June 21, 2021

Mr. Randy Dillon
Director of Engineering
Town of Happy Valley-Goose Bay
212 Hamilton Road, PO Box 40 Stn. B
Happy Valley-Goose Bay, NL A0P 1E0

Dear Mr. Dillon:

RE: Desktop Water Table Study
Town of Happy Valley-Goose Bay

CBCL Limited has completed a desktop review of surface water and groundwater data available for the Happy Valley-Goose Bay area (HVGB). This work was completed at the Town's request to investigate the potential influence of groundwater on flooding issues throughout the town, focused on stormwater drainage (roadside ditches) and flooding of building crawlspaces and basements. The following data were reviewed:

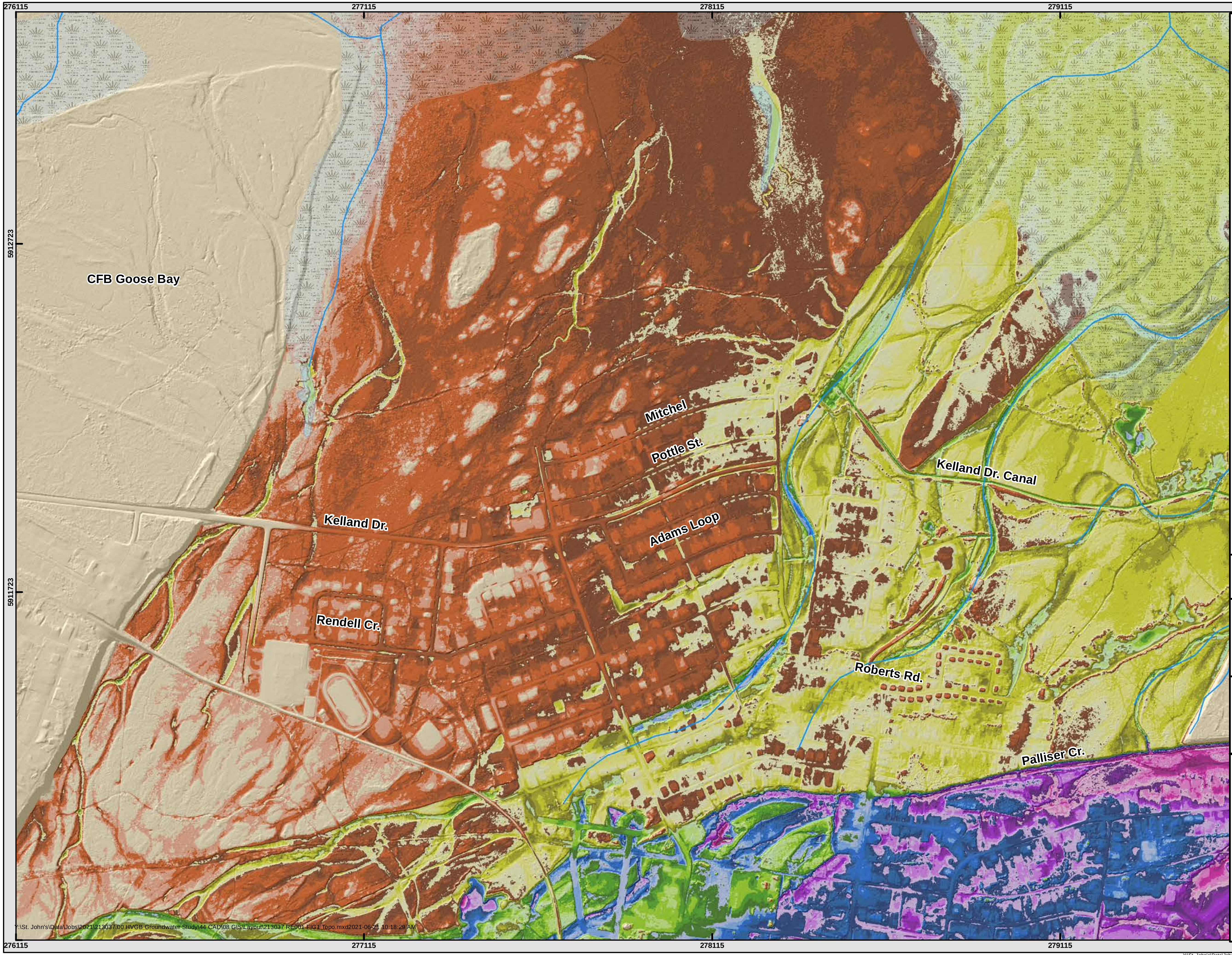
- Previous reporting by CBCL (2018);
- Aerial images of the area showing open water associated with wetlands, watercourses, and coastlines;
- Provincial mapping of watercourses and wetlands;
- High-resolution (cm-scale) Lidar elevation data;
- Photographs and reports of trouble areas;
- Anecdotal reports of flooding and groundwater levels from a local contractor; and
- Geology mapping and test pit logs.

