Assessment of Infill Site Suitability
City of Whitehorse, Yukon

PRESENTED TO
City of Whitehorse

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1.0 INTRODUCTION

Tetra Tech Canada Inc. (Tetra Tech) was retained by the City of Whitehorse, Planning and Building Services (CoW) to provide geotechnical and hydrogeological services in order to evaluate the residential development potential of infill areas within four existing City subdivisions (Mary Lake, Cowley Creek, Whitehorse Copper, and Hidden Valley). This work was authorized by Kinden Kosick, Project Manager at CoW on May 4, 2017.

1.1 Background and Purpose

The City of Whitehorse is evaluating the residential development potential of ten infill areas within four existing City subdivisions. The infill areas are located at:

- Mary Lake (three areas along Fireweed Drive)
- Cowley Creek (one area west of the intersection of Salmon Trail and Dolly Varden Drive)
- Whitehorse Copper (five areas on Moraine Drive and Talus Drive)
- Hidden Valley (one area south of Couch Rd, just off the Alaska Highway)

Figures 1a through 1d show the location of the ten potential infill areas.

The purpose of this project is to undertake a pre-feasibility level geotechnical and hydrogeological assessment of the ten potential infill areas to assess each areas development suitability and potential constraints prior to the areas being released for residential development. This work will also contribute to the future conceptual and residential development design stage planning.

1.2 Scope of Services

Tetra Tech’s scope of services included:

- Collating, compiling and reviewing relevant background information including: previously completed geotechnical and hydrogeological studies, water well records, geotechnical borehole logs, terrain maps, surficial and bedrock geology maps and topographical maps.
- Conducting a reconnaissance of each infill area to assess key site features including: topographical and terrain features; surface drainage patterns; surficial soil conditions and the presence of any bedrock outcrops; surface water bodies; possible groundwater discharge locations; potential for flooding.
- Preparing a report utilizing the available data summarizing relevant surficial and subsurface site conditions; discussion of relevant details that could affect development; and provision of recommendations for minimum lot sizes, construction of onsite sewage disposal systems and if required, additional hydrogeological and geotechnical work to further assess infill areas.

2.0 INFILL AREA SUITABLITY ASSESSMENTS

2.1 Mary Lake

2.1.1 Infill Area Locations

The Mary Lake assessment consists of three infill areas identified for the purpose of this assessment as ML1, ML2 and ML3. The size of each infill area is presented in Table 2-1 and infill area boundaries are presented on Figure 1a, appended to this report.

Table 2-1: Infill Area Sizes – Mary Lake

Infill Area	Approximate Size (ha)	Maximum Number of Lots (Assuming Minimum Lot Size of 1 ha (2.47 Acres))*
ML1	6.00	6
ML2	2.35	2
ML3	3.74	3

* Minimum lot size of 1 ha based on verbal correspondence for Kinden Kosick (CoW)

2.1.2 Geology

2.1.2.1 Surficial Geology

Surficial soils in the Mary Lake subdivision area can be described as a sequence of glacial and post glacial deposits between approximately 20 m and 60 m thick overlying bedrock.

A comprehensive investigation program and mapping of surficial soils was undertaken by Thompson (1984). This study indicated four major soil types within the Mary Lake subdivision area:

1. Glacial tills that underlie the entire subdivision area and are described as a mixture of silt, sand and gravel in a dense to very dense state. The upper unit tends to include a higher proportion of clay and silt while the lower portion include more sand, gravel and cobbles.
2. Overridden outwash described as dense to very dense sand, gravel and cobbles.
3. Reworked outwash described as loose to compact sand, gravel and cobbles.
4. Outwash described as loose to compact sand and/or sand and gravel.

Thompson (1984) indicates that ML1 and ML2 are underlain by around 10 m of reworked outwash, then around 40 m of glacial till that overlies bedrock. ML3 is shown to be underlain by approximately 20 m of glacial till overlying bedrock.

2.1.2.2 Bedrock Geology

The Whitehorse (105D) 1:250 000 Bedrock Geology Map (GSC 2008) indicates the Mary Lake subdivision area is underlain by igneous rocks of the Whitehorse Batholith.

Drilling by Golder Brawner and Assoc. in 1977 and Thompson in 1984 shows that bedrock is between approximately 20 m to 60 m below grade (bg) across the Mary Lake subdivision area and consists of two distinct rock types;

- Granite (inferred to be the Whitehorse Batholith) described by Thompson (1984) as moderately soft and varying from massive to highly fractured, with fracturing most prevalent near the upper surface and fracture prevalence decreasing with depth; and

- Diorite (inferred by Tetra Tech to be the Whitehorse Batholith) described by Thompson (1984) as typically massive and quite impermeable.

Detailed mapping by Thompson (1984) indicates:

- ML1 is underlain primarily by granite with a small section (<10%) at its northeast extent underlain by diorite;

- The northern half of ML2 is underlain by diorite and the southern half by granite; and

- ML3 is underlain by diorite.

Thompson (1984) indicates that bedrock is around 50 m bg at ML1 and ML2 and 20 m bg at ML3.

2.1.2.3 Permafrost

Review of 32 logs presented by Thompson (1984) indicates permafrost is unlikely to be present at ML1 or ML2 while there is some potential for permafrost to be encountered throughout the low lying areas of ML3.

It should be stated that discontinuous permafrost may be present in all areas where there are low permeability soils in poorly drained areas that have heavy moss ground cover and are sheltered from direct sunlight.

2.1.2.4 Terrain Features

Based on recent site reconnaissance and Tetra Tech Tech’s knowledge of the Mary Lake area, terrain features have been noted and are summarized below:

- ML1 and ML2 are located in the southwest corner of the Mary Lake Subdivision, immediately south of a Pipeline Right-Of-Way (ROW) that extents in an east-west direction across the subdivision area.

- The east edge of ML1 is a glacial outwash bench that drops fairly steeply to the central and rear portion of the proposed development area. Driveway construction would require cut and fill access road construction but this is not considered to be a concern as the material along the bench will be suitable for access road construction. Once below the bench, the area is flat.

- ML2 is located on the east side of Fireweed Drive in an area that David Nairne and Associates (1992) identified as a potential park. Aside from minor terrain features throughout this area (mounded in the central portion of the site), there are no steep slopes and no other terrain issues exist.

