, and testing to determine its hydraulic conductivity and porosity is not warranted, or economically justifiable.

- The existing monitoring network is well-suited to monitoring the quality of groundwater between Pot Hole Lake and the Yukon River. It is apparent, however, that opportunity exists to expand the monitoring network to better monitor the quality of the groundwater further to the east, immediately down-gradient of the primary lagoons.

5. RECOMMENDATIONS

Drilling of six deep boreholes, completed, in certain instances, with multi-level monitoring wells, is recommended. The purpose of the boreholes and monitoring wells is to better characterize the groundwater flow regime and to more effectively monitor potential impacts to groundwater quality downgradient of the LTECF. The boreholes and wells would address the key uncertainties identified in this study, which are the degree of connectivity between the south end of the lagoons and the ice-contact deposit, and the possible presence of ice-contact deposit west of the facility. These should be drilled to river level, say 630 mASL, at the following locations, also shown approximately, on **Figure 7 (of Appendix A)**:

Table 5: Recommended Boreholes and Monitoring Wells

ID	Location	Purpose	Notes on Well Installation
XX-MW-01	Northwest of the impoundment	To assess for the presence of ice-contact deposit	Required only if ice-contact deposit encountered
XX-MW-02	Southwest of the impoundment		
XX-MW-03	South of the impoundment	To allow monitoring within the ice-contact deposit	Drill to water table, install
XX-MW-04	Immediately south of the primary cells	To asses connectivity between lagoon and ice-contact deposit, to establish monitoring	Install shallow well in silt and clay and deep well in ice-contact deposit, if encountered
XX-MW-05	Between the primary cells and the Yukon River	To establish monitoring in this area	Drill to water table, install
XX-MW-06			

Where saturated silt and clay is encountered over sand and gravel (possible in XX-MW-01, XX-MW-02, and XX-MW-04, unlikely in the other boreholes), a shallow monitoring well should be installed in the silt and clay (this could be put in the same borehole or in a separate, purpose-drilled borehole), and a deep monitoring well should be installed in the sand and gravel. At least one pumping test should be performed, as necessary, to determine the transmissivity of the sand and gravel closest to the lagoons. The wells should be added to the monitoring network for the LTECF, but the details of the monitoring should be decided based on the outcome of the drilling.

There is no urgency to drill the above-recommended boreholes. Access, land-ownership, funding, and logistics will need to be worked out, and a methodical approach is recommended, such that, in time, the new information can be incorporated into the operation of the LTECF.

6. Closure

We trust the above meets with your current requirements. Should you have any comments, questions, or require additional information, please do not hesitate to contact the undersigned.

Respectfully submitted,
Morrison Hershfield Limited

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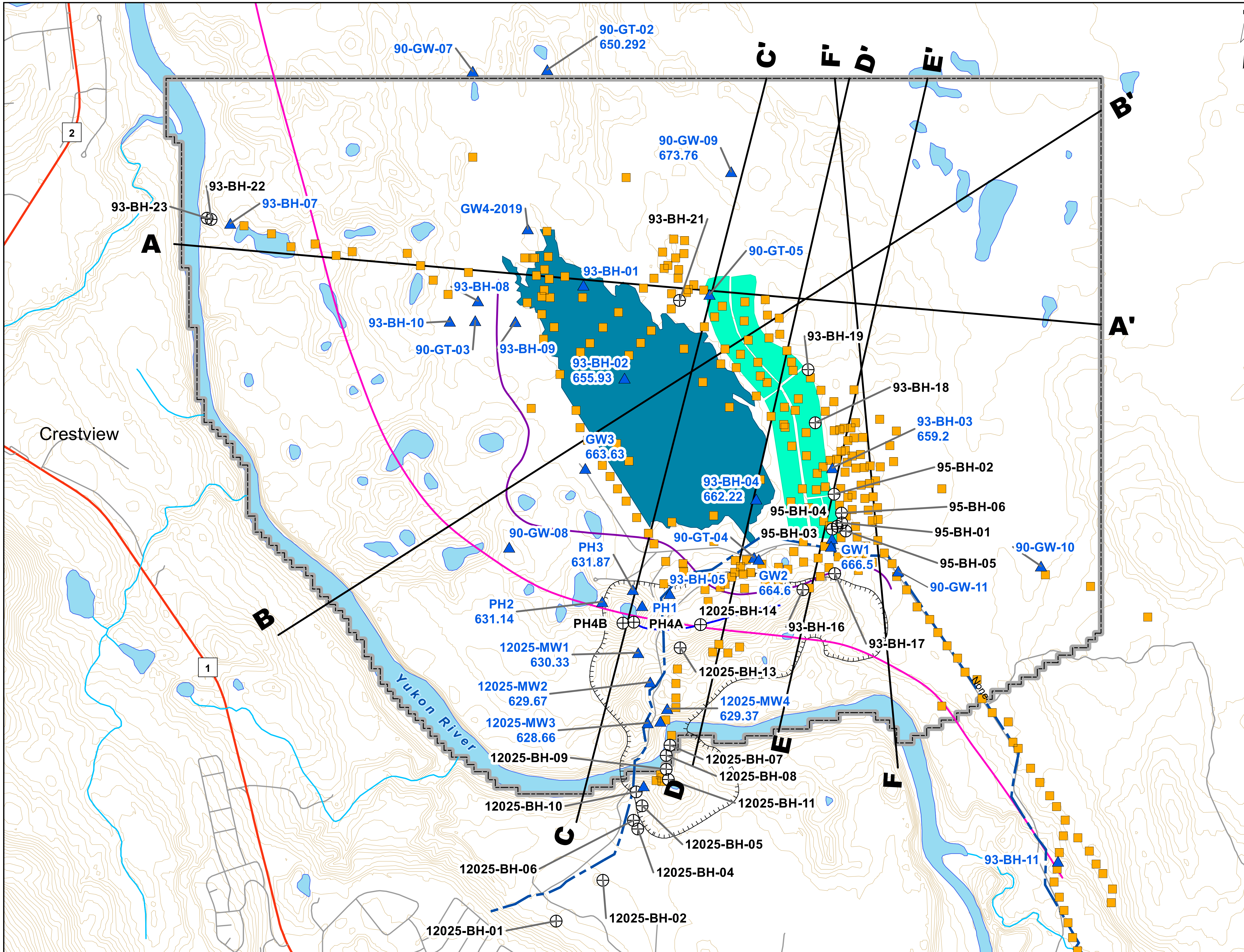
APPENDIX A: FIGURES



Legend

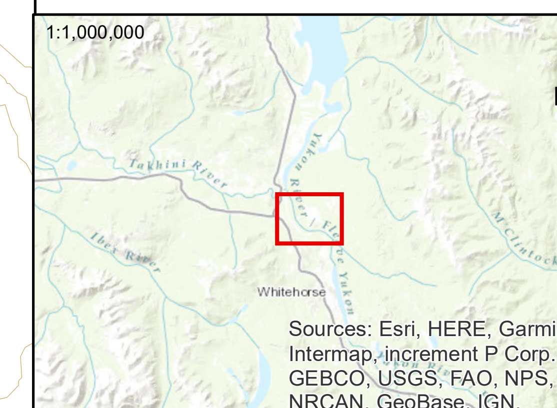
Sampling Point

- Monitoring Well & Water Level (masl)
- Borehole
- Test Pit
- Cross Section
- Contour
- Expressway / Highway
- Local Road
- Forcemain
- Watercourse
- Model Domain
- Ice Contact Deposit (from mapping)
- Waterbody
- Lagoon
- Long Term Water Storage

650 m Groundwater Equipotential Line

Year

- 1992 (Klohn Leonoff / Novatec)
- 1995 (Klohn Crippen)
- 2018 (Annual reporting)



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN,

Coordinate System: NAD 1983 UTM Zone 8N

MORRISON HERSHFIELD

Scale: 1:25,000

0 310 620 1,240 Meters

Title:

LTECF Hydrogeological Study
Study Area and Model Domain

Project No.:	Drawing No.:
190558000	Figure 1
Department:	Date:
Environmental Services	February 2020

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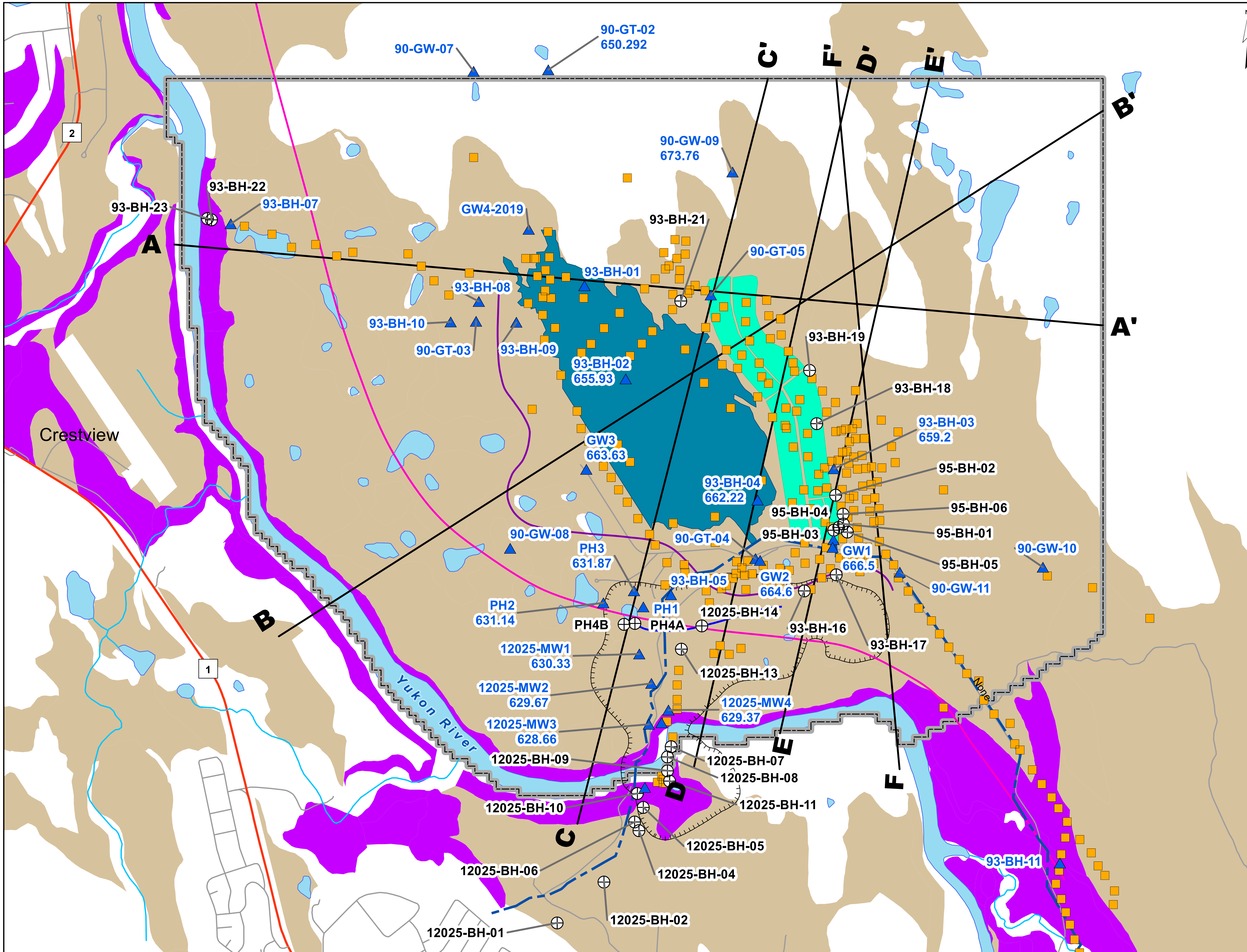

Legend

Sampling Point

- Monitoring Well & Water Level (masl)
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650 m Groundwater Equipotential Line

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- 1992 (Klohn Leonoff / Novatec)
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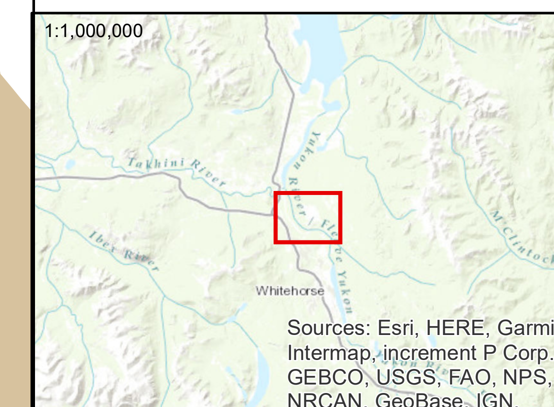
- 2018 (Annual reporting)

Surficial Geology

- F, G, M (Glaciofluvial, McConnell)
- L, G, M (Glaciolacustrine, McConnell)



Coordinate System: NAD 1983 UTM Zone 8N
Source: Surficial Geology - Yukon Geological Survey 2014.