This information was compiled to generate a conceptual model of shallow drainage systems and the regional water table. The following sections describe the results of the desktop investigation.

Physical Setting

The study area is located within the Happy Valley-Goose Bay rift valley (Figure 1). The Town is situated on the southern half of a five- to six-kilometre-wide isthmus that projects eastward from CFB Goose Bay, bounded by the Churchill River to the south, and Lake Melville to the north. These saltwater bodies are tidally influenced.

The Town is situated in the Lower Churchill watershed. The topography is level, sloping gently away in all directions from the central wetlands, from 18 metres in the centre of the peninsula to



Legend

- Watercourse (provincial mapping)
- Water Body (provincial mapping)
- Wetland (provincial mapping)

Ground Surface Elevation from Lidar-Generated Digital Elevation Model (m geodetic)

- 12 - 13
- 13 - 14
- 14 - 15
- 15 - 16
- 16 - 17
- 17 - 18
- >18

Figure 1

Ground Surface Elevation

Happy Valley-Goose Bay Desktop Water Table Study

Coordinate System: NAD 1983 UTM Zone 21N
Projection: Transverse Mercator
Datum: North American 1983
Units: Meter

N W E S

0 125 250 500 m

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Y:\St. John's\Data\Jobs\2021\213037.00 HVGB Groundwater Study\44 CAD\08 GIS\Layout\213037 RE001 FIG1 Topo.mxd

sea level at the coastline. CFB Goose Bay occupies a terrace further to the west, situated at elevations of up to 50 metres geodetic. Select problem areas within the town are situated at elevations from 15 to 17 metres.

Loamy sand and fine sand are the predominant surface soils of the area. Soils are underlain by laterally extensive, thick deposits of pro-glacial or ice contact sand and gravel forming fans, deltas, outwash plains, terraces, and kames (Klassen et al., 1992). The surficial geology is generally mapped as thick glaciomarine and marine deposits of sand and silt overlying clay (Klassen et al., 1992). Glaciofluvial deposits of sand and gravel have also been identified in the area. There is limited information on the underlying bedrock geology in the Goose Bay area, but it has been interpreted to consist of Precambrian arkose and conglomerate (Wardle, 1997).