- ML3 is located on a fairly level bench with micro terrain features. The bench extends all the way back to the Pipeline ROW. West of the proposed area is a long, fairly steep slope that extends up to Columbine Place and along the east edge of the bench is a short but steep slope down to the developed area to the east. The frontage along Fireweed Drive is higher than the road, which may be problematic for driveway access.

2.1.2.5 Geotechnical Conditions

Based on information collected and reviewed for this evaluation, along with current site reconnaissance observations, geotechnical conditions throughout the three Mary Lake development areas will be:

- Throughout ML1, granular glacial outwash soils extend along the front of the site. Vegetation patterns change from pine (suggesting well drained soils) along the upper bench but once down on the flatter terrain throughout the central and rear portion of the site, silt till is expected. The presence of willows and spruce tree cover suggest that the area may not be well drained so near surface soil moisture may be fairly high.

- ML2 has very diverse ground and tree cover. However, vegetation in general indicates that the area is fairly well drained and it is anticipated that sand till over glacial outwash soils will be encountered.
- ML3 is underlain by sand and/or silt till soils. Large boulders can be expected within the till matrix. Since the ML3 area is located along the toe of the slope below Columbine Place, surface water from up-gradient development will likely result in increased moisture contents in the soils close to the toe of slope

2.1.3 Conceptual Level Hydrogeological Assessment

This hydrogeological overview of the infill areas is intended to create a conceptual model of the hydrogeological conditions in order to estimate depth to groundwater, provide an overview of the potential for residential water supply, and identify areas where shallow groundwater may be present, all of which are factors that may impact residential development within each of the Mary Lake infill areas.

2.1.3.1 Aquifers, Depth to Groundwater, Flow Systems

Tetra Tech infers there to be two primary aquifers underlying the Mary Lake subdivision, a local shallow overburden system that flows towards and discharges to Cowley Creek to the east, and a deeper regional igneous bedrock aquifer that flows in a northerly direction and discharges to the Yukon River. No perched aquifers have been identified within the Mary Lake subdivision. Based on groundwater elevation contours presented in Thompson (1984) Mary Lake, between 300 m and 600 m to the south of the three infill areas, appears to be a losing water body that likely recharges the overburden and bedrock aquifers.

Depth to groundwater is expected to be approximately 40 m bg at ML1 and ML2 and 15 m bg at ML3, with the water table located in the lower glacial till unit. The glacial till aquifer underlying all three infill areas is comprised of a high proportion of silt and based on literature values has an estimated hydraulic conductivity in the order of 1×10^{-5} m/day (Sterret 2007).

Six exploratory wells were drilled in the igneous bedrock aquifer across the Mary Lake subdivision area in 1977 and 1984 and pumping tests were conducted on five of these wells (Thompson 1984). Transmissivity values reported in Thompson (1984) indicate transmissivity of the bedrock ranges from 0.01 m^2/day for the diorite to more than 50 m^2/day for the highly fractured granite.

Tetra Tech reviewed well completion data from 14 residential wells within the Mary Lake subdivision available from the Groundwater Information Network. The 14 wells include data from three of the wells drilled during the 1977/1984 exploratory program. All 14 wells are believed to have been completed in the igneous bedrock aquifer. Table 2-2 presents a summary of drilling depth data and yield from the wells.

Table 2-2: Drilling Depth and Yield Data – Mary Lake Subdivision*

Parameter	Top of Bedrock (m bg)	Total Depth (m bg)	Distance Drilled in Bedrock (m)	Yield (L/sec)#
Geometric Mean	34	82	41	0.29
Maximum	57	165	139	1.6
Minimum	15	37	4	0.08

*Data from GIN 2017   # Yield estimate likely based on drillers estimate from short term airlifting, not pumping test.

Conservatively assuming six residents per lot and a daily usage of 250 L/day/person, the minimum well yield required to service a lot is approximately 0.02 L/s. This is ten times less than the geometric mean yield and four times less than the minimum yield of the 14 wells reviewed in the Mary Lake area. We note that the GIN does not provide information on “unsuccessful” wells (i.e., wells that were not completed due to not encountering suitable groundwater supply) and wells may have been drilled with yields below the anticipated daily lot demand.

2.1.3.2 Groundwater Quality

Nairne (1992) conducted a study of water quality at 18 lots with wells completed in the bedrock aquifer in the Mary Lake subdivision and summarized that water quality is often hard and has high concentrations of iron, manganese and calcium.

Based on Tetra Tech's experience in groundwater assessments in the Whitehorse region, we note that wells completed in the igneous rock of the Whitehorse Batholith can have uranium concentrations above the Guidelines for Canadian Drinking Water Quality (GCDWQ) maximum acceptable concentration (MAC). The source of the uranium is believed to be related to uranium concentrations in the host rock in the vicinity of the wells (EBA 2008). Wells completed within each of the three infill areas in the igneous rock aquifer could potentially produce water with uranium concentrations above the GCDWQ MAC.

We note that there are domestic water treatment options for uranium removal including point of entry reverse osmosis or anion exchange water treatment systems. The appropriate system selection and installation should be evaluated and completed by a qualified water treatment professional on a case-by-case basis.

2.1.3.3 Potential for Groundwater Contamination

As with any country residential development, within individual residential lots, groundwater could potentially be impacted by discharge from sewage disposal systems, spills from heating oil tanks, gas tanks and accidental or deliberate disposal of chemicals to ground.

There were no existing large scale potential sources of groundwater contamination located hydraulically up-gradient of the infill areas (e.g. landfill, gas station) identified.

2.1.3.4 Potential for Shallow Groundwater Concerns

For the purposes of this study, shallow groundwater is defined as areas where the groundwater table is within the zone of influence of typical foundation construction (0 to 2.5 m bg). Shallow groundwater may occur as perched aquifers in localized areas with shallow confining layers such as bedrock or fine grained impermeable layers, or as a shallow regional groundwater table.

Where possible, areas with shallow groundwater should be identified during the planning stages to minimize the risk of/or mitigate against groundwater ingress in below ground structures. Shallow aquifers that are not identified during conceptual design stage may become problematic after development if increased groundwater recharge and altered groundwater flow paths leads to changes in the water balance and groundwater levels move closer to ground surface.

Shallow groundwater must also be considered in the design and construction of onsite sewage disposal systems, as a minimum of 1.2 m of vertical separation between the bottom of an infiltration bed and the seasonally high groundwater table must be maintained (YHSS 2017).