MORRISON HERSHFIELD

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Title:

LTECF Hydrogeological Study
Surficial Geology

Project No.:	Drawing No.:
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Department: Environmental Services	Date: February 2020

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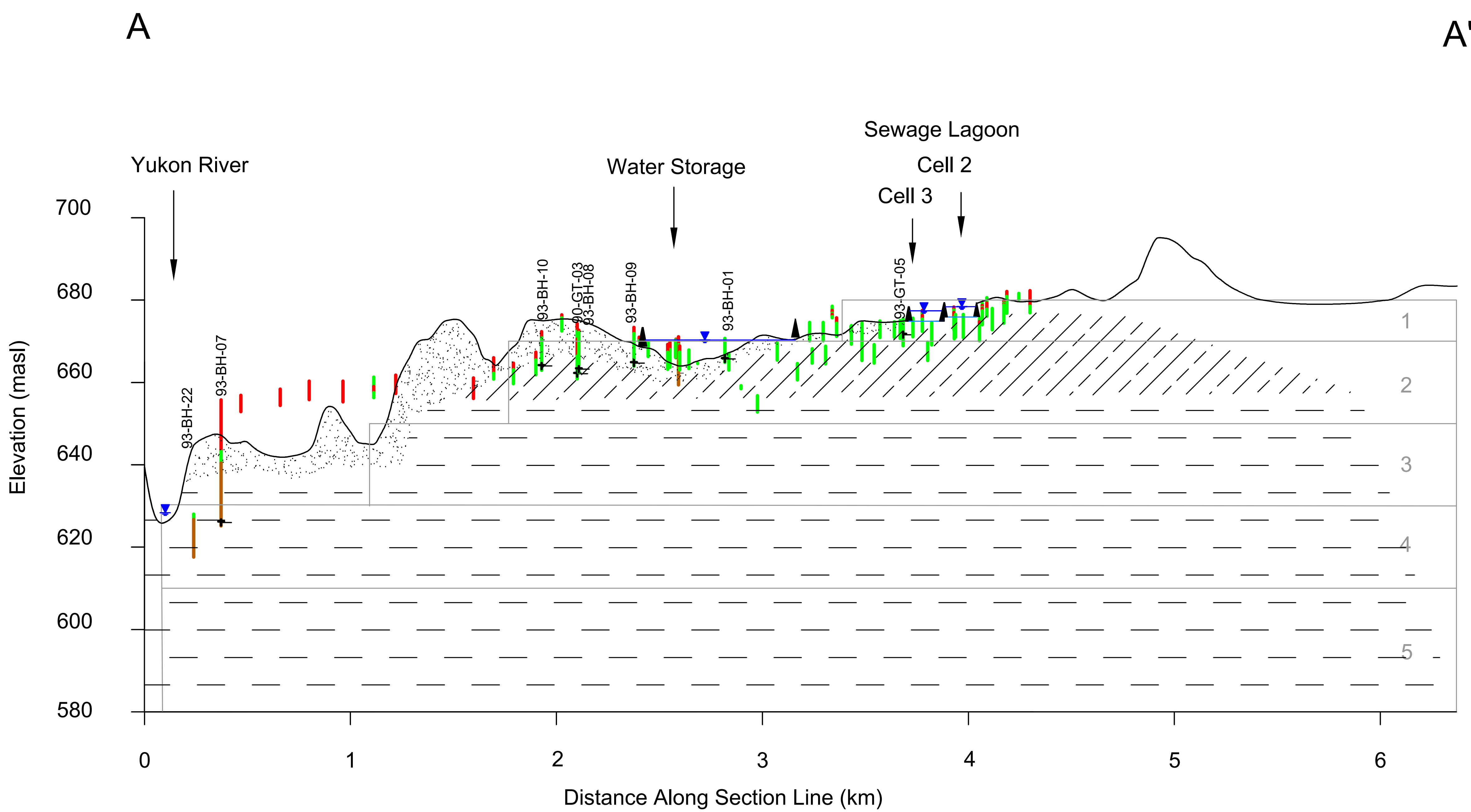


LEGEND

Groundwater Flow Direction

Water Table

Well Screen

Ground Surface

Berm

STRATIGRAPHY

Per Available Well Logs

Clay

Silt

Sand

Gravel

Inferred

Medium to Fine Sand/Sand & Gravel

Silt

Clay

MODEL

MODFLOW Model Layer Number

Data Sources:

MORRISON HERSHFIELD

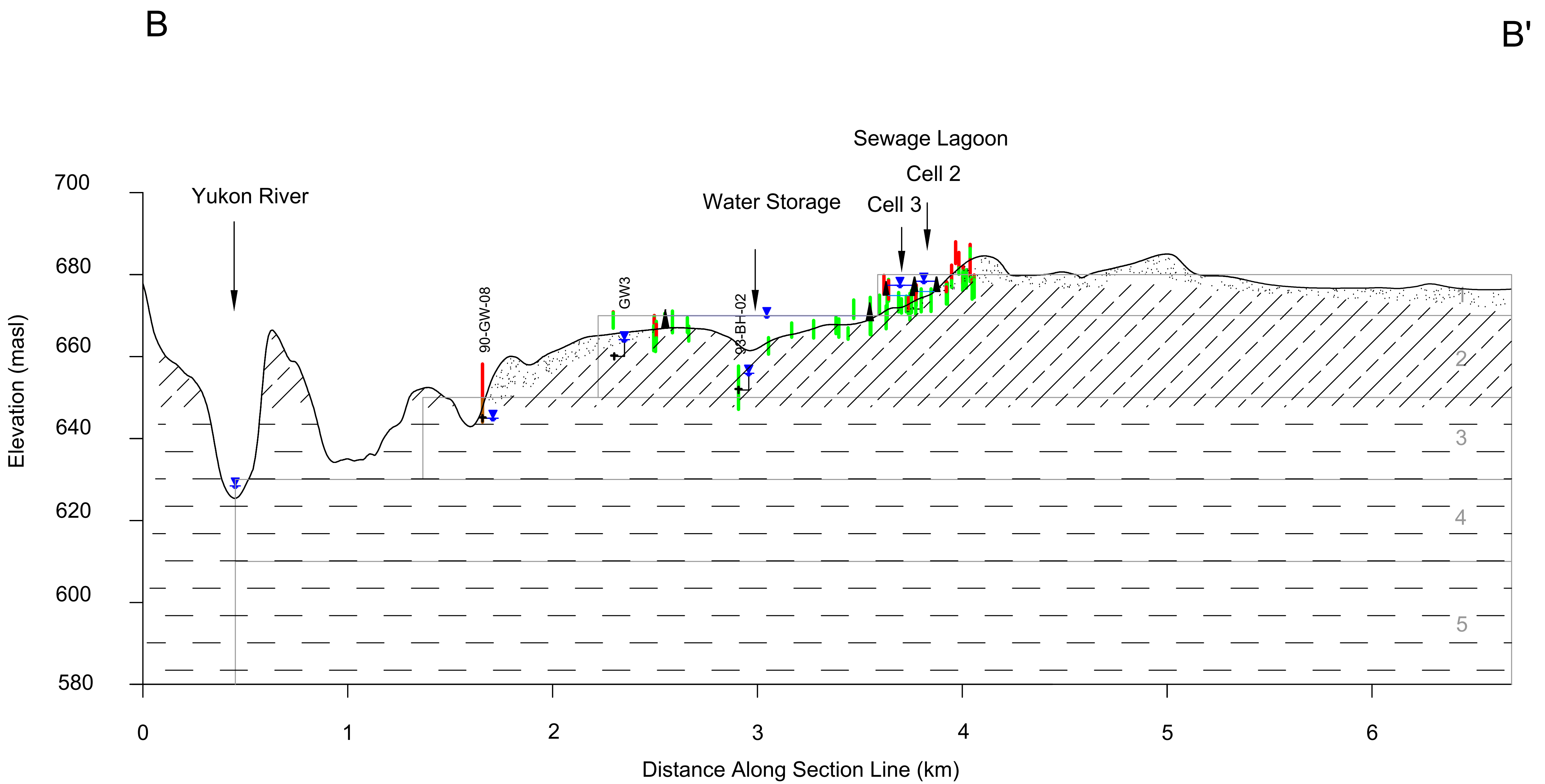
Scale:

See Axes, Vertical Exaggeration x20

Title:

LTECF Hydrogeology Study
Cross Section A-A'

Project No.:	Drawing No.:
190558000	Figure 3a
Department: Environmental Services	Date: February 4, 2020



Data Sources:

MORRISON HERSHFIELD

Scale: See Axes, Vertical Exaggeration x20

Title: LTECF Hydrogeology Study
Cross Section B-B'

Project No.: 190558000	Drawing No.: Figure 3b
Department: Environmental Services	Date: February 4, 2020

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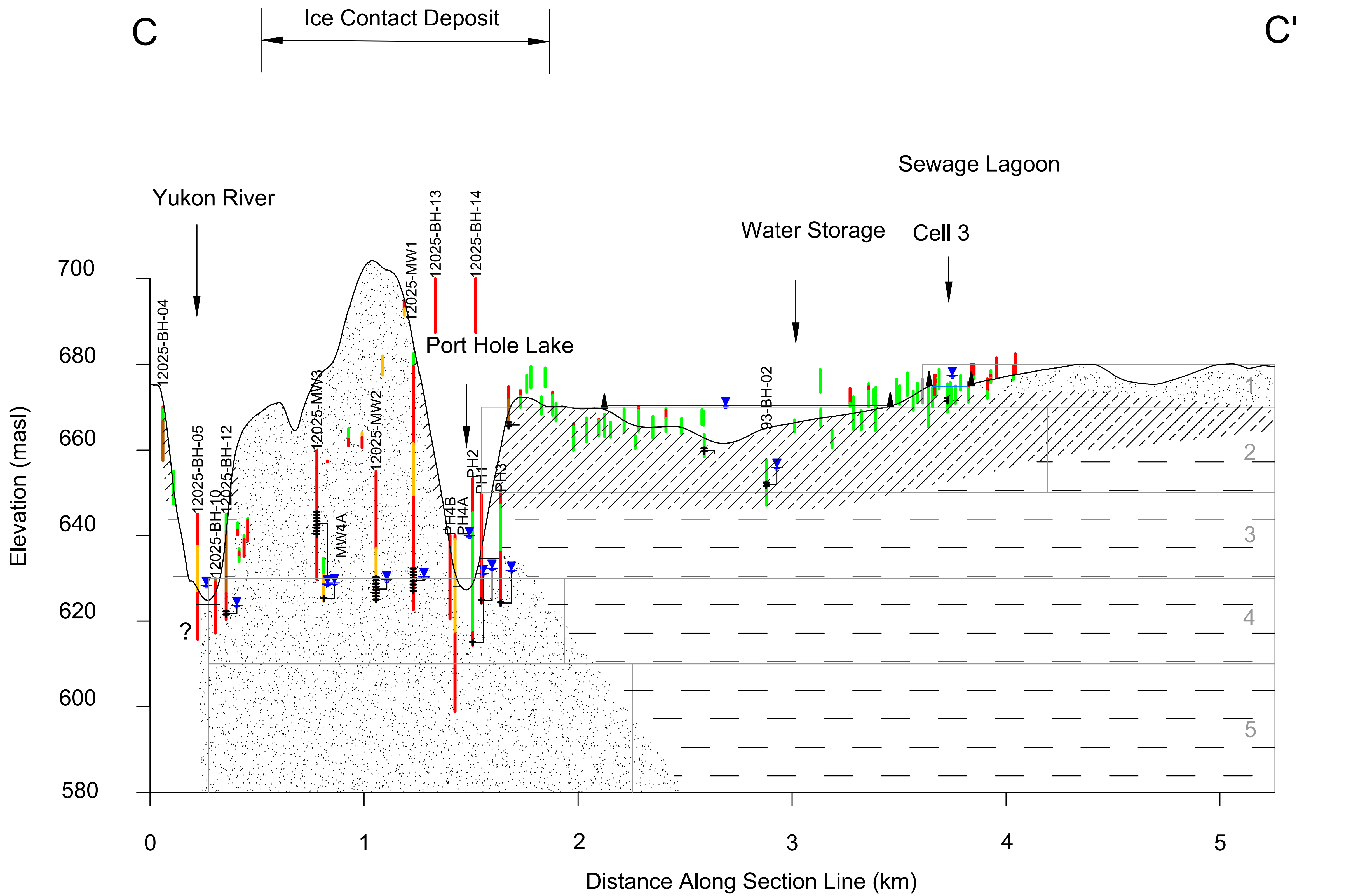

LEGEND

Groundwater Flow Direction

Water Table

Well Screen

Ground Surface

Berm

STRATIGRAPHY

Per Available Well Logs

Clay

Silt

Sand

Gravel

Inferred

Medium to Fine Sand/Sand & Gravel

Silt

Clay

MODEL

MODFLOW Model Layer Number

Data Sources:

MORRISON HERSHFIELD

Scale:
See Axes, Vertical Exaggeration x20

Title:
LTECF Hydrogeology Study
Cross Section C-C'

Project No.:	Drawing No.:
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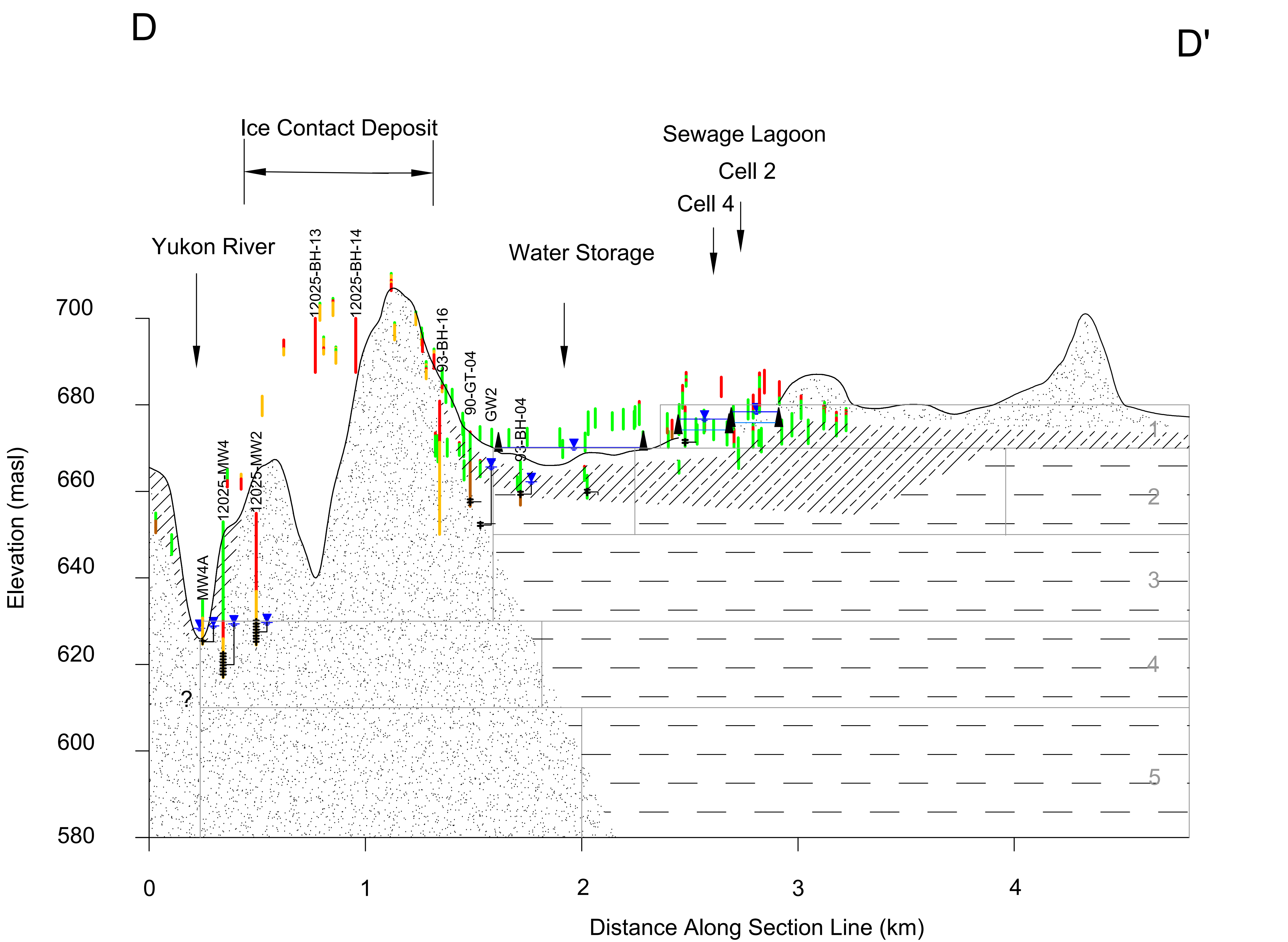
Department: Environmental Services	Date: February 4, 2020