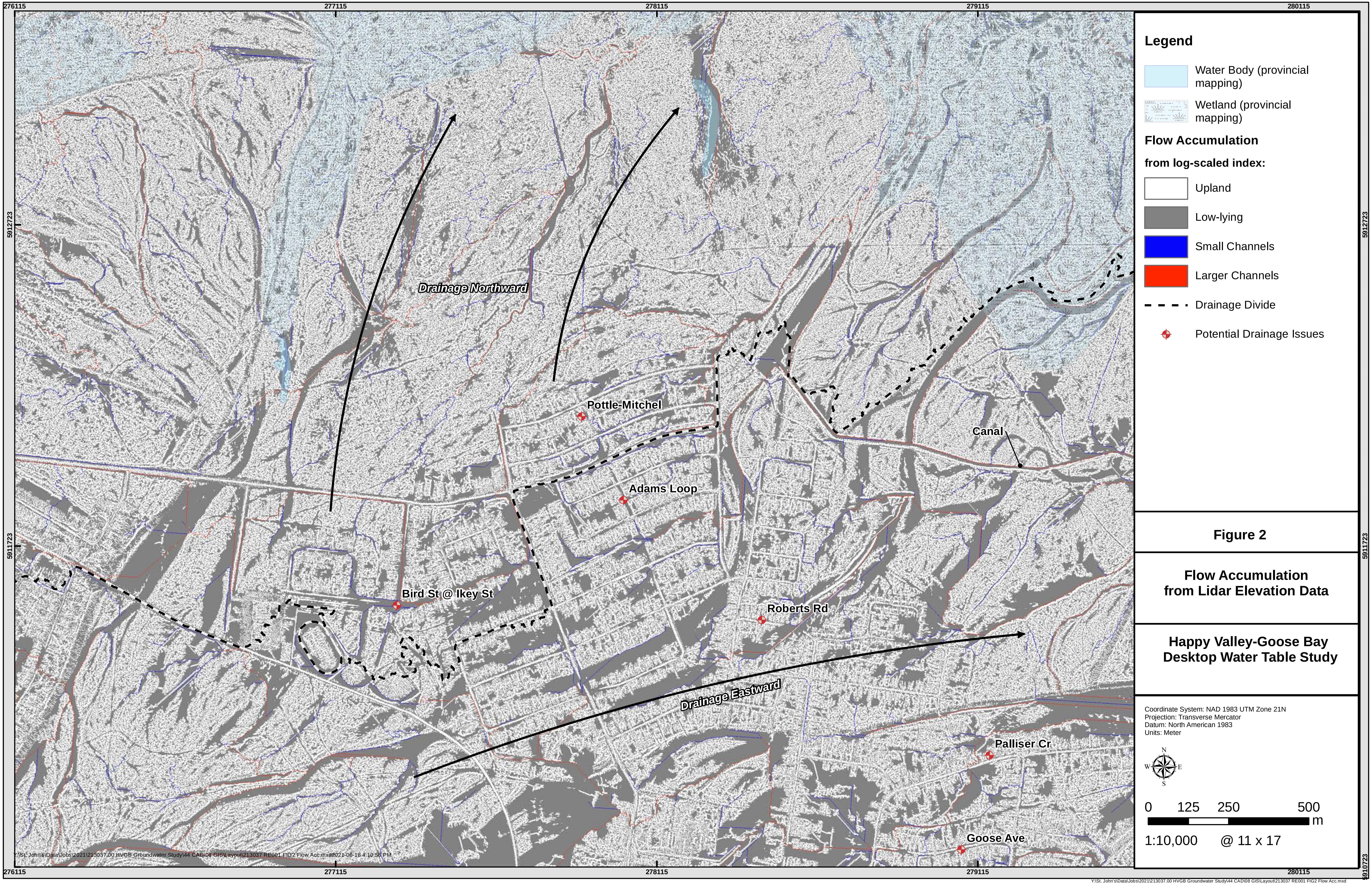
Drainage Assessment

Provincial mapping shows an extensive wetland complex to the north of the Town, with major drainage channels feeding these water bodies. An analysis of high-resolution Lidar elevation data indicated the existence of more localized channels, forming a network that drains primarily eastward (Figure 2). One system to the west of the Town drains effectively northward. There is a canal to the north of Kelland Drive which was excavated to facilitate drainage of surface water eastward, following the natural gradient of this system. Precipitation originating in the Pottle Crescent subdivision appears to drain northward, whereas systems to the south of Kelland Drive and in the immediate vicinity of the canal drain eastward. The flow accumulation analysis does not account for culverts and may not represent all continuous channels at local scales.

Storm water ditches and culverts along many roads in the area have been observed to be partially or completely in-filled. Some culverts are noted to be obstructed. In general, the natural grade in developed parts of the Town is so low that surface water does not drain readily following snow melt or heavy rainfall. Trouble areas noted previously by the Town are shown in Figure 2 and include:

- Crawl spaces and basements in the Pottle Street – Mitchel subdivision;
- A low-lying zone on Palliser Crescent;
- The area in the centre of Adams Loop;
- The subdivision near Roberts Road; and
- A low-lying zone at the intersection of Bird Street and Ikey Street.

Surface water pooling is most frequently observed in the spring months, following large rain events, and in exceptionally wet years. Anecdotal reports suggest that drainage issues have increased over time.


276115
277115
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280115
5912723
5911723
5910723
Drainage Northward
Drainage Eastward
Pottle-Mitchel
Adams Loop
Bird St @ Ikey St
Roberts Rd
Canal
Palliser Cr
Goose Ave
Legend
Water Body (provincial mapping)
Wetland (provincial mapping)
Flow Accumulation
from log-scaled index:
Upland
Low-lying
Small Channels
Larger Channels
Drainage Divide
Potential Drainage Issues
Figure 2
Flow Accumulation from Lidar Elevation Data
Happy Valley-Goose Bay Desktop Water Table Study
Coordinate System: NAD 1983 UTM Zone 21N
Projection: Transverse Mercator
Datum: North American 1983
Units: Meter
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Drainage problems may be associated with one or more of the following issues:

- Low topographic grades limit the ability of ditches and culverts to convey surface water away from the developed parts of the town;
- Infilling of ditches attenuates surface water flow, slowing the rate of drainage during and after storms; and
- A high water table may limit the amount of water that can infiltrate during storms.

This investigation focused on clarifying the position of the regional water table and its effect on local drainage issues.