Based on our data review and May 2017 field inspection, we do not consider there to be potential for shallow groundwater concerns at ML1, ML2 or ML3.

2.1.3.5 Groundwater Discharge Areas

Based on our data review and May 2017 field inspection, we do not interpret there to be any groundwater discharge areas within ML1, ML2 or ML3.

2.1.3.6 Potential Problem Areas

Based on our data review and May 2017 field inspection, there were no potential problem areas identified within infill areas ML1, ML2 or ML3.

2.1.4 Onsite Water Supply Feasibility

2.1.4.1 Groundwater Supply Evaluation

Overburden Aquifer

There is a low probability of a successful well being completed in the glacial till overburden aquifer that underlies ML1, ML2 and ML3 due to its likely low yield and the high proportion of silty sand, which would likely make well development and long term operation problematic.

Igneous Bedrock Aquifer (Granite) - ML1 and ML2 (southern half)

Mapping by Thompson (1984) indicates that a well targeting the igneous bedrock aquifer in infill area ML1 and the southern half of ML2 would likely encounter granite. We note that the Thompson's mapping has been based on limited data and actual contacts between these igneous units may differ to that shown.

Plutonic igneous rocks such as granite (and diorite) typically have very low permeability in the rock matrix, and the majority of groundwater occurring in these rock types is held in fractures associated with faults and open joints. Productivity of wells installed in bedrock will depend on whether a borehole intersects productive fractures within the rock mass. Based on the geological mapping and groundwater well records from 14 wells in the surrounding area (GIN 2017), successful residential water supply wells in the vicinity of the infill areas completed in the granite bedrock aquifer have a variable yield, ranging from 0.08 to 1.6 L/sec with a geometric mean of 0.29 L/sec (4.6 USgpm).

Drilling of wells in the granite of the igneous bedrock aquifer will likely be "hit or miss", and there is the potential to install dry wells as well as successful wells. The cost of well drilling may constrain residents' ability to drill additional wells should initial wells not provide adequate yield. Even if multiple wells are drilled on a lot, it may not guarantee that required yields are met.

Wells completed in granite have the potential for water quality concerns such as hard water, concentrations of iron and manganese above the GCDWQ aesthetic objective (AO) and uranium concentrations above the GCDWQ MAC and may require treatment.

Igneous Bedrock Aquifer (Diorite) - ML2 (northern half) and ML3

Mapping by Thompson (1984) indicates that a well targeting the bedrock aquifer in infill area ML3 and the northern half of ML2 would likely encounter diorite.

Plutonic igneous rocks such as granite and diorite typically have very low permeability in the rock matrix, and the majority of groundwater occurring in these rock types is held in fractures associated with faults and open joints. Productivity of wells installed in bedrock will depend on whether wells intersect productive fractures within the rock mass.

While there are around 18 residential dwellings within the Mary Lake area mapped as underlain by diorite, the GIN shows that only one of these residences has a groundwater well. There are no well completion or yield details available for this well. Based on the description of the diorite unit (massive, impermeable) and the very low transmissivity values presented in Thompson (1984), there is a strong possibility that a well drilled within ML3 and the northern half of ML2 will not be successful. Drilling of wells in the diorite aquifer will likely be "hit or miss" (to an even greater extent than the granite bedrock aquifer), and there is the potential to install multiple dry wells. The cost of well drilling may constrain residents' ability to drill additional wells should initial wells not provide adequate yield. Even if multiple wells are drilled on a lot, it may not guarantee that required yields are met.

Wells completed in diorite are expected to have the potential for water quality concerns such as hard water, concentrations of iron and manganese above the AO, and uranium concentrations above the GCDWQ MAC and may require treatment.

2.1.4.2 Considerations for Water Well Installation Costs

Costs to install water wells typically depend on a variety of factors including depth, type of installation, size of well, location and problems encountered during drilling. It is anticipated that the water wells will be drilled by a local contractor, access will be provided, the wells will be typically sized domestic supply wells (approximately 150 mm diameter) and installed according to typical domestic well design.

The largest factor in well installation costs is typically the total well depth. Bedrock wells are often deeper due to the need to encounter fractures to obtain sufficient flow for water supply. Water wells in the Mary Lake subdivision area are up to 165 m deep, and similar conditions and depths may be encountered within each of the three infill areas. Based on information provided by a local drilling contractor (Brian McDougal, Impact Well Drilling) wells in the Mary Lake area, on average, cost approximately $17,500 to $22,500.

If groundwater has uranium concentrations above the GCDWQ, water supply systems may require point of entry uranium removal using either anion exchange or reverse osmosis. The cost to install, operate and maintain this type of system is approximately $1,000 to $2,500 for a point of use system and $12,000 to $15,000 for a full household system, and should be considered in cost estimates.

2.1.5 Onsite Sewage Disposal Feasibility

Nitrate (N03) and pathogens (e.g., *E.coli*, faecal coliforms) and viruses sourced from onsite sewage disposal systems have been identified as potential contaminants of concern that could impact groundwater, particularly in areas where the water supply comes from private water supply wells. Impacts include adverse health effects (Hagerty, et. al.) and if discharged into surface water, excessive plant and algae growth can deplete oxygen levels that can affect aquatic life in general and have harmful impacts on the development of early life stages in aquatic organisms (CCME 2009).

The potential for impacts to groundwater quality from onsite sewage disposal will depend on lot size and connectivity between the shallow overburden aquifer (if present) and the deep bedrock aquifer where residential water wells will likely be constructed. Bedrock aquifer hydraulic conductivity is dependent on the presence of fractures, and connectivity can be highly variable depending on the fracture geometry and the thickness of the overburden and is therefore inherently unpredictable.

2.1.5.1 Locating of Sewage Disposal Systems and Wells

Sewage disposal systems must be located in compliance with the Yukon *Public Health and Safety Act* (1999) which require they are: 5 m from a lot boundary, road or driveway, 6 m from any building and 30 m from any source for potable water or high water level of any water body.

Onsite sewage disposal throughout the Mary Lake Subdivision has had challenges in the past due to the impervious nature of the dense silt till soils found at depth. However, successful installations in glacial outwash and sand till deposits are common throughout the subdivision and should be no different for the three proposed infill sites.