LEGEND

Groundwater Flow Direction

Water Table

Well Screen

Ground Surface

Berm

STRATIGRAPHY

Per Available Well Logs

Clay

Silt

Sand

Gravel

Inferred

Medium to Fine Sand/Sand & Gravel

Silt

Clay

MODEL

MODFLOW Model Layer Number

Data Sources:

MORRISON HERSHFIELD

Scale:

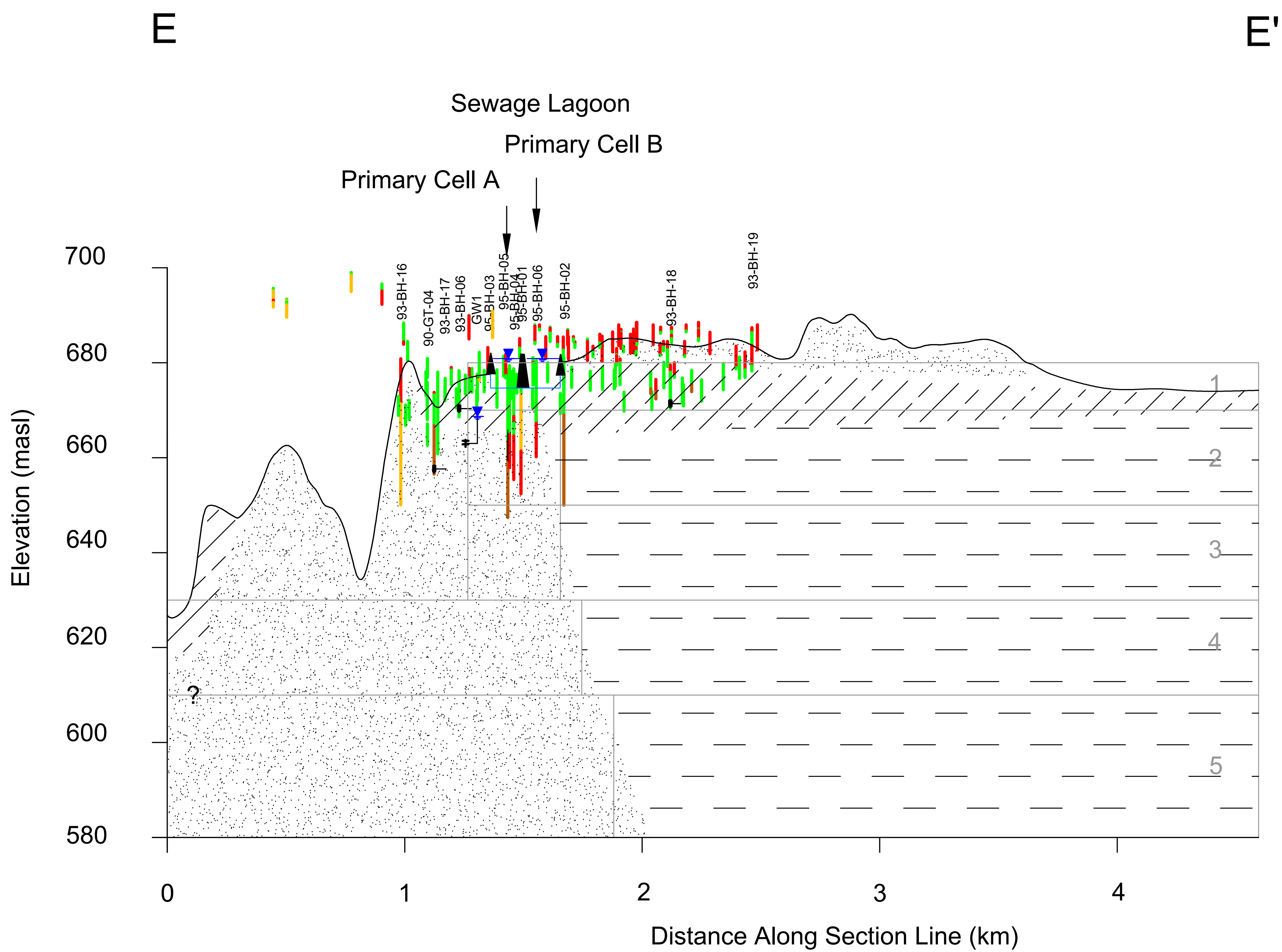
See Axes, Vertical Exaggeration x20

Title:

LTECF Hydrogeology Study
Cross Section D-D'

Project No.:	Drawing No.:
190558000	Figure 3d
Department: Environmental Services	Date: February 4, 2020

2020-Feb-04 12:38:28 PM P:\2019\190558000-LTECF Hydrogeological Study\08. Working\Cross Section\Cross Section.dwg



LEGEND

Groundwater Flow Direction

Water Table

Well Screen

Ground Surface

Berm

STRATIGRAPHY

Per Available Well Logs

Clay

Silt

Sand

Gravel

Inferred

Medium to Fine Sand/Sand & Gravel

Silt

Clay

MODEL

MODFLOW Model Layer Number

Data Sources:

MORRISON HERSHFIELD

Scale: See Axes, Vertical Exaggeration x20

Title: LTECF Hydrogeology Study
Cross Section E-E'

Project No.:	Drawing No.:
190558000	Figure 3e
Department: Environmental Services	Date: February 4, 2020

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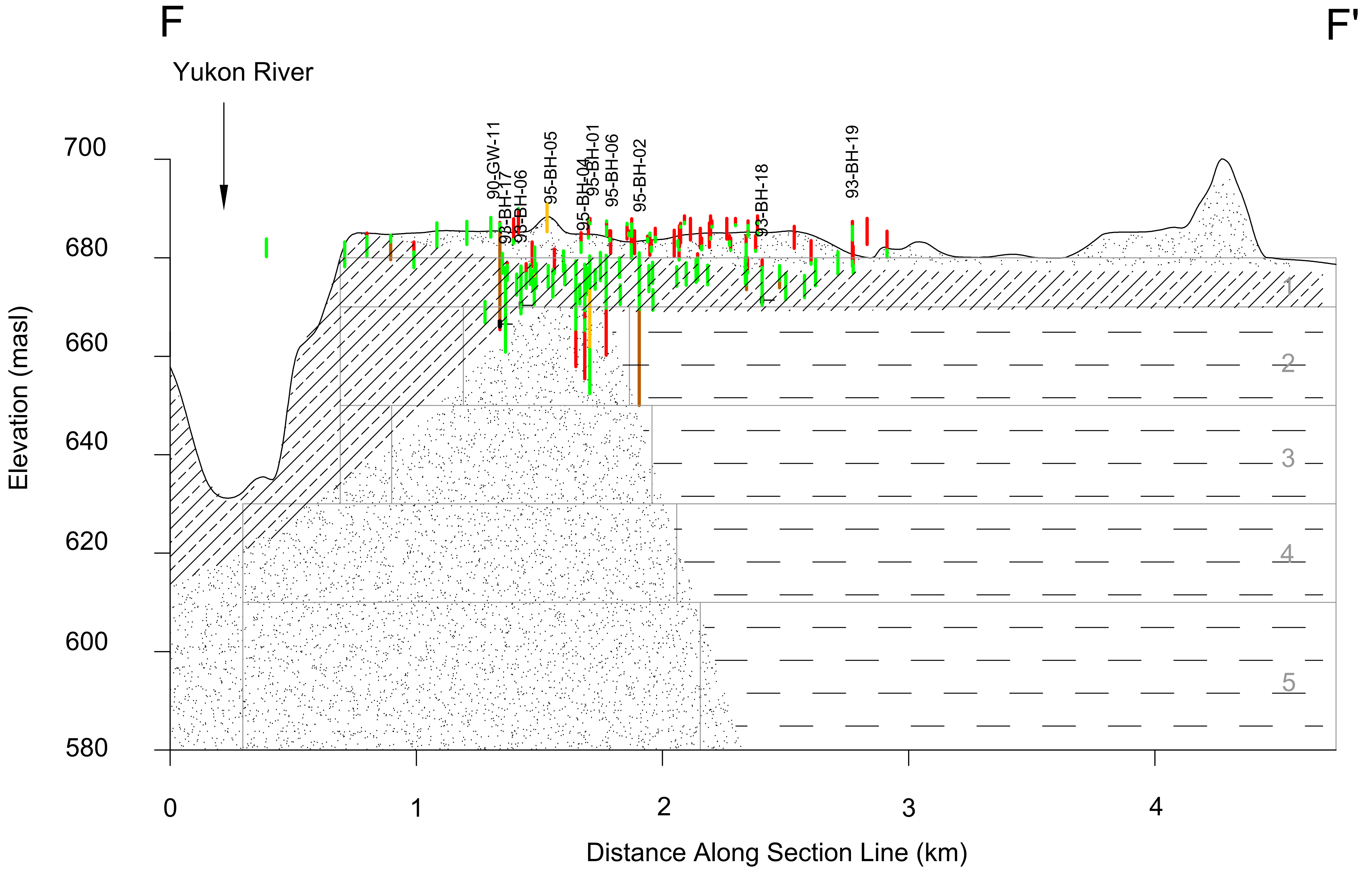


LEGEND

Groundwater Flow Direction

Water Table

Well Screen

Ground Surface

Berm

STRATIGRAPHY

Per Available Well Logs

Clay

Silt

Sand

Gravel

Inferred

Medium to Fine Sand/Sand & Gravel

Silt

Clay

MODEL

MODFLOW Model Layer Number

Data Sources:

MORRISON HERSHFIELD

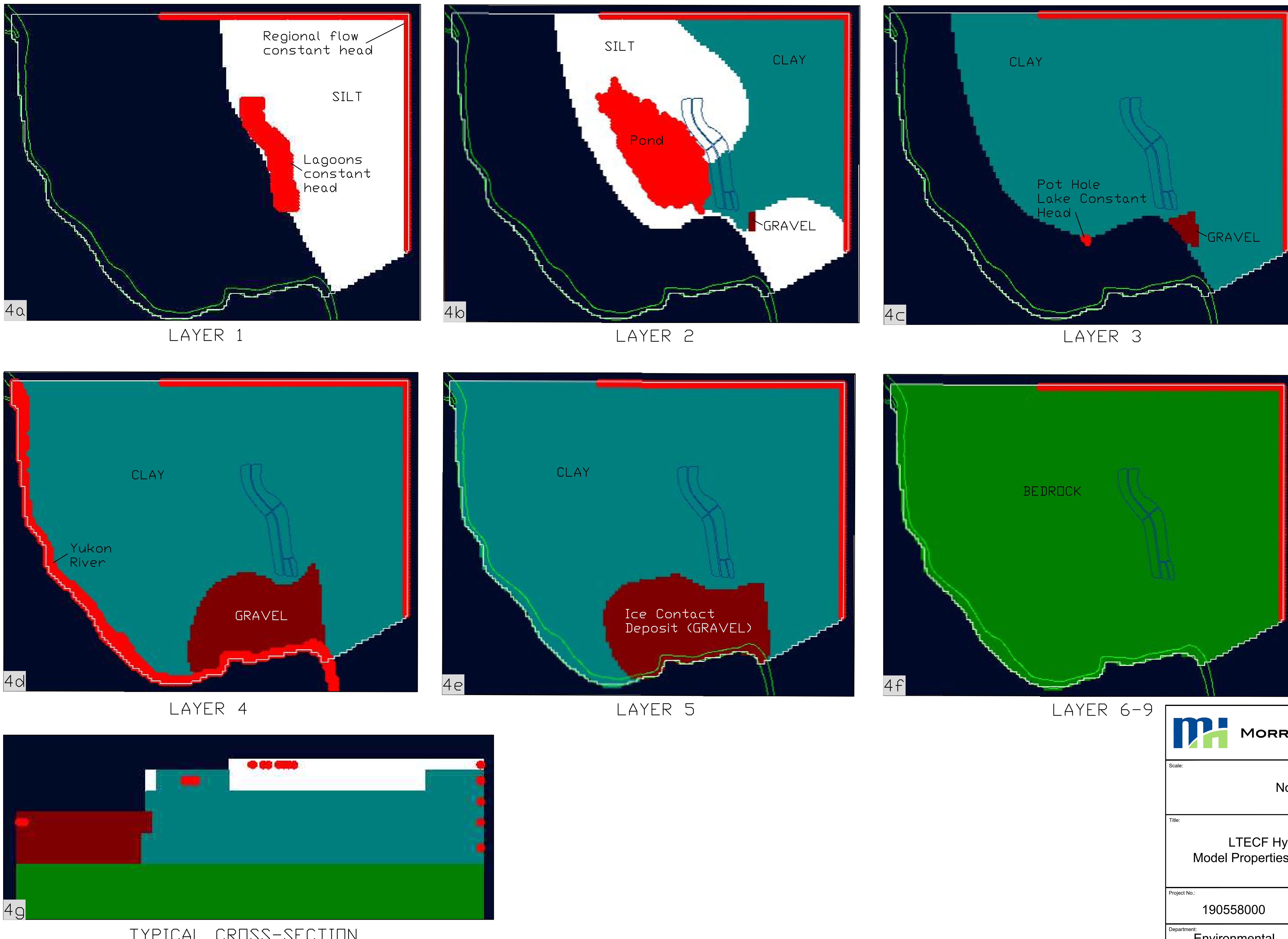
Scale:

See Axes, Vertical Exaggeration x20

Title:

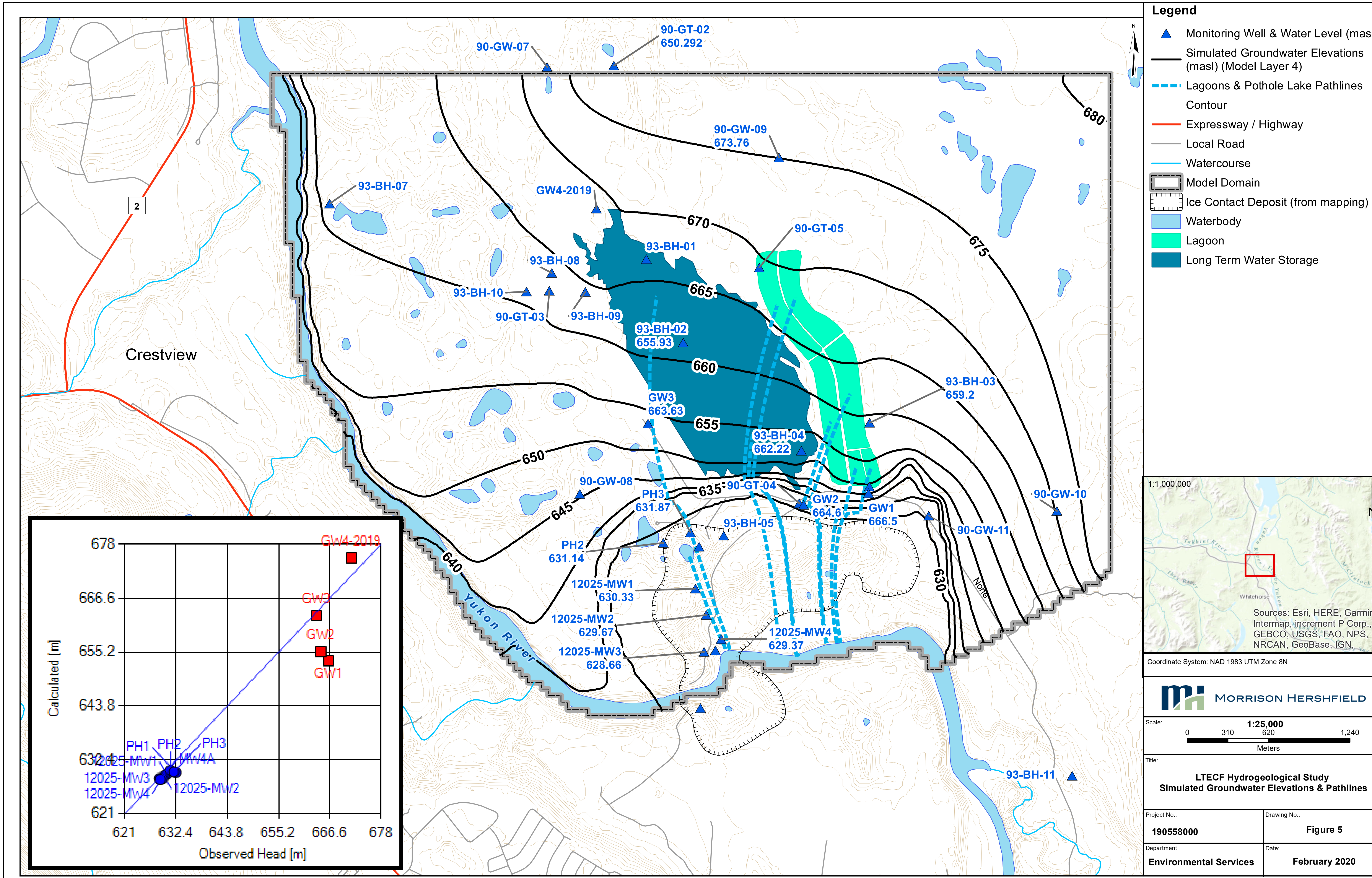
LTECF Hydrogeology Study
Cross Section F-F'

Project No.:	Drawing No.:
190558000	Figure 3f
Department: Environmental Services	Date: February 4, 2020

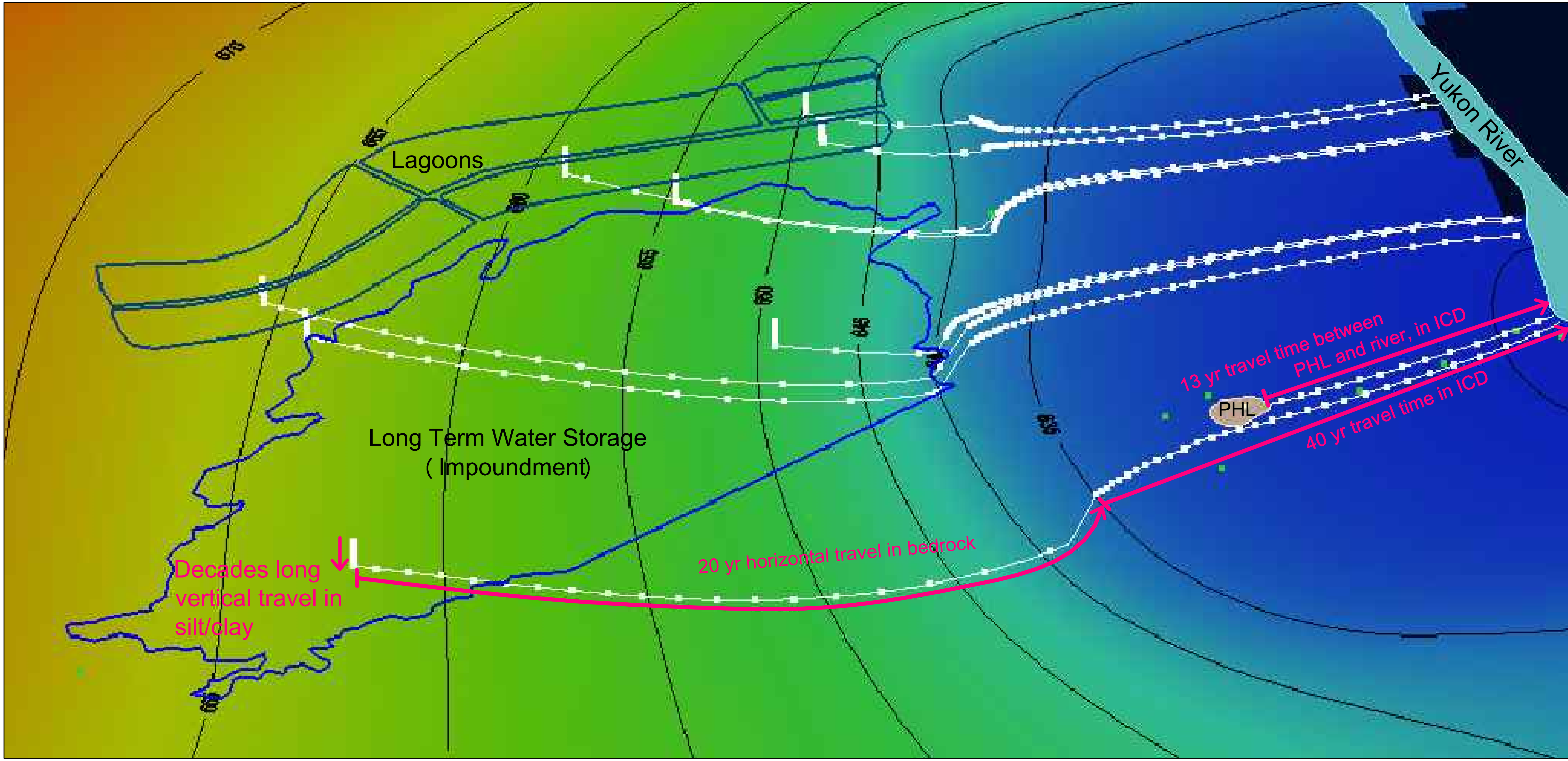


MORRISON HERSHFIELD

Scale: Not to Scale	
Title: LTECF Hydrogeology Study Model Properties & Boundary Conditions	
Project No.: 190558000	Drawing No.: Figure 4
Department: Environmental Services	Date: February 4, 2020



Legend
Monitoring Well & Water Level (masl)
Simulated Groundwater Elevations (masl) (Model Layer 4)
Lagoons & Pothole Lake Pathlines
Contour
Expressway / Highway
Local Road
Watercourse
Model Domain
Ice Contact Deposit (from mapping)
Waterbody
Lagoon
Long Term Water Storage
Crestview
Yukon River
2
90-GW-07
90-GT-02 650.292
90-GW-09 673.76
93-BH-07
GW4-2019
93-BH-01
90-GT-05
93-BH-08
93-BH-10
90-GT-03
93-BH-09
93-BH-02 655.93
93-BH-03 659.2
GW3 663.63
93-BH-04 662.22
90-GW-08
90-GT-04
PH3 631.87
GW2 664.6
GW1 666.5
90-GW-10
90-GW-11
93-BH-05
PH2 631.14
12025-MW1 630.33
12025-MW2 629.67
12025-MW3 628.66
12025-MW4 629.37
93-BH-11
680
675
670
665
660
655
650
645
640
635
630
None
Calculated [m]
Observed Head [m]
621
632.4
643.8
655.2
666.6
678
GW4-2019
GW3
GW2
GW1
PH1
PH2
PH3
12025-MW1
MW4A
12025-MW3
12025-MW4
12025-MW2
1:1,000,000
Whitehorse
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN,
Coordinate System: NAD 1983 UTM Zone 8N
MORRISON HERSHFIELD
Scale: 1:25,000
0 310 620 1,240
Meters
Title:
LTECF Hydrogeological Study
Simulated Groundwater Elevations & Pathlines
Project No.: 190558000
Drawing No.: Figure 5
Department: Environmental Services
Date: February 2020
\\tdc92vh\ArcGIS\2019\190558000\Maps\Figure5_190558000.mxd



- View is looking east.
- Pathline markers delineate 1 year of travel time.
- Contoured Heads are from model layer 6, the uppermost bedrock layer.
- Note that all particles exit the model at the Yukon River in model layer 4.

Acronyms:
PHL - Pot Hole Lake
yr - Year
ICD - Ice Contact Deposit

MORRISON HERSHFIELD

Scale: Not to Scale

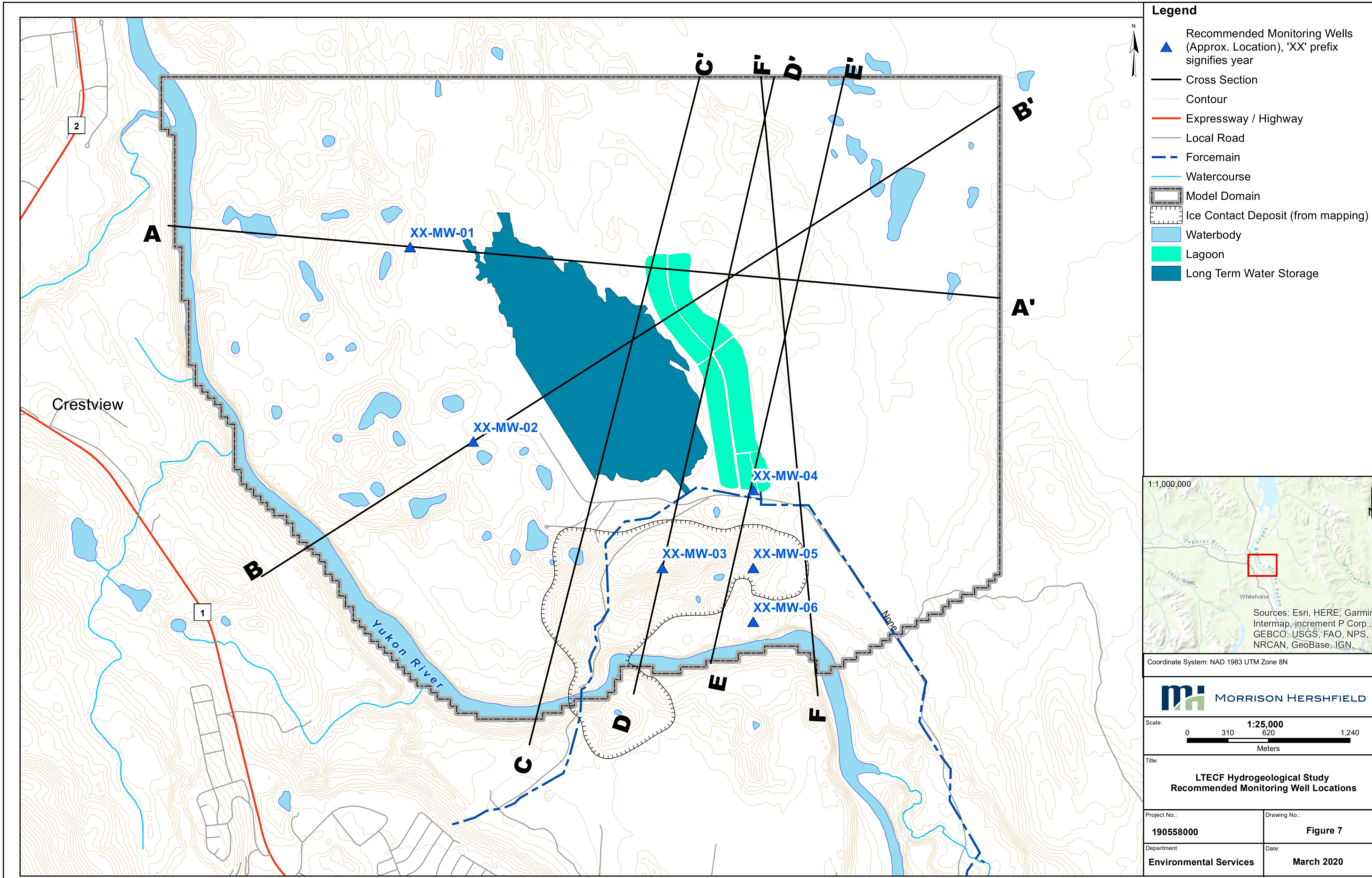
Title: LTECF Hydrogeology Study
Oblique, Annotated View of the Results

Project No.: 190558000

Drawing No.: Figure 6

Department: Environmental Services

Date: February 20, 2020



Legend
Recommended Monitoring Wells (Approx. Location), 'XX' prefix signifies year
Cross Section
Contour
Expressway / Highway
Local Road
Forcemain
Watercourse
Model Domain
Ice Contact Deposit (from mapping)
Waterbody
Lagoon
Long Term Water Storage
A
A'
B
B'
C
C'
D
D'
E
E'
F
F'
XX-MW-01
XX-MW-02
XX-MW-03
XX-MW-04
XX-MW-05
XX-MW-06
Crestview
Yukon River
None
2
1
N
1:1,000,000
Whitehorse
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN,
Coordinate System: NAD 1983 UTM Zone 8N
MORRISON HERSHFIELD
Scale:
1:25,000
0
310
620
1,240
Meters
Title:
LTECF Hydrogeological Study
Recommended Monitoring Well Locations
Project No.:
190558000
Drawing No.:
Figure 7
Department
Environmental Services
Date:
March 2020
G:\2019\190558000\Maps\Figure7_190558000_Rev2.mxd

APPENDIX B: WATER BALANCE MEMO

MEMORANDUM

MORRISON HERSHFIELD

TO:	Cindy Zhao Anthony West	**FROM:**	Katy Bosma Forest Pearson
		PROJECT No.:	1905580.00
RE:	Livingstone Lagoon Water Balance	**DATE:**	2/28/2020

P:\2019\190558000-LTECF HYDROGEOLOGICAL STUDY\08. WORKING\LAGOON WATER BALANCE\MEM-2020-02-26-LAGOON WATER BALANCE_KRB-1905580.DOCX

Context

This memorandum documents an updated water balance that was completed for the Livingstone Trail Environmental Control Facility (LTECF). The objective of this exercise was to quantify an approximate exfiltration rate from the lagoon by balancing lagoon water inflows and outflows.