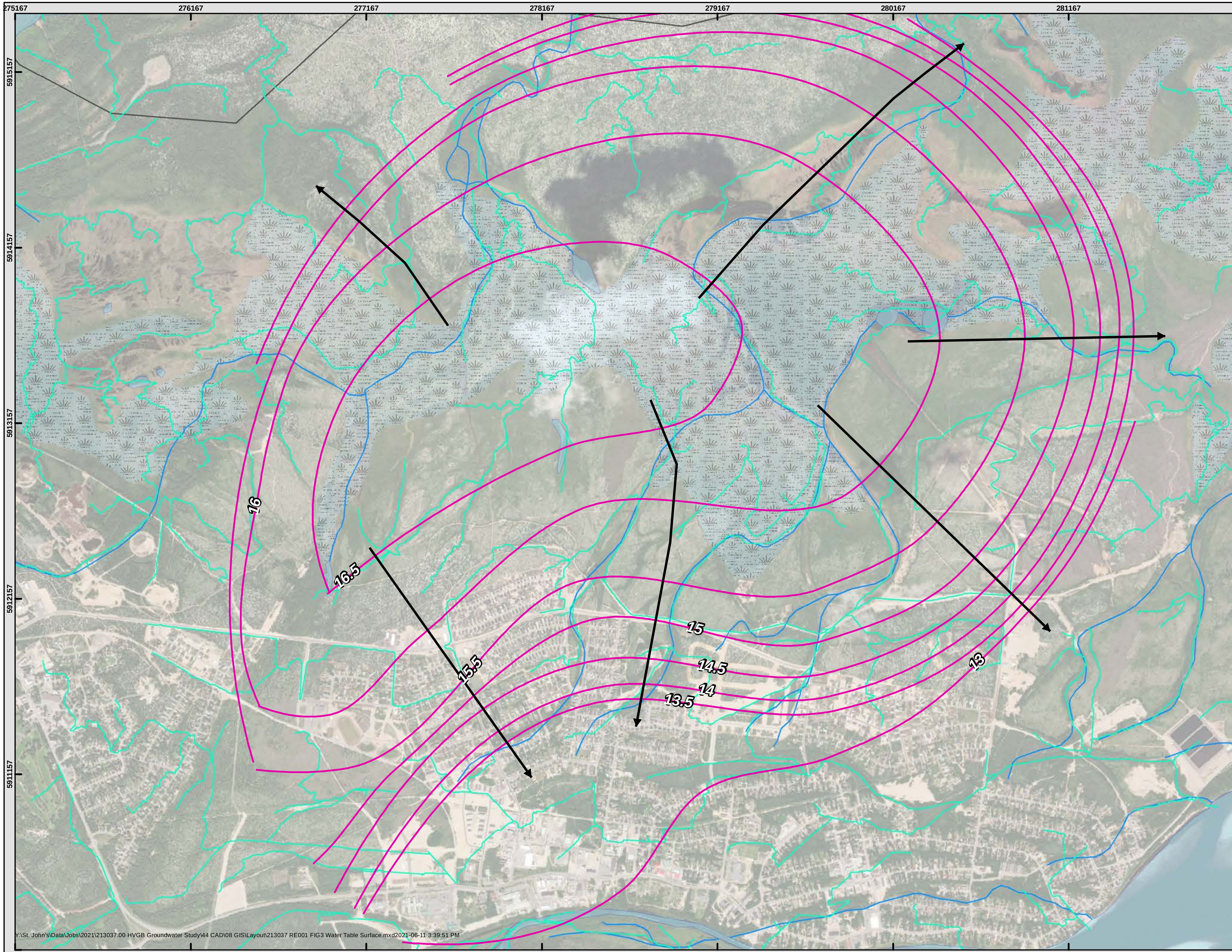
Water Table Mapping

HVGB experiences cool summers and cold winters, with frost typically extending from mid-September to early June of each year. At its peak extent the frost zone is reported to extend to depths up to or exceeding three metres. As conditions at the ground surface thaw, rates of snow melt and spring precipitation periodically exceed the infiltration capacity of surface soils, leading to localized flooding. This condition is likely to be exacerbated by the underlying frost zone, which is expected to thaw more slowly than the ground surface. The combination of high rates of infiltration and a deeper frozen zone in April-May is interpreted to lead to locally perched conditions, which would limit infiltration and contribute to flooding. HVGB experiences its highest rates of precipitation in July and August, which would tend to maintain wet conditions throughout the summer months.

A local contractor reported that a monitoring well installed prior to 2010 showed a water table depth on the order of 1.5 metres. In a separate study of the Mud Lake agricultural area to the east of HVGB, the water table was observed to decline by 0.5 metres from August to October (CBCL, 2012). The hydraulic conductivity of sands constituting the water table unit was on the order of 10^{-4} m/s.

The regional water table surface was interpolated using Lidar elevation data, the flow accumulation analysis shown in Figure 2, and aerial photography. The water table is interpreted to be positioned within a regional unit of glaciofluvial sands, comprising a relatively consistent and uniform shallow flow system. The interpolated water table is shown in Figure 3 and is consistent with a conventional conceptual model of groundwater flow. Higher topography and wetland areas to the north of the town represent a regional groundwater recharge area. The large wetlands may store and attenuate surface water drainage, acting as a focused recharged area. Groundwater flow is expected to be predominantly horizontal and radially outward from this recharge zone, with discharge to the coastlines.