2.1.5.2 Lot Density and Impacts to Groundwater

If a groundwater well was to be completed on a lot in ML1, ML2 and ML3, it would be expected to be completed targeting the bedrock aquifer. Tetra Tech considers that under this scenario, given the vertical separation distance and the sequence of low permeability till that separates the water table aquifer from the bedrock aquifer there is low risk to the bedrock aquifer from wastewater discharged from onsite septic systems. In addition, based on the large lot sizes and low density of residential development in the area, the cumulative impact to groundwater from multiple sewage disposal systems is considered to be low.

However, as a precautionary measure, we would recommend that property owners have their well water tested on a regular basis (at minimum yearly) for impact from sewage disposal. Samples should be analyzed at minimum for nitrate, *E.coli* and Total Coliforms and results reviewed by a qualified, experienced professional.

2.1.5.3 Recommendation for Lot Sizes

It is understood that the proposed lot sizes for infill will remain consistent with current Mary Lake lot sizes. A minimum lot size of 1 hectare is considered appropriate.

2.1.6 Geotechnical Development Considerations

The three proposed infill areas in Mary Lake have good development potential. Foundation construction and onsite sewage disposal system construction are considered possible for each site. However, there are a few concerns to be considered, including:

- The lower elevation portion of ML1 is likely underlain by silt till soils, which may result in slower percolation rates and dictate the construction of a larger absorption field. Since this portion of the site is quite flat, along with the recommendation to install shallow absorption fields, onsite sewage disposal system installations may require a pump-up system. Driveway access onto Fireweed Drive is possible for ML1 but the driveways will then proceed down a fairly steep slope to access the central portions of the lots.
- ML2 has no development concerns and driveway access onto Fireweed Drive is possible.
- ML3 can be developed as infill with two individual driveways accessing onto Fireweed Drive. Driveway construction will have to include a significant slope cut to access at least one of the lots (the west half). Soils along the toe-of-slope below Columbine Place may be quite wet after freshet or periods of heavy rain. A cut-off trench may be required to direct surface water away from the lots.

2.1.7 Summary and Recommendations

2.1.7.1 Summary

Based upon information collected and reviewed as part of this pre-feasibility level evaluation, it has been determined that the three Mary Lake infill sites have good residential development potential with acceptable soils for foundation construction and onsite sewage disposal system construction. Developing residential water supply wells may be “hit or miss” prospect and if successful, potable water from a groundwater supply may require treatment.

2.1.7.2 Recommendations

- It is recommended that two testpits be excavated and percolation tests performed throughout the lower area in ML1 to ensure that the underlying silt till soils will support onsite sewage disposal.
- To reduce uncertainty in relation to the feasibility of groundwater supply, a test well(s) could be drilled on one or more of the proposed infill areas. Assuming the well(s) is successful, costs could be recovered with the sale of individual lots, similar to what was done in support of the development of Whitehorse Copper Subdivision.

2.2 Cowley Creek

2.2.1 Infill Area Description

The Cowley Creek assessment consists of one infill area identified for the purpose of this assessment as CC1.

CC1 is approximately 2.11 hectares in size and is located on the west side of the Salmon Trail, opposite from the intersection of Salmon Trail and Dolly Varden Drive (Figure 1b). Based on minimum lot sizes of 1 hectare, the maximum number of lots that can be placed in this infill area is two.

2.2.2 Geology

2.2.2.1 Surficial Geology

Surficial soils in the Cowley Creek subdivision area can generally be described as a sequence of glacial and post glacial deposits between 2 m and 60 m thick overlying bedrock.

Extension of surficial deposit mapping of the Mary Lake subdivision area completed by Thompson (1994) indicates that CC1 is likely underlain by outwash deposits (loose to compact sand and/or sand and gravel). Testpitting by EBA in 1994 supports this inference, showing that CC1 is underlain by at least 3 m of sand and gravels.

The depth of the outwash deposits and surficial soils in general beneath infill area CC1 is not known. Based on logs from two residential wells (Yukon water well database ID's 204100290 and 204100369) approximately 450 m to the west of CC1 and located in a similar geological setting, outwash deposits extend to a depth of approximately 15 m bg. Glacial till (silt and silt/clay) is logged underlying the outwash deposits at both wells. Well 204100369 shows the glacial till extends to 44 m bg and overlies bedrock. Well 204100290 transitions to a silty sand and gravel at 33 m bg, which may be representative of an overridden outwash deposit (described in Section 2.1.2.1). Drilling was halted 39 m bg at Well 204100290, prior to intercepting bedrock.

2.2.2.2 Bedrock Geology

The Whitehorse (105D) 1:250 000 Bedrock Geology Map (GSC 2008) indicates the Cowley Creek subdivision area is underlain by igneous rocks from the Whitehorse Batholith which intrudes the Triassic aged rocks of the Aksala formation.

Detailed bedrock mapping of the Mary Lake subdivision area was completed by Thompson (1994). Extension of this mapping indicates that CC1 is likely underlain by granite, described as moderately soft and varying from massive to highly fractured, with fracturing most prevalent near the upper surface and fracture prevalence decreasing with depth (Thompson 1994).

2.2.2.3 Permafrost

EBA (1994) reported that permafrost was not observed within 3 m of the ground surface in five testpits dug in the near vicinity of CC1 during a 1994 geotechnical investigation program. However, we note that discontinuous permafrost may be present where there are low permeability, poorly drained areas, sheltered from direct sunlight.

2.2.2.4 Terrain Features

The area as outlined is flat with a large, cleared central portion. The terrain is indicative of glaciofluvial topography with a kettle depression off the southwest corner of the site and the crest of a fairly steep slope defining the northern edge. The area is also elevated above the Salmon Trail.

2.2.2.5 Testpit Information

In 1994, two testpits were excavated at this location as part of the Cowley Phase II project. At the north end of the cleared portion, granular soils were noted to a termination depth of 3.0 m and in the base of the kettle depression to the southwest, 2.0 m of sand was noted over the underlying glaciofluvial gravels. At this location, a percolation test was performed in the sand at 1.1 m and the percolation rate was acceptable as a filter sand layer for onsite sewage disposal system construction.

2.2.3 Conceptual Level Hydrogeological Assessment

This hydrogeological overview of the CC1 infill area is intended to create a conceptual model of the hydrogeological conditions in order to estimate depth to groundwater, provide an overview of the potential for residential water supply, and identify areas where shallow groundwater may be present, all of which are factors that may impact residential development within the Cowley Creek infill area.