Wastewater from the City of Whitehorse is pumped to the LTCEF which is located on the east side of the Yukon River. The system is comprised of two primary lagoon cells with a combined retention time of 20 days, four secondary cells which have a retention time of 120 days, and a long term storage pond. The retention time of the storage pond is approximately one year. (2018 Annual Monitoring Water Use License MN93-001-013 and Drinking Water Regulation, City of Whitehorse).

The LTCEF was constructed in 1996 and the pipe to discharge effluent from the long term storage pond was completed the following year (2018 Annual Monitoring Water Use License MN93-001-013 and Drinking Water Regulation, City of Whitehorse). Initially, the treated effluent was discharged through a buried pipe to Pot Hole Lake (PHL) which is a small natural depression southwest of the storage pond. The design intention was to discharge to PHL for as long as possible before constructing the outfall to the Yukon River, which was completed in 2009. With time, a layer of fine sediment accumulated at the bottom of PHL which reduced its ability to exfiltrate the effluent water. At this point (2009) the City began using the outfall pipe to discharge treated effluent to the Yukon River. The discharge history of the LCTEF including annual inflows, outflows and discharge durations is shown in Table 2.

Method

The basic equation of a water balance is shown below, as well as the total inflows and outflows of the LTECF.

Equation 1 Water Balance

$$\sum Flow_{In} - \sum Flow_{Out} = \Delta\, Storage$$

Equation 2 Total Flow In

$$\sum Flow_{In} = Wastewater\ Inflows + Precipitation$$

Equation 3 Total Flow out

$$\sum Flow_{Out} = Discharge + Evaporation + Exfiltration$$

Substituting terms and isolating the exfiltration term yields the equation below. The remaining terms of the water balance are defined in the following paragraphs.

Equation 4 Exfiltration

$$Exfiltration = Wastewater\ Inflows + Precipitation - Discharge - Evaporation - \Delta\ Storage$$

1) Wastewater Inflows

The City of Whitehorse provided annual wastewater inflows to the primary lagoons from 1998 to 2019 (Table 2). The total wastewater inflow to the lagoon is the sum of cumulative meter readings at the Marwell Lift Station and the Porter Creek Flush Tank. The inflow readings for 1998 and for 2019 have been adjusted to match the discharge period.

2) Precipitation

Daily precipitation data from the Whitehorse Airport was retrieved online from Environment Canada. Total annual precipitation was compiled for each year from 1998-2019 and the average annual precipitation was calculated to be 274 mm/year. The catchment area contributing to precipitation and runoff into the lagoon is approximately 3.1 km^2. This area was estimated using recent aerial imagery and roughly follows the fence line of the facility.

3) Discharge

The City provided the volume of treated effluent that was discharged from the storage impoundment from 1998-2018 (Table 2**Error! Reference source not found.**). The City estimates the discharge with a volume-elevation curve for the storage impoundment, which was derived from a topographic survey. The water elevation before and after discharge is known and can be used to find the corresponding change in volume. Wastewater inflows during the discharge period are subtracted from the discharge to account for new water entering the storage impoundment. Due to the irregular shape of the storage impoundment and the unknown precision of survey data, this method presents some uncertainty. The data in Table 2 indicates that from 1998-2019 the total wastewater inflows exceeded the discharge by approximately 2% (2,068,096 m^3). This exceedance is within the expected uncertainty for a volume-elevation curve estimate. Thus, it is possible that the true discharge was approximately equal to the wastewater inflow, or even slightly higher.

4) Evaporation

An evaporation rate of 483 mm/year was used for the current exercise based on the water balance completed for the Whitehorse Sewage Treatment Feasibility Study[1]. The report does not cite a source for the evaporation rate.

To verify the evaporation rate, MH reviewed a climate evaluation report that was prepared for the pre-design of the lagoons in Carcross, Yukon. Pan evaporation data was collected in Carcross from 1998-2005 and the average cumulative rate was found to be 460 mm/year[2]. Carcross is approximately 100km southwest of Whitehorse and has a similar climate and is thus a reasonable comparison. The estimated evaporation rate for Carcross is 4% lower than the rate for Whitehorse, likely due to the slightly cooler climate. Based on the Carcross study, the estimated evaporation rate for Whitehorse was assumed to be suitable.

The evaporation area is estimated to be 2.3 km^2 based on the approximate water surface area of the primary, secondary and storage cells combined.

5) Change in Storage (Δ Storage)

The water elevation in the long term storage cell can be is used to estimate the change in storage from year to year, using the approximate surface area of the cell. The elevations were provided by the City, and are included in Table 2. The water surface of the long term storage cell is estimated to be 1.5 km^2

6) Exfiltration

Exfiltration represents water exiting the lagoon cells through the berms or floor. This is the unknown term of the water balance.

The estimated areas for evaporation, precipitation and storage are stated in Table 1 with the corresponding total volumes for the period of record.

Table 1 Precipitation, Evaporation and Storage Terms

Parameter	Value	Unit
Average Annual Precipitation Rate	0.274	m/yr
Estimated Catchment Area	3,073,168	m^2
Total Precipitation (1998-2019)	17,401,506	m^3
Average Annual Evaporation Rate	0.483	m/yr
Estimated Evaporation Area	2,277,172	m^2
Total Evaporation (1998-2019)	23,189,012	m^3
Long Term Storage Start Elevation (1998)	668.00	m
Long Term Storage Start Elevation (2019)	668.57	m
Estimated Long Term Storage Area	1,541,470	m^2
Change in Storage (1998-2019)	878,638	m^3

[1] Klohn Leonoff Yukon Consulting Engineers, NovaTec Consultants Inc., *City of Whitehorse Sewage Treatment Feasibility Study Phase III Report.* April 1993
[2] Pottinger Gaherty Environmental Consultants, *Carcross Sewage Treatment and Disposal Pre-design Report: Climate Re-evaluation,* January 2006

Table 2 LCTEF Annual Inflows and Outflows (Source: City of Whitehorse)

Date	LTS Elevation (m)	Start Date	End Date	Number of Discharge Days	Total Discharge (m3)	Note	Wastewater Inflow to Primary Lagoons (m3)
3-Sep-19	668.57	3-Sep-2019	29-Oct-2019	57	3,716,966	Discharge to Yukon River	2,251,395
1-Aug-18	668.45	1-Aug-2018	18-Oct-2018	79	3,865,798	PHL - 1,960,961 m^3; YR - 1,904,837m^3	3,765,018
1-Aug-17	668.43	1-Aug-2017	1-Nov-2017	93	3,534,523	Discharge to PHL	3,855,266
1-Sep-16	668.40	1-Sep-2016	9-Nov-2016	57	3,181,286	PHL - 3,059,216m^3 ; YR - 122,070 m^3	3,748,289
2-Sep-15	668.56	2-Sep-2015	29-Oct-2015	57	3,968,822	Discharge to Yukon River	3,903,114
2-Sep-14	668.76	2-Sep-2014	29-Oct-2014	57	4,200,658	Discharge to Yukon River	4,039,162
3-Sep-13	668.74	3-Sep-2013	23-Oct-2013	50	4,016,773	Discharge to Yukon River	4,155,278
17-Sep-12	668.78	17-Sep-2012	15-Nov-2012	48	4,224,687	Discharge to Yukon River	3,894,659
1-Sep-11	668.64	1-Sep-2011	27-Oct-2011	49	3,910,059	Discharge to Yukon River	3,696,182
8-Sep-10	668.40	8-Sep-2010	18-Oct-2010	41	3,075,789	Discharge to Yukon River	3,735,073
1-Sep-09	670.05	1-Aug-2009	11-Dec-2009	118	6,833,956	PHL - 2,319,732 m^3; YR - 4,514,224 m^3	4,016,053
4-Jun-08	670.31	4-Jun-2008	15-Dec-2008	195	5,164,227	Discharge to PHL	4,638,275
1-Sep-07	670.18	1-Aug-2007	31-Oct-2007	92	3,391,638	Discharge to PHL	4,483,384
1-Aug-06	668.82	1-Aug-2006	31-Oct-2006	92	3,419,595	Discharge to PHL	4,200,724
1-Aug-05	669.62	7-Aug-2005	3-Oct-2005	86	3,197,187	Discharge to PHL	4,200,724
1-Aug-04	669.04	1-Aug-2004	30-Oct-2004	91	2,875,484	Discharge to PHL	3,944,790
1-Aug-03	668.97	1-Aug-2003	31-Oct-2003	91	3,374,660	Discharge to PHL	3,771,514
1-Aug-02	668.98	1-Aug-2002	31-Oct-2002	91	3,356,195	Discharge to PHL	3,925,421
1-Aug-01	668.84	15-Aug-2001	31-Oct-2001	78	3,253,619	Discharge to PHL	3,950,000
1-Aug-00	668.65	8-Aug-2000	31-Oct-2000	85	3,405,413	Discharge to PHL	4,230,000
1-Aug-99	668.72	8-Sep-1999	31-Oct-1999	54	3,482,881	Discharge to PHL	4,313,853
1-Aug-98	668.00	8-Sep-1998	20-Oct-1998	43	2,973,255	Discharge to PHL	1,773,395

Notes:

[1] *Waste water inflows are for the period of August 1 to December 31, 1998*
[2] *Waste water inflows are for the period of January 1 to September 3, 2019.*

Water Balance

A total water balance for the period of record (1998-2019) was completed to solve for the estimated total exfiltration. Assigning the values listed in Table 3 into Equation 3, the resulting exfiltration is a negative number as shown below in Table 3. This would indicate groundwater infiltration into the lagoon which is not believed to be the case.

Table 3 LTECF Water Balance 1998-2019

Term	Total Volume 1998-2019 (m^3)	Average Annual Flow (m^3/year)
Wastewater Inflow	84,491,569	4,007,505
Precipitation	17,401,506	825,368
Wastewater Discharge	82,423,472	3,909,414
Evaporation	23,189,012	1,099,874
Change in Storage	878,638	41,675
Exfiltration	**-4,598,047**	**-218,089**

There is uncertainty in the wastewater discharge term due to the method of estimation. It is possible that the discharge is underestimated, which would result in a larger negative exfiltration value. It is also possible that the discharge is overestimated, and that the actual discharge is less than the value listed in Table 2. In this case, the water balance would yield a larger value for the exfiltration term. Table 4 shows the result of the water balance assuming that the discharge has been overestimated by 10% (i.e. the actual discharge is 90% of the value listed in Table 3). All other terms remain the same. This scenario produces a positive total exfiltration volume of 3,644,300 m^3 over the period of record, or 172,852 m^3 per year. This calculation demonstrates that the value of the exfiltration term is a small value and is within the uncertainty of the water balance.

Table 4 Water balance with modified discharge

Term	Total Volume 1998-2019 (m^3)	Average Annual Flow (m^3/year)
Total Wastewater Inflow	88,090,792	4,178,219
Total Precipitation	17,401,506	825,368
Wastewater Discharge (90% of 1998-2019 total)	74,181,125	3,518,472
Total Evaporation	23,189,012	1,099,874
Total Change in Storage	878,638	41,675
Total Exfiltration	3,644,300	172,852

Conclusion

Due to uncertainty in the water balance terms it is not possible to estimate exfiltration from the lagoon. As demonstrated in Table 4, the exfiltration value appears to be within the uncertainty of the discharge measurement. Similarly, there is uncertainty in the estimated evaporation rate which could have the same effect on the exfiltration term. Decreasing the evaporation rate by 10% would yield a positive exfiltration value. This calculation indicates that the exfiltration rate is a relatively small value compared to the other terms of the water balance.