The shallowest local groundwater flow systems may interact with local drainage courses and ditches. Identification and mapping of these systems was beyond the scope of this desktop



Legend

- Regional Groundwater Flow Systems
- Inferred Regional Water Table Contour Line (m geodetic)
- Apparent Drainage Course (Lidar Mapping)
- Watercourse (provincial mapping)
- Water Body (provincial mapping)
- Wetland (provincial mapping)

Figure 3

Approximate Elevation of Water Table Surface

Happy Valley-Goose Bay Desktop Water Table Study

Coordinate System: NAD 1983 UTM Zone 21N
Projection: Transverse Mercator
Datum: North American 1983
Units: Meter

N W E S

0 250 500 1,000 m

1:20,000 @ 11 x 17

exercise. The presence of a low permeability frost zone would tend to emphasize these local flow paths over more regional flow systems in April and May. Local flow systems would tend to stagnate as ditches and drainages courses fill following heavy rainfall. In some circumstances these ditches could act as temporary recharge areas, contributing to shallow groundwater systems and maintaining a high water table.

The interpolated water table surface was compared to the ground surface elevation to generate a map of the depth to the water table, shown in Figure 4. The depth to the water table decreases from its apparent greatest thickness (>3 m) on White Crescent, northward toward the wetland complex. Areas further to the south are lower-lying and appear to be associated with a relatively shallow water table. Figure 4 indicates that the water table depth in the Pottle-Mitchel subdivision is on the order of 1.5 metres. Basement crawlspaces in this area are reported to be approximately 1 metre below grade, suggesting that crawlspaces should on average be dry, but that as the water table rises, flooding becomes more likely to occur. Figures 3 and 4 do not capture the variability of the regional and local water tables. Figure 4 suggests that full basements in this area are likely to be below the regional water table, which would be associated with more consistent flooding.

Numerical Test Bed

A three-dimensional numerical model of groundwater flow in the study area was created using FEFLOW 7.2 (Figure 5). The model was created to test theoretical scenarios for groundwater recharge rates, and to verify initial indications from Lidar mapping. The model incorporated the influence of the higher terraced area occupied by the base to the west. This elevated area is likely to act as groundwater recharge area and could influence regional groundwater flow patterns. A brief description of model development and test bed parameters is provided in Appendix A. The model showed the theoretical depth of the regional water table under varying conditions.

Figure 6 shows the theoretical depth of the water table under conditions of average rainfall. The modelled depth to the water table is generally consistent with the results of the Lidar analysis shown in Figure 4. The depth to the water table in the Pottle-Mitchell subdivision was on the order of 1.5 metres, decreasing for homes furthest to the north and east. Figure 7 shows the modelled depth to the water table with a moderate increase in rainfall, consistent with conditions observed in the springtime or after periods of extended rainfall in July and August. The scenario demonstrated in Figure 7 suggests that the water table could reach the ground surface with only moderate increases in rainfall or meltwater. These results did not include scenarios involving a perched water table (related to a deep frost zone).

Drainage Options

Desktop work indicates that the position of the water table is a factor in the drainage issues experienced in HVGB. The position of the water table may furthermore be the controlling factor