2.2.3.1 Aquifers, Depth to Groundwater, Flow Systems

Based on hydrogeological assessment work undertaken by Thompson (1984) for the Mary Lake subdivision, approximately 300 m to the west of CC1, there are inferred to be two primary aquifers underlying the area: a local shallow overburden system that flows towards and discharges to Cowley Creek to the east/northeast of CC1, and a deeper regional bedrock aquifer that flows in a northerly direction and discharges to the Yukon River.

Depth to groundwater is expected to be approximately 20 m to 25 m bg at CC1, with the water table located either in glacial till or overridden outwash deposits. The glacial till unit that underlies CC1 is comprised of a high proportion of silt and based on literature values has an estimated hydraulic conductivity in the order of 1×10^{-5} m/day (Sterrett 2007). The overridden outwash is comprised of sand, gravel and cobbles and may be significantly more permeable than the glacial deposits. Perched groundwater shallower than 3 m bg was not observed during EBA's 1994 test pitting program

Tetra Tech infers that CC1 is underlain by granitic bedrock. Three exploratory wells were drilled in the granitic bedrock across the Mary Lake subdivision area in 1977 and 1984 with pumping tests conducted on all three wells. Transmissivity values reported in Thompson (1984) indicate transmissivity of the granite bedrock aquifer ranges from 0.08 m^2/day to more than 50 m^2/day. Given the regional nature of the granite bedrock aquifer, we consider these transmissivity values are representative of the potential range that may be found in bedrock at CC1.

Table 2-3 presents a summary of available drilling data and yield from seven residential wells within an approximate 600 m radius of CC1. Based on well logs, six wells are believed to have been completed in the granite bedrock aquifer and one well in an overridden outwash overburden aquifer.

Table 2-3: Drilling Depth and Yield Data – 600 m Radius of CC1*

Parameter	Top of Bedrock (m bg)	Total Depth (m bg)	Distance Drilled in Bedrock (m)	Yield (L/sec)[#]
Granite Bedrock Aquifer Wells (6 wells)				
Mean	32	88	56	0.26
Maximum	44	165	136	0.61
Minimum	27	61	25	0.08
Overburden Aquifer (1 well)				
Total	-	39	-	0.46

*Data from GIN 2017 [#] Yield estimate likely based on drillers estimate from short term airlifting, not pumping test.

Conservatively assuming six residents per lot and a daily usage of 250 L/day/person, the minimum well yield required to service a lot is approximately 0.02 L/s. This values is:

- Thirteen times less than the mean yield and four times less than the minimum yield of the six wells in the Cowley Creek area completed in the granite bedrock aquifer reviewed for this study.
- Twenty three times less than the yield of the single well in the Cowley Creek area completed in the overburden aquifer reviewed for this study.

We note that the GIN does not provide information on "unsuccessful" wells (i.e. wells that were not completed due to not encountering suitable groundwater supply) and wells may have been drilled with yields below the anticipated daily lot demand.

2.2.3.2 Groundwater Quality

There is no groundwater quality information available from the overburden aquifer.

Nairne (1992) conducted a study of water quality at 18 lots with wells completed in the bedrock aquifer in the Mary Lake subdivision and summarized that water quality is often hard and is high in concentrations of iron, manganese and calcium. Given the regional nature of the granite bedrock aquifer, this summary of water quality is considered representative of what may be encounter in the bedrock aquifer underlying CC1.

Based on Tetra Tech's experience in groundwater assessments in the Whitehorse region, we note that wells completed in the igneous rock of the Whitehorse Batholith can have uranium concentrations above the GCDWQ MAC. The source of the uranium is believed to be related to uranium concentrations in the host rock in the vicinity of the wells (EBA 2008). Wells completed within CC1 in the igneous rock aquifer could potentially produce water with uranium concentrations above the GCDWQ MAC. Domestic water treatment options for uranium removal include a point of entry reverse osmosis or anion exchange water treatment system. The appropriate system selection and installation should be evaluated and completed by a qualified water treatment professional on a case-by-case basis.

2.2.3.3 Potential for Groundwater Contamination

As with any country residential development, within individual residential lots, groundwater could potentially be impacted by discharge from sewage disposal systems, spills from heating oil tanks, gas tanks and accidental or deliberate disposal of chemicals to ground.

There were no existing large scale potential sources of groundwater contamination located hydraulically up-gradient of the infill area identified.

2.2.3.4 Potential for Shallow Groundwater Concerns

Based on our data review and May 2017 field inspection, we do not interpret there to be potential for shallow groundwater concerns at CC1.

2.2.3.5 Groundwater Discharge Areas

Based on our data review and May 2017 field inspection, we do not interpret there to be any groundwater discharge areas within CC1.

2.2.3.6 Potential Problem Areas

Based on our data review and May 2017 field inspection, there were no potential problem areas identified within infill area CC1.

2.2.4 Onsite Water Supply Feasibility

2.2.4.1 Groundwater Supply Evaluation

Overburden Aquifer

If groundwater is present in glacial till beneath CC1, a water supply well would be unlikely to be completed successfully in this aquifer due its likely low yield and high proportion of silty sand.

If overridden outwash deposits are present beneath CC1, this unit has the potential to host a productive aquifer, with an overburden well potentially completed in overridden outwash deposits approximately 300 m northwest of CC1 having an estimated a yield of 0.46 L/sec (Table 2-3).

There is no information available on groundwater quality in the overburden aquifer.

Bedrock Aquifer

Extension of mapping by Thompson (1984) indicates that a well targeting bedrock in infill area CC1 would likely encounter granite. We note that the Thompson's mapping has been based on limited data and actual contacts between igneous units may differ to that shown.

Plutonic igneous rocks such as granite typically have very low permeability in the rock matrix, and the majority of groundwater occurring in these rock types is held in fractures associated with faults and open joints. Productivity of wells installed in bedrock will depend on whether wells intersect productive fractures within the rock mass. Based on the geological mapping and groundwater well records from the surrounding area (GIN 2017), the majority residential water supply wells in the vicinity of CC1 are completed in granite of the igneous bedrock aquifer (Table 2-3). Yields of successful wells in this aquifer in the vicinity of CC1 are variable ranging from 0.08 to 0.61 L/sec with a geometric mean of 0.26 L/sec (4.1 USgpm).

Drilling of wells in the granite of the igneous bedrock aquifer will likely be "hit or miss", and there is the potential to install dry wells as well as successful wells. The cost of well drilling may constrain residents' ability to drill additional wells should initial wells not provide adequate yield. Even if multiple wells are drilled on a lot, it may not guarantee that required yields are met.