APPENDIX C: BOREHOLE AND MONITORING WELL SUMMARY

LTECF Hydrogeology Study - Borehole and Test Pit Database

Location (UTM)			Ground Elev. (masl)	Depth (m)	Status	"Formations"												"Heads"				
ID	East	North				No.	Mat 1 Codes					Top Elevations + Bottom Elevation (masl)						No.	Screen Top and Bottom Elevation (masl)		Head (masl)	Date (mm/dd/yyy)
90-GT-01	491120	6745840	667.1	16.76		3	9	8	6	5		667.1	666.19	660	653.9	650.34		1	651.84	650.34	DRY	
90-GT-02	493010	6744160	675.48	6.55	MW_S	2	8	6				675.48	670.78	668.93				1	671.48	669.88	670.772	12/5/1990
90-GT-03	492516	6742441	674.27	13.41	MW_D	4	8	6	8	6		674.27	672.47	670.57	666.37	660.86		1	662.87	661.37	DRY	
90-GT-04	494425	6740819	673.76	17.22	MW_D	3	8	6	5			673.76	673.26	666.76	656.54			1	658.36	656.86	DRY	
90-GT-05	494120	6742620	675.45	6.55	MW_S	1	6					675.45	668.9					1	672.35	670.85	DRY	
90-GW-01	494240	6752370	638	6.1	MW_S	2	6	9				638	637	631.9				1	634.3	632.8	633.867	12/4/1990
90-GW-02	494140	6748450	647.78	5.79	MW_S	2	6	8				647.78	647.18	641.99				1	644.88	643.38	644.192	12/4/1990
90-GW-03	495190	6748230	650.01	6.71	MW_S	1	9					650.01	643.3					1	647.61	646.11	647.004	12/4/1990
90-GW-04	495680	6747180	658.54	12.95	MW_D	1	8					658.54	645.59					1	647.44	645.94	647.05	12/4/1990
90-GW-05	492450	6747100	660.87	7.62	MW_D	1	8					660.87	653.25					1	655.37	653.87	654.53	12/4/1990
90-GW-06	493870	6746180	668.04	8.08	MW_D	2	8	6				668.04	662.54	659.96				1	664.04	662.54	663.256	12/4/1990
90-GW-07	492500	6744150	672.58	6.55	MW_S	2	8	6				672.58	671.68	666.03				1	670.18	668.68	DRY	
90-GW-08	492750	6740890	658.18	14.17	MW_D	2	8	5				658.18	649.48	644.01				1	645.68	644.18	DRY	
90-GW-09	494270	6743460	680.01	6.86	MW_S	2	8	6				680.01	678.21	673.15				1	674.65	673.15	673.76	12/4/1990
90-GW-10	496390	6740760	684.31	10.67	MW_D	5	9	6	8	6	34	684.31	681.91	681.11	678.81	676.71	673.64	1	675.14	673.64	dry	
90-GW-11	495412	6740725	687.16	21.79	MW_D	4	8	6	5	8		687.16	686.96	685.06	667.36	665.37		1	667.26	665.76	dry	
90-TP-1	495710	6739800	683.83	3.6	TP	1	6					683.83	680.23					0				
90-TP-2	495140	6740730	678.99	3.6	TP	2	8	6				678.99	678.49	675.39				0				
90-TP-3	494150	6740930	667.18	3.8	TP	2	8	6				667.18	666.88	663.38				0				
90-TP-4	492900	6741840	670.91	4	TP	2	8	6				670.91	670.71	666.91				0				
90-TP-5	492470	6742770	676.41	3.9	TP	2	8	6				676.41	675.71	672.51				0				
90-TP-6	492500	6743560	672.41	4.1	TP	2	8	6				672.41	671.21	668.31				0				
90-TP-7	492490	6744820	672.6	3.9	TP	1	6					672.6	668.7					0				
90-TP-8	492400	6746340	663.03	3.8	TP	2	8	6				663.03	661.03	659.23				0				
90-TP-9	493460	6746580	664.58	3.9	TP	2	9	6				664.58	663.38	660.68				0				
90-TP-10	493780	6746240	668.38	3.6	TP	1	9					668.38	664.78					0				
90-TP-11	494400	6746440	670.17	3.6	TP	2	9	6				670.17	668.07	666.57				0				
90-TP-12	494980	6747770	652.45	3.8	TP	1	9					652.45	648.65					0				
90-TP-13	494560	6748100	649.65	4	TP	1	9					649.65	645.65					0				
90-TP-14	494060	6749010	646.95	4	TP	2	9	6				646.95	645.35	642.95				0				
90-TP-15	494250	6750000	641.67	3.6	TP	3	9	5	9			641.67	640.47	639.87	638.07			0				
90-TP-16	494880	6750950	646.64	4	TP	2	9	6				646.64	644.04	642.64				0				
90-TP-17	495040	6751490	637.17	3	TP	3	8	9	5			637.17	636.57	635.37	634.17			0				
90-TP-18	495620	6747290	659.28	4	TP	2	9	8				659.28	657.08	655.28				0				
90-TP-19	495900	6746450	-	#VALUE!	TP	1	9						3					0				
90-TP-20	495020	6748370	646.91	1.6	TP	2	6	9				646.91	646.71	645.31				0				
90-TP-21	494240	6748900	644.6	4	TP	3	9	6	5			644.6	642.1	641.1	640.6			0				
90-TP-22	494590	6749230	642.36	4	TP	3	8	6	5			642.36	640.36	639.56	638.36			0				
90-TP-23	494580	6749650	637.35	3.8	TP	2	6	5				637.35	636.95	633.55				0				
90-TP-24	494700	6748570	645.65	2.8	TP	3	6	9	6			645.65	645.05	643.85	642.85			0				
90-TP-25	494630	6741730	676.47	4.1	TP	2	8	5				676.47	673.87	672.37				0				
90-TP-26	494080	6742650	674.73	3.8	TP	1	6					674.73	670.93					0				
90-TP-27	493550	6743420	676.56	4	TP	2	8	6				676.56	676.06	672.56				0				
90-TP-28	495710	6741290	687.9	3.6	TP	2	9	6				687.9	686.9	684.3				0				
90-TP-29	496420	6740700	683.82	3.8	TP	2	9	6				683.82	682.62	680.02				0				
90-TP-30	496730	6740620	692	3.6	TP	2	8	6				692	691.7	688.4				0				
90-TP-31	497120	6740410	701.72	3.2	TP	5	8	6	9	6	11	701.72	701.42	701.12	700.72	699.62	698.52	0				
93-TP-01	493207	6741827	670.5	3.2	TP	1	6					670.5	667.3					0				
93-TP-02	493374	6741635	669	3.2	TP	1	6					669	665.8					0				

LTECF Hydrogeology Study - Borehole and Test Pit Database

Location (UTM)			Ground Elev. (masl)	Depth (m)	Status	"Formations"													"Heads"				
ID	East	North				No.	Mat 1 Codes					Top Elevations + Bottom Elevation (masl)						No.	Screen Top and Bottom Elevation (masl)		Head (masl)	Date (mm/dd/yyy)
93-TP-03	493484	6741598	669.5	3.6	TP	1	6					669.5	665.9					0				
93-TP-04	493568	6741479	667.4	3.6	TP	1	6					667.4	663.8					0				
93-TP-05	493737	674192	663.2	3	TP	1	6					663.2	660.2					0			660.6	
93-TP-06	493862	6741060	666.5	3.5	TP	1	6					666.5	663					0				
93-TP-07	494255	6741849	667	2.8	TP	1	6					667	664.2					0			664.6	
93-TP-08	494333	6742209	674.1	3.5	TP	1	6					674.1	670.6					0				
93-TP-09	494469	6741352	665.8	3.3	TP	2	8	6				665.8	665.3	662.5				0			663	
93-TP-10	494149	6741106	663.4	3	TP	1	6					663.4	660.4					0			662.3	
93-TP-11	494298	6740797	671.3	3	TP	2	8	6				671.3	670.9	668.3				0				
93-TP-12	494765	6740788	675	3	TP	1	6					675	672					0				
93-TP-13	494864	6740816	674.5	4	TP	1	6					674.5	670.5					0				
93-TP-14	494879	6740687	680.9	4	TP	1	6					680.9	676.9					0				
93-TP-15	494591	6740667	684.5	4	TP	1	6					684.5	680.5					0				
93-TP-16	494656	6740738	667.1	4.5	TP	1	6					667.1	662.6					0				
93-TP-17	494804	6740609	671.1	4.3	TP	1	6					671.1	666.8					0				
93-TP-18	494937	6740750	676.7	4.3	TP	1	6					676.7	672.4					0				
93-TP-19	495001	6740822	677.4	4	TP	1	6					677.4	673.4					0				
93-TP-20	495062	6740891	678.4	4.5	TP	1	6					678.4	673.9					0				
93-TP-21	495090	6740820	678.6	4	TP	1	6					678.6	674.6					0				
93-TP-22	495130	6740959	681.4	4.2	TP	1	6					681.4	677.2					0				
93-TP-23	495021	6740955	678.5	4	TP	1	6					678.5	674.5					0				
93-TP-24	494903	6741067	677.6	4	TP	1	6					677.6	673.6					0				
93-TP-25	494479	6740772	678.1	5	TP	1	6					678.1	673.1					0				
93-TP-26	494503	6740648	672.9	4	TP	1	6					672.9	668.9					0				
93-TP-27	494193	6740615	701.5	3	TP	2	6	11				701.5	701	698.5				0				
93-TP-28	494116	6740681	690	4	TP	5	6	11	6	10	11	690	689.3	688.8	688.4	688	686	0				
93-TP-29	494089	6740598	677.5	4	TP	1	6					677.5	673.5					0				
93-TP-30	493944	6740723	679.2	4.5	TP	1	6					679.2	674.7					0				
93-TP-31	493876	6740673	679.5	5	TP	1	6					679.5	674.5					0				
93-TP-32	494014	6740687	672.4	4	TP	1	6					672.4	668.4					0				
93-TP-33	493808	6740640	674	4	TP	3	6	9	6			674	673.7	672.5	670			0				
93-TP-34	493938	6740777	671	4.2	TP	1	6					671	666.8					0				
93-TP-35	494178	6740688	673.5	4	TP	1	6					673.5	669.5					0				
93-TP-36	494403	6740716	672.1	4	TP	1	6					672.1	668.1					0				
93-TP-37	494332	6740756	683.6	4	TP	1	6					683.6	679.6					0				
93-TP-38	494271	6740684	692.9	4.5	TP	3	6	11	9			692.9	692.4	691.6	688.4			0				
93-TP-39	494373	6740801	675.9	4.2	TP	1	6					675.9	671.7					0				
93-TP-40	494293	6740717	687.5	4.5	TP	2	6	11				687.5	684	683				0				
93-TP-41	494226	6740635	697.8	4	TP	2	6	11				697.8	696.5	693.8				0				
93-TP-42	494110	6740517	710.4	4	TP	5	6	11	10	11	10	710.4	709.9	708.8	708.4	707.9	706.4	0				
93-TP-43	494184	6740224	704.6	4	TP	3	6	10	11			704.6	704.1	703.6	700.6			0				
93-TP-44	494143	6740171	703.5	4	TP	2	6	11				703.5	703	699.5				0				
93-TP-45	494246	6740166	695.7	4	TP	4	6	11	10	11		695.7	695.2	693.2	692.7	691.7		0				
93-TP-46	494327	6740205	693.4	3.8	TP	4	6	11	6	11		693.4	693.1	692.8	692.2	689.6		0				
93-TP-47	494399	6740467	699	4	TP	2	6	11				699	698.5	695				0				
93-TP-48	494361	6740608	696.6	4.3	TP	2	6	10				696.6	695.1	692.3				0				
93-TP-49	494351	6740704	688.4	4.5	TP	2	6	10				688.4	684.4	683.9				0				
93-TP-50	493721	6742373	668.8	4.3	TP	1	6					668.8	664.5					0				
93-TP-51	493648	6742288	668.2	3.5	TP	1	6					668.2	664.7					0				

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LTECF Hydrogeology Study - Borehole and Test Pit Database

Location (UTM)			Ground Elev. (masl)	Depth (m)	Status	"Formations"												"Heads"				
ID	East	North				No.	Mat 1 Codes					Top Elevations + Bottom Elevation (masl)						No.	Screen Top and Bottom Elevation (masl)		Head (masl)	Date (mm/dd/yyy)
93-TP-52	493568	6742203	664.6	4	TP	1	6					664.6	660.6					0				
93-TP-53	493496	6742497	669.6	4.2	TP	1	6					669.6	665.4					0				
93-TP-54	493390	6742393	656.8	4	TP	1	6					656.8	652.8					0				
93-TP-55	493301	6742287	659.2	0.7	TP	1	6					659.2	658.5					0				
93-TP-56	492872	6742564	670	3.7	TP	1	6					670	666.3					0				
93-TP-57	493022	6742727	670.5	4.5	TP	2	9	8				670.5	667.3	666				0				
93-TP-58	492984	6742314	670.3	4.2	TP	1	6					670.3	666.1					0				
93-TP-59	493056	6742396	667.9	4.5	TP	1	6					667.9	663.4					0				
93-TP-60	493251	6742600	688.1	4	TP	1	6					688.1	684.1					0				
93-TP-61	493096	6742071	671.1	4	TP	1	6					671.1	667.1					0				
93-TP-62	493236	6742225	667	4	TP	1	6					667	663					0				
93-TP-63	494086	6742398	675	4.3	TP	1	6					675	670.7					0				
93-TP-64	494075	6742020	669.6	4	TP	1	6					669.6	665.6					0				
93-TP-65	494543	6741783	677.1	4	TP	2	8	6				677.1	675.1	673.1				0				
93-TP-66	494638	6741711	673.9	3.8	TP	1	6					673.9	670.1					0				
93-TP-67	494683	6741580	673.8	4	TP	1	6					673.8	669.8					0				
93-TP-68	494785	6741515	678.5	4	TP	1	6					678.5	674.5					0				
93-TP-69	494857	6741395	678.2	4	TP	1	6					678.2	674.2					0				
93-TP-70	494756	6741289	673.5	4.2	TP	1	6					673.5	669.3					0				
93-TP-71	494679	6741201	671.8	4	TP	1	6					671.8	667.8					0				
93-TP-72	494912	6741302	679.1	4.3	TP	1	6					679.1	674.8					0				
93-TP-73	495010	6741177	680	4	TP	1	6					680	676					0				
93-TP-74	494797	6741160	674.5	4	TP	1	6					674.5	670.5					0				
93-TP-75	494833	6740997	674.6	4	TP	1	6					674.6	670.6					0				
93-TP-76	494763	6740926	674.3	4	TP	1	6					674.3	670.3					0				
93-TP-77	494697	6740860	674.4	4	TP	1	6					674.4	670.4					0				
93-TP-78	494593	6740751	672	4	TP	1	6					672	668					0				
93-TP-79	495120	6741030	685.1	4	TP	2	9	6				685.1	683.1	681.1				0				
93-TP-80	495273	6740935	681.8	5	TP	2	9	6				681.8	677.3	676.8				0				
93-TP-81	495317	6740848	683.2	5	TP	1	8					683.2	678.2					0				
93-TP-82	495369	6740778	687.9	5	TP	2	9	6				687.9	683.7	682.9				0				
93-TP-83	495402	6740687	688.2	4	TP	1	6					688.2	684.2					0				
93-TP-84	495470	6740596	687.4	4.7	TP	1	6					687.4	682.7					0				
93-TP-85	495541	6740481	687.1	5	TP	1	6					687.1	682.1					0				
93-TP-86	495628	6740395	683.2	5.2	TP	2	8	6				683.2	681.2	678				0				
93-TP-87	495684	6740305	684.6	5	TP	2	6	5				684.6	683.2	679.6				0				
93-TP-88	495747	6740214	685	4.7	TP	2	9	6				685	684.3	680.3				0				
93-TP-89	495819	6740130	683.2	5	TP	1	6					683.2	678.2					0				
93-TP-90	495869	6740033	682.3	5	TP	1	6					682.3	677.3					0				
93-TP-91	495952	6739983	682.6	5	TP	1	6					682.6	677.6					0				
93-TP-92	495987	6739852	682	5	TP	1	6					682	677					0				
93-TP-93	496056	6739757	682	4.5	TP	1	6					682	677.5					0				
93-TP-94	496167	6739693	684.7	5	TP	2	6	5				684.7	681.7	679.7				0				
93-TP-95	496197	6739554	684.9	5.5	TP	2	8	6				684.9	684.15	679.4				0				
93-TP-96	496234	6739510	685	5	TP	2	8	6				685	684.4	680				0				
93-TP-97	496319	6739375	684.9	5	TP	2	8	6				684.9	683.6	679.9				0				
93-TP-98	496382	6739278	685	5	TP	4	9	6	8	6		685	683.8	683.6	683.5	680		0				
93-TP-99	496449	6739187	689	4.5	TP	2	9	6				689	688.4	684.5				0				
93-TP-100	496497	6739114	690.3	4.5	TP	3	9	6	8			690.3	689.7	687.1	685.8			0				