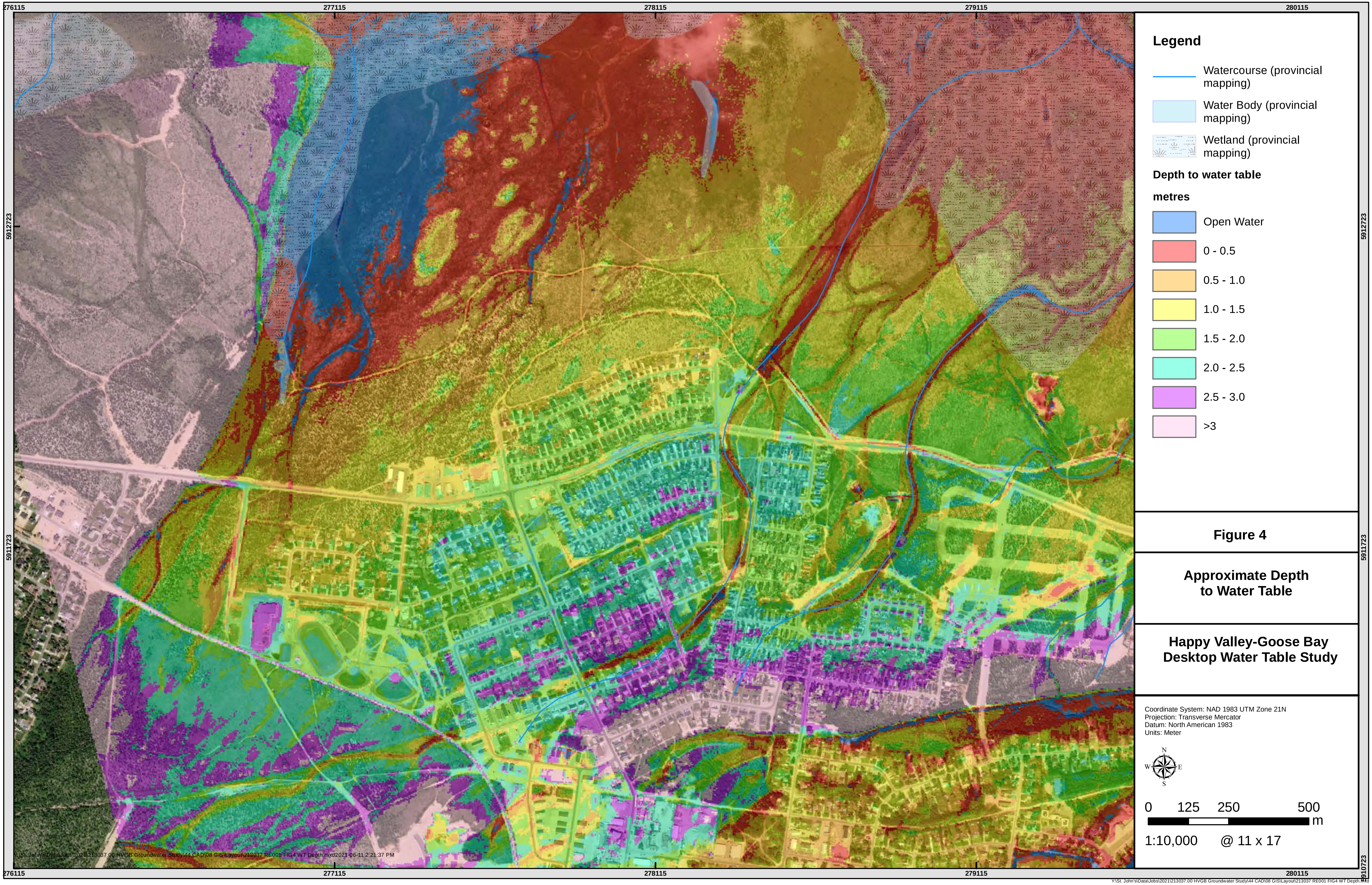


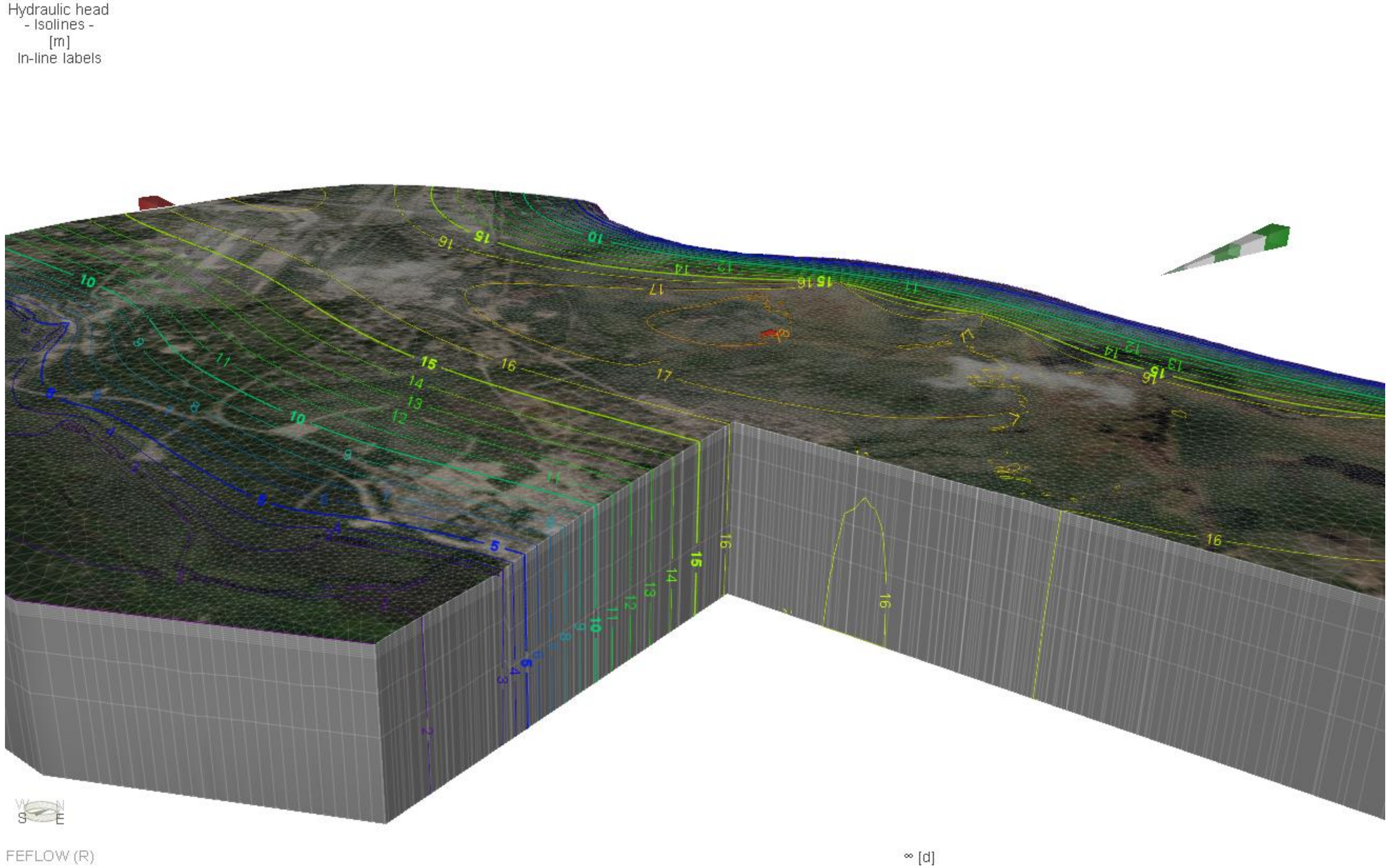
Figure 4

Approximate Depth to Water Table

Happy Valley-Goose Bay Desktop Water Table Study

Figure 5. 3D Groundwater System Test Bed

Happy Valley-Goose Bay Desktop Water Table Study