Wells completed in the granite are expected to have the potential for water quality concerns such as hard water, concentrations of iron and manganese above the AO, and uranium concentrations above the GCDWQ MAC and may require treatment.

2.2.4.2 Considerations for Water Well Installation Costs

Costs to install water wells typically depend on a variety of factors including depth, type of installation, size of well, location and problems encountered during drilling. It is anticipated that the water wells will be drilled by a local contractor, access will be provided, the wells will be typically sized domestic supply wells (approximately 150 mm diameter) and installed according to typical domestic well design.

The largest factor in well installation costs is typically the total well depth. Bedrock wells are often deeper due to the need to encounter fractures to obtain sufficient flow for water supply. Water wells in the surrounding Mary Lake and Cowley Creek subdivision area are up to 165 m deep, and similar conditions and depths may be encountered within CC1. Based on information provided by a local drilling contractor (Brian McDougal, Impact Well Drilling) wells in the Cowley Creek area, on average, cost approximately $17,500 to $22,500.

If groundwater has uranium concentrations above the GCDWQ, water supply systems may require point of entry uranium removal using either anion exchange or reverse osmosis. The cost to install, operate and maintain this type of system is approximately $1,000 to $2,500 for a point of use system and $12,000 to $15,000 for a full household system, and should be considered in cost estimates.

2.2.5 Onsite Sewage Disposal Feasibility

2.2.5.1 Locating of Sewage Disposal Systems

Sewage disposal systems must be located in compliance with the Yukon *Public Health and Safety Act* (1999) which require they are: 5 m from a lot boundary, road or driveway, 6 m from any building and 30 m from any source for potable water or high water level of any water body.

Testpitting and percolation testing completed in 1994 confirm that the area is suitable for onsite sewage disposal system construction.

2.2.5.2 Lot Density and Impacts to Groundwater

If a groundwater well was to be completed on a lot in CC1, it could potentially be completed in either an overburden or bedrock aquifer. Inferred thick (10 m+) sequences of low permeability till from surface would likely protect an overburden aquifer from impact from onsite sewage disposal systems. Given the vertical separation and sequence of low permeability till that is inferred to extend from ground to the bedrock aquifer, there is likely to be little risk to the bedrock aquifer from wastewater discharged from onsite septic systems.

However, as a precautionary measure, we would recommend that property owners have their well water tested on a regular basis (at minimum yearly) for impact from sewage disposal. Samples should be analyzed at minimum for nitrate, *E.coli* and Total Coliforms and results reviewed by a qualified, experienced professional.

2.2.5.3 Recommendation for Lot Sizes

Consistent with most country residential development in Whitehorse, a 1 hectare minimum lot size is considered appropriate for this site.

2.2.6 Geotechnical Considerations

The Salmon Trail infill site has good development potential. Foundation construction on good quality granular soils, as well as onsite sewage disposal system construction in sands and gravels is ideal. It is the opinion of Tetra Tech that the development area could be expanded to the area south of the defined boundaries. This opinion is based on the 1994 testpit excavated in the kettle depression (which would be ideal for locating an onsite sewage disposal system and still leaving room for a driveway and residential structure on the flat area fronting onto Salmon Trail.

2.2.7 Summary and Recommendations

2.2.7.1 Summary

Based upon information collected and reviewed as part of this pre-feasibility level evaluation, it has been determined that this area is ideal for country residential infill and has potential to have an additional lot. Developing residential water supply wells may be a “hit or miss” prospect and if successful, potable water from a groundwater supply may require treatment.

2.2.7.2 Recommendations

- No additional geotechnical testing will be required to assess development potential at this site.
- To reduce uncertainty in relation to the feasibility of groundwater supply, a test well(s) could be drilled on the proposed infill area. Assuming the well(s) is successful, costs could be recovered with the sale of individual lots.

2.3 Whitehorse Copper

2.3.1 Infill Area Locations

The Whitehorse Copper assessment consists of five infill area identified for the purpose of this assessment as WC1, WC2, WC3, WC4 and WC5. The size of each infill area is presented in Table 2-4 and infill area locations are presented on Figure 1c, appended to this report.

Table 2-4: Infill Area Sizes – Whitehorse Copper

Infill Area	Approximate Size (ha)	Maximum Number of Lots (Assuming Minimum Lot Size of 1 ha (2.47 Acres))
WC1	4.32	4
WC2	14.53	14
WC3	3.29	3
WC4	5.39	5
WC5	2.03	2

2.3.2 Geology

2.3.2.1 Surficial Geology

Surficial geology mapping for the Whitehorse Copper area (Bond et al. 2005) shows that the main overburden unit is a veneer of glacial till that overlies bedrock.

Based on our May 2017 inspection and cross sections presented in EBA (2008), overburden thickness varies across the five infill areas:

- At WC1, overburden is likely to be in the range of 10 m to 15 m thick, and likely increases in thickness moving to the south.
- Bedrock outcrops were noted along the western edge of WC2 (along Moraine Drive) indicating bedrock is at or very close to surface in this area. Overburden thickness will potentially increase towards the southeastern corner of this infill area.
- At WC3, WC4 and WC5, overburden is likely to be in the order of 10 m to 20 m thick.

2.3.2.2 Bedrock Geology

Mapping by EBA (2008) indicates that:

- WC1 is underlain on the eastern third by Miles Canyon basalt and the western two thirds by igneous bedrock of the Whitehorse Batholith. The Miles Canyon basalt consists of several sequences of flows located between Mary Lake, MacRae, Miles Canyon and Whitehorse Rapids. The basalts are dominated by columnar-jointed, variably vesicular and amygdaloidal flows and scoria (Pearson et al. 2001).
- The majority of WC2 is mapped as underlain by Miles Canyon basalt, with a small (approximately 10%) section at the northern end underlain by igneous bedrock of the Whitehorse Batholith.
- WC3, WC4 and WC5 are mapped as being underlain by Miles Canyon basalt.

Bedrock outcrops have been noted along most of the western side and central portion of WC2 and is expected to be close to surface throughout much of this infill area, although we note that there is the potential that bedrock depth increases to in excess of 10 m bg in the south eastern section of this area. At WC1, WC3, WC4 and WC5, bedrock is expected to be in the order of 10 m to 20 m bg.