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LTECF Hydrogeology Study - Borehole and Test Pit Database

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ID	East	North				No.	Mat 1 Codes					Top Elevations + Bottom Elevation (masl)						No.	Screen Top and Bottom Elevation (masl)		Head (masl)	Date (mm/dd/yyy)
93-TP-101	496556	6739019	693.2	5	TP	4	9	11	6	10		693.2	692.7	692.5	691	688.2		0				
93-TP-102	496642	6738899	689.2	4.5	TP	2	9	34				689.2	688.6	684.7				0				
93-TP-103	496721	6738808	692	2.7	TP	2	9	34				692	691.5	689.3				0				
93-TP-104	496766	6738719	691.9	4.5	TP	2	6	34				691.9	691.15	687.4				0				
93-TP-105	496813	6738654	690.3	5	TP	1	6					690.3	685.3					0				
93-TP-106	496879	6738548	690.9	4.5	TP	1	6					690.9	686.4					0				
93-TP-107	496872	6738455	687.2	4	TP	1	6					687.2	683.2					0				
93-TP-108	492330	6742621	667.367	5.5	TP	2	8	6				667.367	665.467	661.867				0				
93-TP-109	492229	6742718	664.652	5	TP	2	9	6				664.7	663.1	659.7				0				
93-TP-110	492142	6742818	666.014	5.2	TP	2	9	6				666.0	662.2	660.8				0				
93-TP-111	492051	6742901	661.063	5	TP	1	8					661.1	656.1					0				
93-TP-112	491673	6742914	661.752	4.5	TP	1	8					661.8	657.3					0				
93-TP-113	491563	6742887	661.345	5	TP	3	6	8	6			661.3	659.0	657.5	656.3			0				
93-TP-114	491420	6742966	660.259	5	TP	1	8					660.3	655.3					0				
93-TP-115	491254	6742947	660.316	4.5	TP	2	9	8				660.3	658.5	655.8				0				
93-TP-116	491121	6743035	658.392	4	TP	1	9					658.4	654.4					0				
93-TP-117	490934	6743091	656.914	4	TP	1	9					656.9	652.9					0				
93-TP-118	496501	6738685	653.515	5	TP	4	6	11	6	11		653.5	652.5	651.765	650.0	648.5		0				
93-TP-119	496479	6738596	652.483	5.2	TP	3	6	11	6			652.5	651.2	650.8	647.3			0				
93-TP-120	496516	6738493	650.887	5.2	TP	1	6					650.9	645.7					0				
93-TP-121	496546	6738401	650.263	5	TP	3	6	11	6			650.3	649.2	648.3	645.3			0				
93-TP-122	496575	6738316	648.853	4.8	TP	3	6	9	6			648.9	647.4	646.4	644.1			0				
93-TP-123	496605	6738216	649.191	5	TP	1	6					649.2	644.2					0				
93-TP-124	496640	6738124	649.49	5	TP	3	6	9	6			649.5	648.5	648.0	644.5			0				
93-TP-125	496624	6738015	640.635	5	TP	2	8	6				640.6	639.7	635.6				0			637.6	
93-TP-126	496515	6738798	672.345	5	TP	3	6	5	11			672.3	669.8	667.8	667.3			0				
93-TP-127	496542	6738912	685.719	5	TP	5	8	6	11	6	11	685.7	684.6	684.2	683.6	681.969	680.7	0				
93-TP-128	496725	6737000	680.515	5	TP	2	8	6				680.5	675.8	675.5				0				
93-TP-129	496708	6737095	680.026	5.5	TP	2	8	6				680.0	675.0	674.5				0				
93-TP-130	496891	6737186	679.998	5.5	TP	1	8					680.0	674.5					0				
93-TP-131	496670	6737298	678.353	5.3	TP	2	8	6				678.4	677.4	673.1				0				
93-TP-132	496647	6737430	677.547	5	TP	1	6					677.5	672.5					0				
93-TP-133	496623	6737561	674.289	5.5	TP	2	8	6				674.3	672.5	668.8				0				
93-TP-134	496592	6737694	672.26	4.8	TP	2	8	6				672.3	671.8	667.5				0				
93-TP-135	496592	6737814	652.652	2.5	TP	1	6					652.7	650.2					0				
93-TP-136	496594	6737934	644.799	4.8	TP	3	6	9	6			644.8	644.2	644.0	640.0			0				
93-TP-137	496597	6737975	640.885	4.5	TP	3	6	9	6			640.9	640.4	639.6	636.4			0				
93-TP-138	495021	6741544	687.11	5	TP	1	8					687.1	682.1					0				
93-TP-139	494946	6741483	679.637	4.6	TP	1	6					679.6	675.0					0				
93-TP-140	494897	6741439	678.966	4.6	TP	1	6					679.0	674.4					0				
93-TP-141	494973	6741886	686.427	4.5	TP	1	8					686.4	681.9					0				
93-TP-142	494913	6741821	678.354	4.5	TP	2	6	5				678.4	675.4	673.9				0				
93-TP-143	494782	6741674	678.048	4.5	TP	2	6	5				678.0	674.5	673.5				0				
93-TP-144	494811	6742050	681.186	4.5	TP	1	6					681.2	676.7					0				
93-TP-145	494729	6741905	676.401	4.5	TP	1	6					676.4	671.9					0				
93-TP-146	494633	6741849	675.426	4.5	TP	1	6					675.4	670.9					0				
93-TP-147	494469	6742061	674.438	4.2	TP	2	8	6				674.4	670.9	670.2				0				
93-TP-148	494198	6742145	669.842	4.5	TP	1	6					669.8	665.3					0				
93-TP-149	493946	6742248	669.165	4.5	TP	1	6					669.2	664.7					0				

LTECF Hydrogeology Study - Borehole and Test Pit Database

Location (UTM)			Ground Elev. (masl)	Depth (m)	Status	"Formations"												"Heads"				
ID	East	North				No.	Mat 1 Codes					Top Elevations + Bottom Elevation (masl)						No.	Screen Top and Bottom Elevation (masl)		Head (masl)	Date (mm/dd/yyy)
93-TP-150	494154	6742466	675.558	4.5	TP	1	6					675.6	671.1					0				
93-TP-151	493668	6742663	674.554	4.5	TP	1	6					674.6	670.1					0				
93-TP-152	493740	6742731	674.554	4.5	TP	1	6					674.6	670.1					0				
93-TP-153	493811	6742799	675.687	4.5	TP	2	8	6				675.7	674.4	671.2				0				
93-TP-154	493888	6742871	676.59	4.5	TP	2	8	6				676.6	673.6	672.1				0				
93-TP-155	493859	6742521	673.799	4.5	TP	1	6					673.8	669.3					0				
93-TP-156	493962	6742633	679.775	4.5	TP	1	8					679.8	675.3					0				
93-TP-157	494013	6742686	674.941	4	TP	1	6					674.9	670.9					0				
93-BH-01	493257	6742684	670.7	5.8	MW_S	1	6					670.7	664.9					1	666.45	664.95	DRY	
93-BH-02	493538	6742046	657.7	10.6	MW_D	1	6					657.7	647.1					1	652.6	651.1	655.93	11/23/1993
93-BH-03	494961	6741434	663.7	5.3	MW_S	1	6					663.7	658.4					1	660.6	659.1	659.2	11/23/1993
93-BH-04	494441	6741220	666.8	10	MW_D	2	6	5				666.8	659.8	656.8				1	660.12	658.62	662.22	11/23/1993
93-BH-05	493847	6740572	674.8	9.7	MW_D	2	9	5				674.8	671.7	665.1				1	666.6	665.1	dry	
93-BH-06	494959	6740948	678.3	9.7	MW_D	1	6					678.3	668.6					1	671.1	669.6	670.4	11/23/1993
93-BH-07	490839	6743107	655.739	30.6	MW_D	3	9	6	5			655.739	643.239	640.439	625.139			1	626.739	625.239	DRY	
93-BH-08	492536	6742577	672.678	10.2	MW_D	2	8	6				672.678	672.178	662.478				1	663.978	662.478	DRY	
93-BH-09	492792	6742434	673.348	9.4	MW_D	2	8	6				673.348	671.848	663.948				1	665.448	663.948	DRY	
93-BH-10	492342	6742436	672.348	9.4	MW_D	2	8	6				672.348	670.848	662.948				1	664.748	663.248	DRY	
93-BH-11	496507	6738739	671.334	9.5	MW_D	2	6	5				671.334	669.334	661.834				1	663.334	661.834	DRY	
93-BH-12	496592	6737756	671.636	29	MW_D	4	6	5	8	6		671.636	670.836	645.636	645.136	642.636		1	643.836	642.336	DRY	
93-BH-13	496591	6737819	652.32	11	BH_D	1	6					652.32	641.32					0				
93-BH-14	496724	6736821	681.802	6.5	MW_S	1	9					681.802	675.302					1	677.302	675.802	dry	
93-BH-15	496730	6736884	681.646	6.5	MW_S	2	8	6				681.646	676.146	675.146				1	676.546	675.046	dry	
93-BH-16	494761	6740599	680.863	30.8	BH_D	2	9	11				680.863	671.363	650.063				0				
93-BH-17	494978	6740709	678.051	17.2	BH_D	1	6					678.051	660.851					0				
93-BH-18	494846	6741743	679.525	9.1	BH_D	2	8	6				679.525	678.025	670.425				1	672.125	670.625	DRY	
93-BH-19	494796	6742107	687.369	9.1	BH_D	4	8	6	8	6		687.369	686.369	683.619	679.369	678.269		0				
93-BH-20	494366	6731964	678.966	9.1	BH_D	1	6					678.966	669.866					0				
93-BH-21	493916	6742581	674.439	9.1	BH_D	1	6					674.439	665.339					0				
93-BH-22	490708	6743136	628	10.4	BH_D	2	6	5				628	626.7	617.6				0				
93-BH-23	490680	6743144		0	BH_S													0				
95-TP-01	495049	6740840	678.8	5	TP	1	6					678.8	673.8					0				
95-TP-02	495139	6740808	678.8	5	TP	2	8	6				678.8	676.8	673.8				0				
95-TP-03	495056	6741102	681.1	5.8	TP	3	6	8	6			681.1	680.1	679.9	675.3			0				
95-TP-04	495019	6741292	684.4	1.2	TP	2	8	6				684.4	683.9	683.2				0				
95-TP-05	494991	6741493	680.8	5.4	TP	2	8	6				680.8	680	675.4				0				
95-TP-06	494973	6741686	680.1	5.4	TP	1	6					680.1	674.7					0				
95-TP-07	494882	6741964	679.7	5.4	TP	1	6					679.7	674.3					0				
95-TP-08	494693	6742100	682.3	5.4	TP	2	8	6				682.3	678.5	676.9				0				
95-TP-09				0	TP													0				
95-TP-10	494451	6742155	675.5	5.4	TP	3	6	8	6			675.5	674.8	673.8	670.1			0				
95-TP-11	494386	6742307	676.5	5.6	TP	1	6					676.5	670.9					0				
95-TP-12	494528	6742322	678	5.2	TP	1	6					678	672.8					0				
95-TP-13	494516	6742480	680.6	4.5	TP	3	6	8	6			680.6	679.3	677.8	676.1			0				
95-TP-14	494503	6742585	679.2	5.2	TP	5	6	8	6	8	6	679.2	678.7	678.2	678	677.4	674	0				
95-TP-15	494363	6742570	678.3	5.5	TP	4	8	6	8	6		678.3	677.6	677	675.8	672.8		0				
95-TP-16	494207	6742541	677.5	5.1	TP	4	8	6	8	6		677.5	676.8	676.3	675.4	672.4		0				
95-TP-17	494359	6742438	676.5	5.5	TP	1	6					676.5	671					0				
95-TP-18	494227	6742246	674.6	5.5	TP	1	6					674.6	669.1					0				