Legend

Depth to Water Table (m)

- <0
- >0
- Watercourse (provincial mapping)
- Water Body (provincial mapping)
- Wetland (provincial mapping)

Figure 6

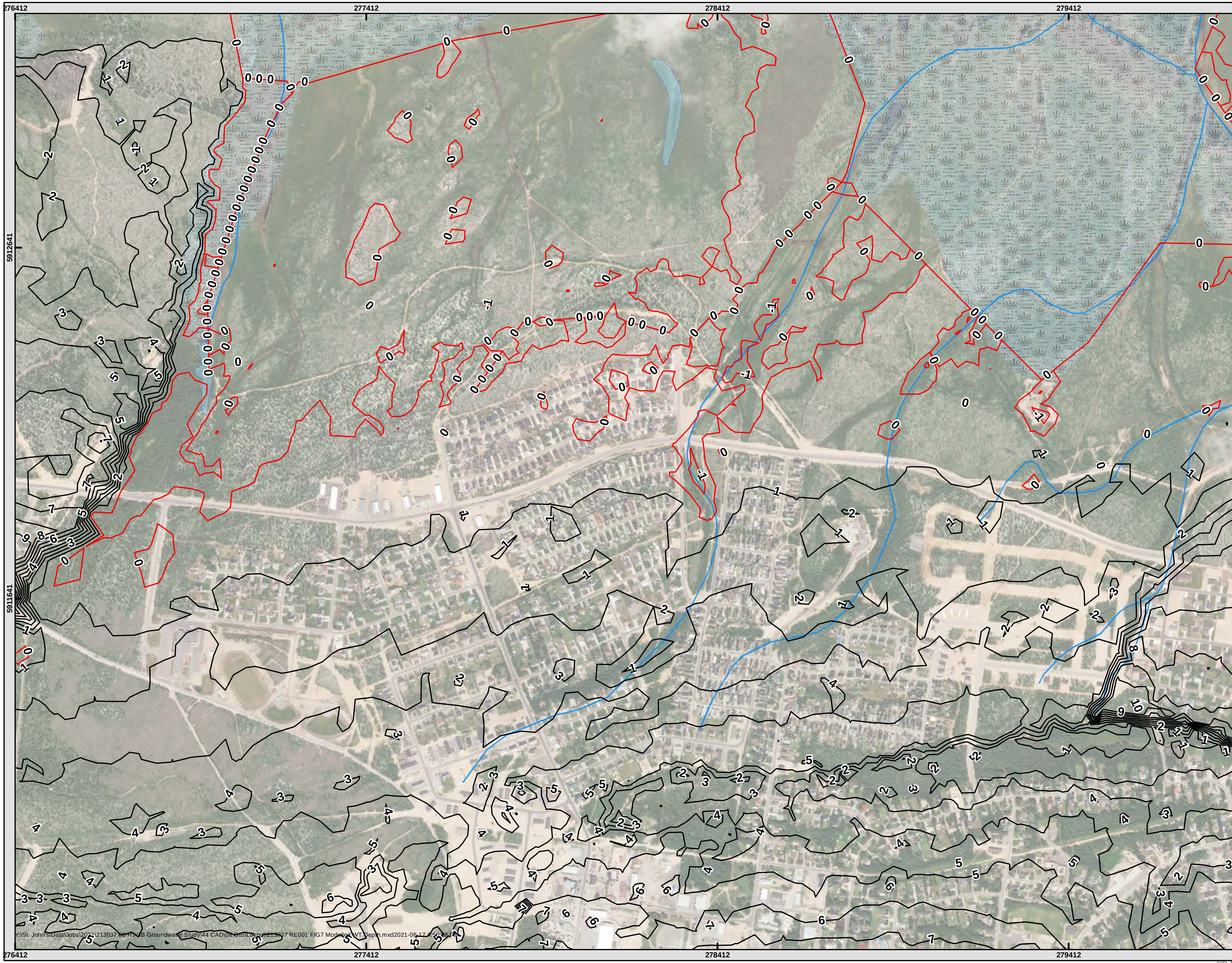
Modelled Depth to Water Table (average rainfall)