2.3.2.3 Permafrost

Permafrost may be encountered in areas where there are low permeability soils in poorly drained areas, sheltered from direct sunlight. WC4 and the south end of WC2 have the greatest potential for permafrost soils since thick moss ground cover and near surface groundwater flow was noted during WC4 site reconnaissance and thick moss ground cover and dwarf black spruce were noted throughout the south end of WC2.

2.3.2.4 Terrain Features

The five sites identified for infill around the Moraine Drive/Talus Drive loop are all quite flat. It should be noted that development to date throughout much of the Whitehorse Copper Subdivision has taken advantage of areas where elevated terrain features and preferable soil conditions exist (for instance, the lot cluster located directly north of WC1 and Crevasse Court off Talus Drive). The areas being considered for infill are fairly level and located in low lying portions of the subdivision. The only steep slopes encountered during site reconnaissance were noted along the east and west sides of WC4.

2.3.2.5 Testpit and Borehole Information

Three testpits were excavated along Talus Drive in 2002. Two of the testpits were excavated close to WC3 and the third was a pit exposure located slightly north of WC5. Granular soils were encountered at all three locations. No testpit data was available for the areas defined as WC1, WC2 and WC4, however current site reconnaissance suggest that either bedrock or till soils underlie these three proposed infill sites.

2.3.3 Conceptual Level Hydrogeological Assessment

This hydrogeological overview of the Whitehorse Copper area is intended to create a conceptual model of the hydrogeological conditions in order to estimate depth to groundwater, provide an overview of the potential for residential water supply, and identify areas where shallow groundwater may be present, all of which are factors that may impact residential development within each of the five infill areas.

2.3.3.1 Aquifers, Depth to Groundwater, Flow Systems

Tetra Tech undertook a comprehensive hydrogeological assessment of the Whitehorse Copper area in 2008 as part of the Whitehorse Copper Subdivision country residential water supply feasibility assessment. Based on this work, the following primary aquifers have been identified in the vicinity of the five infill areas:

- Where overburden is thick enough, a local shallow overburden system may be present. Extractable groundwater in the surficial deposits generally occurs within interbedded sands and gravels, which may exist intermittently throughout the Whitehorse Copper Subdivision footprint. The water supply potential of these surficial (overburden) deposits is variable, and dependent on the occurrence of sufficient thicknesses of permeable sands and gravels. EBA (2008) oversaw the drilling of one test well in a sand and gravel overburden aquifer in the area between WC1 and WC5. This well has a hydraulic conductivity of 1.1×10^{-5} m/sec and a safe sustainable yield of 0.8 L/sec (12 USgpm).

- A deeper regional basalt aquifer that flows in a northeasterly direction and discharges to the Yukon River. The columnar joints of the Miles Canyon basalt give rise to good vertical and secondary permeability and the connectivity of the joints provides considerable horizontal permeability (Pearson et al. 2001). These characteristics provide good domestic water supply potential, and relatively consistent aquifer performance parameters. Aquifers in the basalt are not highly productive, but with sufficient thickness are commonly adequate for single residence usage (Pearson et al. 2001).

- A deeper regional aquifer is present in the igneous rocks of the Whitehorse Batholith that flows in a northeasterly direction and discharges either to the adjacent basalt aquifer to the east or to the Yukon River. Two wells completed in this aquifer close to the infill areas have conductivities of around 4×10^{-7} m/sec and safe sustainable yields of 0.04 L/sec (0.6 USgpm) and 0.5 L/sec (7.7 USgpm).

Depth to groundwater is variable and inferred to be in the order of 10 m to 15 m bg at WC1, WC2, WC4 and WC5 and approximately 20 m bg at WC3. There is the potential for shallow perched aquifers within each of the five areas.

Table 2-5 presents a summary of drilling data and yield from 14 residential wells in the Whitehorse Copper Subdivision compiled by EBA (2008). Based on well logs, seven wells are believed to be completed in basalt, six wells in granite and one in overburden.

Table 2-5: Drilling Depth and Yield Data – Whitehorse Copper*

Parameter	Top of Bedrock (m bg)	Total Depth (m bg)	Distance Drilled in Rock (m)	Yield (L/sec)#
Basalt Aquifer Wells (7 wells)				
Mean	23.8	55.2	31.4	0.6
Maximum	49.7	61	45	1.22
Minimum	3.7	48.7	11.3	0.12
Igneous Bedrock Aquifer Wells (6 wells)				
Mean	13.2	58.1	44.9	0.2
Maximum	27.4	123.1	113.7	0.5
Minimum	1.2	25.6	11	0.03
Overburden Aquifer (1 well)				
Total	-	27.5	-	0.77

*Data from EBA 2008 # Yield estimate likely based on drillers estimate from short term airlifting, not pumping test.

Conservatively assuming six residents per lot and a daily usage of 250 L/day/person, the minimum well yield required to service a lot is approximately 0.02 L/s. This value is:

- Thirty times less than the mean yield and six times less than the minimum yield of the seven wells in the Whitehorse Copper area completed in the basalt aquifer reviewed for this study.
- Ten times less than the mean yield and 1.5 times less than the minimum yield of the six wells in the Whitehorse Copper area completed in the igneous bedrock aquifer reviewed for this study.
- Almost forty times less than the yield of the single well in the Whitehorse Copper area completed in the overburden aquifer reviewed for this study.

We note that the GIN does not provide information on “unsuccessful” wells (i.e., wells that were not completed due to not encountering suitable groundwater supply) and wells may have been drilled with yields below the anticipated daily lot demand.

2.3.3.2 Groundwater Quality

EBA (2008) reported that test wells drawing water from the Miles Canyon Basalt and from the overlying overburden deposits within the Whitehorse Copper Subdivision produce water meeting all GCDWQ health based parameters, with iron and/or manganese concentrations potentially exceeding the GCDWQ AO.

EBA (2008) reported that two wells completed in the igneous rock of the Whitehorse Batholith have uranium concentrations above the GCDWQ MAC. The source of the uranium is believed to be related to uranium concentrations in the host rock in the vicinity of the wells (EBA 2008). Wells completed within each of the five infill areas in the igneous rock aquifer could potentially produce water with uranium concentrations above the GCDWQ MAC. Domestic water treatment options for uranium removal include a point of entry reverse osmosis or anion exchange water treatment system. The appropriate system selection and installation should be evaluated and completed by a qualified water treatment professional on a case-by-case basis.