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Location (UTM)						"Formations"													"Heads"				
ID	East	North	Ground Elev. (masl)	Depth (m)	Status	No.	Mat 1 Codes					Top Elevations + Bottom Elevation (masl)						No.	Screen Top and Bottom Elevation (masl)		Head (masl)	Date (mm/dd/yyy)
95-TP-19	494303	6742119	672.4	5.6	TP	1	6					672.4	666.8					0			667.4	
95-TP-20	494441	6741925	678.8	5.3	TP	1	6					678.8	673.5					0				
95-TP-21	494514	6742018	676.1	5.4	TP	1	6					676.1	670.7					0				
95-TP-22	494707	6741827	676.8	5.3	TP	1	6					676.8	671.5					0			671.8	
95-TP-23	494851	6741282	678.4	5.3	TP	1	6					678.4	673.1					0				
95-TP-24	494943	6741036	678.1	5.6	TP	1	6					678.1	672.5					0				
95-TP-25	494909	6740896	677.6	5.6	TP	3	6	9	6			677.6	677.1	676.8	672			0				
95-TP-26	495190	6740897	690.9	5.6	TP	1	11					690.9	685.3					0				
95-TP-27	495169	6740845	682.2	5.9	TP	2	6	11				682.2	676.5	676.3				0				
95-TP-28	495068	6741230	685.4	5.5	TP	2	9	6				685.4	682.7	679.9				0				
95-TP-29	495048	6741403	685.6	5.3	TP	1	8					685.6	680.3					0				
95-TP-30	495012	6741694	684.5	5.3	TP	2	8	6				684.5	682.75	679.2				0				
95-TP-31	494681	6742156	688	5.3	TP	1	9					688	682.7					0				
95-TP-32	494650	6742235	685.4	5.3	TP	2	8	6				685.4	681.6	680.1				0				
95-TP-33	494602	6742348	682.1	5.3	TP	2	8	6				682.1	680.9	676.8				0				
95-TP-34	494597	6742457	679.9	5.5	TP	4	8	6	8	6		679.9	679.3	679	678.8	674.4		0				
95-TP-35	493820	6740792	673.529	5.4	TP	2	8	6				673.529	672.829	668.129				0				
95-TP-36	493740	6740912	666.145	6.2	TP	2	8	6				666.145	665.445	659.945				0				
95-TP-37	493703	6740983	667.48	5.6	TP	1	6					667.48	661.88					0				
95-TP-38	493622	6741093	668.345	5.2	TP	1	6					668.345	663.145					0				
95-TP-39	493550	6741205	669.583	5.5	TP	1	6					669.583	664.083					0				
95-TP-40	493489	6741289	670.004	5.6	TP	2	8	6				670.004	669.204	664.404				0				
95-TP-41	493439	6741373	667.796	5	TP	1	6					667.796	662.796					0				
95-TP-42	493386	6741450	669.788	5.6	TP	3	6	8	6			669.788	669.288	667.288	664.188			0				
95-TP-43	493328	6741537	667.523	6.1	TP	1	6					667.523	661.423					0				
95-TP-44	493284	6741622	667.436	6.2	TP	1	6					667.436	661.236					0				
95-TP-45	493234	6741708	668.576	5.5	TP	3	6	8	6			668.576	667.876	664.576	663.076			0				
95-TP-46	492972	6742484	669.749	6.1	TP	2	8	6				669.749	667.999	663.649				0				
95-TP-47	492971	6742605	669.266	6.1	TP	2	8	6				669.266	667.366	663.166				0				
95-TP-48	493029	6742599	668.845	5.8	TP	2	8	6				668.845	667.345	663.045				0				
95-TP-49	493130	6742743	669.586	5	TP	2	8	6				669.586	664.686	664.586				0				
95-TP-50	493008	6743053	671.092	11.7	TP	3	8	6	5			671.092	669.192	665.292	659.392			0				
95-TP-51	493016	6742878	678.138	5.8	TP	2	8	6				678.138	676.138	672.338				0				
95-TP-52	492988	6742649	674.959	5.3	TP	1	8					674.959	669.659					0				
95-TP-53				0	TP													0				
95-TP-54				0	TP													0				
95-TP-55				0	TP													0				
95-TP-56				0	TP													0				
95-TP-57				0	TP													0				
95-TP-58				0	TP													0				
95-TP-59				0	TP													0				
95-TP-60	495235	6740785	690	5	TP	2	6	8				690	689.9	685				0				
95-TP-61	495235	6741070	688	4	TP	3	6	8	6			688	687.7	684.3	684			0				
95-TP-62	495207	6741142	687.5	3	TP	3	6	8	6			687.5	687.3	686.3	684.5			0				
95-TP-63	495183	6741223	687	3.2	TP	2	6	8				687	686.7	683.8				0				
95-TP-64	495158	6741314	685	4.5	TP	2	6	8				685	684.5	680.5				0				
95-TP-65	495123	6741431	686.5	4.2	TP	1	8					686.5	682.3					0				
95-TP-66	495097	6741514	686	4	TP	1	8					686	682					0				
95-TP-67	495066	6741620	688	4.2	TP	1	8					688	683.8					0				

LTECF Hydrogeology Study - Borehole and Test Pit Database

Location (UTM)			Ground Elev. (masl)	Depth (m)	Status	"Formations"													"Heads"				
ID	East	North				No.	Mat 1 Codes					Top Elevations + Bottom Elevation (masl)						No.	Screen Top and Bottom Elevation (masl)		Head (masl)	Date (mm/dd/yyy)
95-TP-68	495041	6741704	687.5	3.2	TP	4	8	6	8	6		687.5	686.6	685.8	685.1	684.3		0				
95-TP-69	495109	6741639	684	2.5	TP	2	8	6				684	681.6	681.5				0				
95-TP-70	495170	6741640	684.5	2	TP	2	8	6				684.5	683.3	682.5				0				
95-TP-71	495155	6741525	684	2.4	TP	2	8	6				684	682.4	681.6				0				
95-TP-72	495180	6741435	683	3.5	TP	4	8	6	8	6		683	681.7	681.5	679.8	679.5		0				
95-TP-73	495220	6741445	687	4	TP	3	8	6	8			687	686.4	686.2	683			0				
95-TP-74	495215	6741325	683.5	2.2	TP	2	8	6				683.5	682.2	681.3				0				
95-TP-75	495240	6741235	685.5	1	TP	2	8	6				685.5	685	684.5				0				
95-TP-76	495270	6741160	685.5	2.1	TP	2	8	6				685.5	683.9	683.4				0				
95-TP-77	495275	6741080	688	1.1	TP	2	8	6				688	687.1	686.9				0				
95-TP-78	495258	6741345	686	2.8	TP	2	8	6				686	684.2	683.2				0				
95-TP-79	495088	6741706	680	3.1	TP	2	8	6				680	677.2	676.9				0				
95-TP-80	495121	6741742	684.5	3.2	TP	2	8	6				684.5	681.5	681.3				0				
95-TP-81	495290	6741440	683.5	1.2	TP	1	6					683.5	682.3					0				
95-TP-82	495380	6741475	688.5	1.6	TP	2	8	6				688.5	687.2	686.9				0				
95-TP-83	495355	6741585	687.5	1.3	TP	2	8	6				687.5	686.4	686.2				0				
95-TP-84	495400	6741685	688	1.5	TP	2	8	6				688	686.7	686.5				0				
95-TP-85	495285	6741765	688.5	3.9	TP	4	8	6	8	6		688.5	687.1	686.9	685.1	684.6		0				
95-TP-86				0	TP													0				
95-TP-87				0	TP													0				
95-TP-88	495110	6741967	683.5	4.8	TP	2	8	6				683.5	679	678.7				0				
95-TP-89	495051	6741552	688.5	4.7	TP	2	8	6				688.5	684.1	683.8				0				
95-TP-90	495064	6741471	688	4.4	TP	1	8					688	683.6					0				
95-TP-91	495097	6741246	685.5	4.7	TP	1	8					685.5	680.8					0				
95-TP-92	495097	6741148	685.5	4.6	TP	1	8					685.5	680.9					0				
95-TP-93	492990	6742790	681.5	4.5	TP	1	8					681.5	677					0				
95-TP-94	492935	6742750	676	4.6	TP	1	8					676	671.4					0				
95-TP-95	492925	6742870	678.5	5.8	TP	1	8					678.5	672.7					0				
95-TP-96	492915	6742870	676.5	5.7	TP	1	8					676.5	670.8					0				
95-TP-97	492855	6742870	671	1	TP	2	8	6				671	670.1	670				0				
95-TP-98	493975	6742654	678.5	4.5	TP	1	8					678.5	674					0				
95-TP-99	493860	6742625	677.5	4.6	TP	1	8					677.5	672.9					0				
95-TP-100	493905	6742730	681.5	4.7	TP	1	8					681.5	676.8					0				
95-TP-101	493910	6742790	680	4.5	TP	1	8					680	675.5					0				
95-TP-102	493835	6742820	680	3.3	TP	2	8	6				680	677.1	676.7				0				
95-TP-103	493800	6742910	678.5	2.8	TP	5	6	8	6	8	6	678.5	677.5	676.8	676.5	676	675.7	0				
95-TP-104	493945	6742900	681.5	4.6	TP	1	8					681.5	676.9					0				
95-TP-105	493950	6742990	682.5	4.7	TP	1	8					682.5	677.8					0				
95-TP-106	493875	6743000	679.5	3	TP	2	8	6				679.5	677	676.5				0				
95-BH-01	495027	6741057	680.4	28	BH_D	3	6	11	6			680.4	673.4	661.4	652.4			0				
95-BH-02	494974	6741254	681	31	BH_D	2	6	5				681	669	650				0				
95-BH-03	494961	6741015	678.5	31.1	BH_D	2	6	5				678.5	663.5	647.4				0				
95-BH-04	494995	6741033	678.7	23.3	BH_D	5	6	8	6	5	8	678.7	668.7	667.4	664.7	664.5	655.4	0				
95-BH-05	495054	6741002	679.4	21.5	BH_D	2	6	8				679.4	664.9	657.9				0				
95-BH-06	495025	6741124	680.5	20.3	BH_D	2	6	8				680.5	669.2	660.2				0				
12025-BH-01	493070	6738330	675	4.5	BH_S	2	6	5				675	674	670.5				0				
12025-BH-02	493390	6738610	679	7.8	BH_D	2	8	6				679	675	671.2				0				
12025-BH-03	493590	6728720	675	4.6	BH_S	3	8	6	5			675	674.5	671	670.4			0				
12025-BH-04	493630	6738960	670	12.5	BH_D	3	8	6	5			670	669.8	666.7	657.5			0				

Prepared by: CZ
Reviewed by: AW

LTECF Hydrogeology Study - Borehole and Test Pit Database

Location (UTM)						"Formations"												"Heads"				
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12025-BH-05	493660	6739120	645	29.2	BH_D	3	8	11	8			645	637.5	626.5	615.8			0			630	
12025-BH-06	493600	6739020	655	7.6	BH_D	1	6					655	647.4					0				
12025-BH-07	493850	6739535	650	4.6	BH_S	1	6					650	645.4					0				
12025-BH-08	493825	6739465	655	4.6	BH_S	2	6	5				655	653.2	650.4				0				
12025-BH-09	493825	6739370	645	4.6	BH_S	3	8	6	8			645	643.7	643.5	640.4			0				
12025-BH-10	493620	6739215	630	12.8	BH_D	2	5	8				630	629	617.2				0			629	
12025-BH-11	493840	6739300	645	4.6	BH_S	1	8					645	640.4					0				
12025-BH-12	493670	6739255	645	24.7	MW_D	3	6	5	8			645	641	626.5	620.3			1	622.5	621	623.7	10/16/1995
12025-BH-13	493920	6740200	700	12.5	BH_D	1	8					700	687.5					0				
12025-BH-14	494060	6740360	700	12.5	BH_D	1	8					700	687.5					0				
12025-TP-01	493900	6740055	695	3.5	TP	2	8	11				695	693	691.5				0				
12025-TP-02	493890	6739955	682	4.5	TP	1	11					682	677.5					0				
12025-TP-03	493890	6739855	664	3.5	TP	2	11	8				664	662.9	660.5				0				
12025-TP-04	493890	6739790	665	4	TP	2	6	8				665	662.5	661				0				
12025-TP-05	493820	6739705	662	4.8	TP	2	6	8				662	657.4	657.2				0				
12025-TP-06	493860	6739600	657	5.3	TP	2	8	6				657	656.1	651.7				0				
12025-TP-07	493785	6739330	644	5.3	TP	2	6	8				644	643.6	638.7				0				
12025-TP-08	493755	6739290	643	2.8	TP	2	6	8				643	641.3	640.2				0				
12025-TP-09	493795	6739285	637	3	TP	3	6	8	6			637	636.15	634.9	634			0				
12025-TP-10	493795	6739310	640	4.9	TP	2	6	8				640	639.2	635.1				0				
PH4A	493603	6740376	640	41.1	BH_D	3	8	11	8			640	639	617	598.9			0				
PH4B	493528	6740371	640	19.5	BH_D	1	8					640	620.5					0				
12025-MW1	493632	6740168	682.493	59.8	MW_D	4	6	9	11	9		682.493	679.493	661.493	648.993	622.693		1	632.493	626.493	630.33	average Sep '99 to May '03
12025-MW2	493715	6739967	654.905	30.4	MW_D	2	8	11				654.905	636.905	624.505				1	630.505	624.505	629.67	average Sep '99 to May '03
12025-MW3	493698	6739686	651	30	MW_D	1	8					651	621					1	627	621	628.66	average Sep '99 to May '03
12025-MW4	493830	6739783	652.948	36	MW_D	3	6	8	11			652.948	629.948	625.948	616.948			1	622.948	616.948	629.37	average Sep '99 to May '03
PH1	493660	6740489	649.6	25.4	MW_D	1	8					649.6	624.2					1	625.4	624.2	632.36	average Sep '99 to Jul '01
PH2	493387	6740517	653.36	39	MW_D	3	8	6	8			653.36	645.36	617.36	614.36			1	615.56	614.36	631.14	average Sep '99 to Jul '01
PH3	493595	6740599	650.13	26.5	MW_D	3	8	6	8			650.13	647.13	636.13	623.63			1	624.83	623.63	631.87	average Sep '99 to Jul '01
MW4A	493785	6739697	634.75	10.1	MW_D	2	6	11				634.75	630.75	624.65				1	625.85	624.65	628.91	average Sep '99 to May '03
GW4-2019	492877	6743069	677			3	9	6	5			677	673.5	672.4	669.5			1	666.45	669.5	671.545	
GW1	494953	6740896																1	661.9	661.9	666.5	8/15/2018
GW2	494458	6740807																1	652.4	652.4	664.6	8/15/2018
GW3	493270	6741428																1	654.9	654.9	663.63	8/15/2018

Prepared by: CZ
Reviewed by: AW

GSC Material Codes

CODE	DES		CODE	DES
00	UNKNOWN TYPE		39	FELDSPAR
01	FILL		40	FLINT
02	TOPSOIL		41	GNEISS
03	MUCK		42	GREYWACKE
04	PEAT		43	GYPSUM
05	CLAY		44	IRON FORMATION
06	SILT		45	MARBLE
07	QUICKSAND		46	QUARTZ
08	FINE SAND		47	SCHIST
09	MEDIUM SAND		48	SOAPSTONE
10	COARSE SAND		60	CEMENTED
11	GRAVEL		61	CLAYEY
12	STONES		62	CLEAN
13	BOULDERS		63	COARSE-GRAINED
14	HARDPAN		64	CRYSTALLINE
15	LIMESTONE		65	DARK-COLOURED
16	DOLOMITE		66	DENSE
17	SHALE		67	DIRTY
18	SANDSTONE		68	DRY
19	SLATE		69	FINE-GRAINED
20	QUARTZITE		70	FOSILIFEROUS
21	GRANITE		71	FRACTURED
22	GREENSTONE		72	GRAVELLY
23	PREVIOUSLY DUG		73	HARD
24	PREV. DRILLED		74	LAYERED
25	OVERBURDEN		75	LIGHT-COLOURED
26	ROCK		76	LIMY
27	**		77	LOOSE
28	SAND		78	MEDIUM-GRAINED
29	FINE GRAVEL		79	PACKED
30	MEDIUM GRAVEL		80	POROUS
31	COARSE GRAVEL		81	SANDY
32	PEA GRAVEL		82	SHALY
33	MARL		83	SHARP
34	TILL		84	SILTY
35	WOOD FRAGMENTS		85	SOFT
36	BASALT		86	STICKY
37	CHERT		87	STONEY
38	CONGLOMERATE		88	THICK
			89	THIN
			90	VERY
			91	WATER-BEARING
			92	WEATHERED