Happy Valley-Goose Bay Desktop Water Table Study

Coordinate System: NAD 1983 UTM Zone 21N
Projection: Transverse Mercator
Datum: North American 1983
Units: Meter

0 125 250 500 m

1:10,000 @ 11 x 17



Legend

Depth to Water Table (m)

- <0
- >0
- Watercourse (provincial mapping)
- Water Body (provincial mapping)
- Wetland (provincial mapping)

Figure 7

Modelled Depth to Water Table (increased rainfall)

Happy Valley-Goose Bay Desktop Water Table Study

Coordinate System: NAD 1983 UTM Zone 21N
Projection: Transverse Mercator
Datum: North American 1983
Units: Meter

0 125 250 500 m

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that determines whether crawl spaces and basements are flooded in the Pottle-Mitchel subdivision. As the sandy soils in the area exhibit a high permeability, groundwater is expected to drain readily into the voids created by crawl spaces and basements. The high permeability of this material is likely to limit the application of tile drains and sump pumps, as the pumping rates required to create a zone of dewatering around the subdivision are likely to be impractical. The low grade of the existing storm water system may likewise hinder efforts to discharge pumped water away from the subdivision.

Typical measures to manage basements below the water table include a combination of impermeable barriers, drainage pipe, and sump pumps. The results of this study suggest that an internal or external drainage system would be required for each building, and that continuous pumping would be required. Site-specific work would need to be completed to determine if this water could be discharged effectively without recirculation.

Yours very truly,

CBCL Limited

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Project Manager

Figure 1, Figure 2, Figure 3, Figure 4, Figure 5, Figure 6, Figure 7
Appendix A

Project No: 213037.00

APPENDIX A

Model Development

APPENDIX A – Model Development

The regional test bed was developed as follows:

- A model mesh of triangular elements was created and refined near surface water courses
- The mesh was extended into three-dimensional triangular prismatic elements
- The ground surface was assigned using cm-scale lidar data
- All surface water bodies were assigned as constant-head boundary conditions (Type 1, Dirichlet)
- Streams were assigned as groundwater discharge zones only, and wetlands were allowed to contribute water to or receive water from the model
- The recharge rate was estimated from a simple regional water balance (AECOM 2013)
- The model domain consisted of a single, uniform geologic unit consisting of glaciofluvial sand
- The model domain was subdivided into 11 layers to allow for resolution of vertical flow paths
- The water table was modelled as a free surface
- The model domain was 100 metres deep
- The model domain was assigned a uniform, isotropic hydraulic conductivity varying from 1 to 10 m/d
- Simulations using a hydraulic conductivity of 2 m/d and a recharge rate of 7×10^{-4} m/d provided an approximate match to Lidar mapping data and reports of the water table depth in the Pottle-Mitchel subdivision
- The recharge rate was varied from 5×10^{-4} to 13×10^{-4} m/d
- Resulting depths to the water table were evaluated.

Table A1. Precipitation Norms and Estimated Monthly Recharge

Month	Total Precipitation (mm)	Estimated Recharge (m/d x 10^{-4})
Jan	64.6	7.3
Feb	56.8	7.1
Mar	65.3	7.4
Apr	63.6	7.4
May	69.3	7.8
Jun	91.4	10.7
Jul	121.3	13.7
Aug	99.3	11.2
Sep	91	10.6
Oct	81.2	9.2
Nov	72.2	8.4
Dec	64.4	7.3

Monthly recharge estimates based on evapotranspiration rate of 443 mm/a and run-off coefficient of 0.35.

Table A2. Modelled Depth to Water Table with Varying Recharge Rates and K=2 m/d

Subdivision	Recharge Rate (mm/day)				
	0.5	0.7	0.9	1.1	1.3
Depth to Water Table (m)					
Pottle Cr	2.3	**1.2**	0.6	0.2	-0.2
Palliser Cr	3.8	2.9	2.2	1.4	0.9
Adams Loop	3.0	1.9	1.1	0.4	-0.1
Roberts Rd	4.6	3.5	2.6	1.8	1.1
Bird St	4.6	3.1	1.9	0.9	0.0