2.3.3.3 Potential for Groundwater Contamination

As with any country residential development, within individual residential lots, groundwater could potentially be impacted by discharge from sewage disposal systems, spills from heating oil tanks, gas tanks and accidental or deliberate disposal of chemicals to ground.

There were no existing large scale potential sources of groundwater contamination located hydraulically up-gradient of the infill areas (e.g. landfill, gas station) identified.

2.3.3.4 Potential for Shallow Groundwater Concerns

Based on current site reconnaissance, there is potential for shallow perched groundwater, particularly throughout WC2.

Shallow groundwater has been proven throughout most of the central portion of WC4. An additional reconnaissance trip was completed for WC4 because backslope instability was noted along Moraine Drive at the south end of the infill area and along the crest of the slope above the areas west side. This area should be monitored in the future because it appears that shallow groundwater flow in a southeast direction will be the cause of ongoing maintenance issues along Moraine Drive.

Centrally located in WC3 is a discontinuous drainage channel. Additional reconnaissance along the pipeline ROW at Esker Drive (west end of WC3) noted major flow through twin culverts at Esker Drive, across the pipeline ROW and onto WC3.

2.3.3.5 Groundwater Discharge Areas

Shallow groundwater is inferred to discharge in the close vicinity of one infill area, WC4. Discharge is considered to be occurring at the southern end of the area in a low lying poorly drained area where major frost heave damage to Moraine Drive was observed during the site reconnaissance. It is likely that frost heave and backslope instability related to shallow groundwater and groundwater discharge will be ongoing.

2.3.3.6 Potential Problem Areas

Based on our data review and May 2017 field inspection, there are potential problem areas identified within four of the five infill areas:

- WC1 appears conducive to infill development but the fact that it sits lower than Kettle Lake Place and the row of lots along the west side of Moraine Drive directly south of WC1 is a concern.
- Bedrock at or near surface throughout the north and central portions of WC2 will limit development potential. The south end of WC2 has dense dwarf black spruce tree cover and heavy moss ground cover. This is often indicative of underlying permafrost soils.
- Unless water flowing across the pipeline ROW and onto WC3 is redirected, development potential will be reduced.
- Near surface groundwater will severely limit the development potential in WC4.

2.3.4 Onsite Water Supply Feasibility

2.3.4.1 Groundwater Supply Evaluation

Overburden Aquifer

At least one well in the Whitehorse Copper Subdivision has been successfully completed targeting the overburden aquifer. This well was installed between WC1 and WC5 with the screen installed to a total depth of 27.1 m bg. Overburden aquifers are potentially present underlying WC1, WC3, WC4, WC5 and the southeastern section of WC2. A successful well would rely on encountering laterally extensive coarse outwash deposits (coarse sand, gravel, and cobble) with a lower proportion of silt and fine sand than the surrounding glacial till.

Igneous Bedrock Aquifer

The igneous bedrock aquifer is inferred to underlie the western two thirds of WC1 and the very northern section of WC2. EBA (2008) concluded that wells completed in the igneous bedrock aquifer have a lower potential than the basalt aquifer for encountering sufficient water quantity and quality. Although the well yields are lower than the yields of wells completed in the basalt, when successful, yields are still considered sufficient for domestic water supply to single family residences. Drilling of wells in the igneous bedrock aquifer will likely be “hit or miss”, and there is the potential to install dry wells as well as successful wells. The cost of well drilling may constrain residents’ ability to drill additional wells should initial wells not provide adequate yield. Even if multiple wells are drilled on a lot, it may not guarantee that required yields are met.

Without proper treatment, water quality for wells completed in the igneous rock aquifer may be unacceptable for human consumption due to uranium concentrations above the GCDWQ MAC. A point of use reverse osmosis system can be installed at the main consumption point which would enable homeowners to consume treated water, and use untreated water for other household needs.

Miles Canyon Basalt Aquifer

The Miles Canyon Basalt aquifer is inferred to underlie the eastern third of WC1, the majority of WC2 and all of WC3, WC4 and WC5. Groundwater occurring in the basalt aquifer is held in fractures associated with faults and open joints and productivity of wells installed in this aquifer will depend on whether they intersect productive fractures within the rock mass.

EBA (2008) concluded that the water supply potential of the Miles Canyon Basalt is considered to be good, as test wells completed within the basalt display adequate water quantity and acceptable water quality for domestic water supply. We note that drilling of wells in the Miles Canyon Basalt aquifer could also be “hit or miss”, and there is the potential to install dry wells as well as successful wells. The cost of well drilling may constrain residents’ ability to drill additional wells should initial wells not provide adequate yield. Even if multiple wells are drilled on a lot, it may not guarantee that required yields are met.

2.3.4.2 Considerations for Water Well Installation Costs

Costs to install water wells typically depend on a variety of factors including depth, type of installation, size of well, location and problems encountered during drilling. It is anticipated that the water wells will be drilled by a local contractor, access will be provided, the wells will be typically sized domestic supply wells (approximately 150 mm diameter) and installed according to typical domestic well design.

The largest factor in well installation costs is typically the total well depth. Bedrock wells are often deeper due to the need to encounter fractures to obtain sufficient flow for water supply. Water wells drilled in the Whitehorse Copper area as part of the 2008 study ranged from 20 m to 60 m deep and similar conditions and depths may be encountered within the five infill areas. Based on information provided by a local drilling contractor (Brian McDougal, Impact Well Drilling) wells in the Whitehorse Copper area, on average, cost approximately $17,500 to $22,500.

If groundwater has uranium concentrations above the GCDWQ, water supply systems may require point of entry uranium removal using either anion exchange or reverse osmosis. The cost to install, operate and maintain this type of system is approximately $1,000 to $2,500 for a point of use system and $12,000 to $15,000 for a full household system, and should be considered in cost estimates.

2.3.5 Onsite Sewage Disposal Feasibility

2.3.5.1 Locating of Sewage Disposal Systems

Sewage disposal systems must be located in compliance with the Yukon Public Health and Safety Act (1999) which require they are: 5 m from a lot boundary, road or driveway, 6 m from any building and 30 m from any source for potable water or high water level of any waterbody.

It is also best practice to locate sewage disposal systems down or cross-hydraulic gradient of existing or potential locations of groundwater supply wells to minimize the potential for impact.

Shallow or surface bedrock minimizes potential for onsite sewage disposal system construction throughout much of WC2 and shallow groundwater (expected to be very close at surface) minimizes potential throughout WC4.

2.3.5.2 Lot Density and Impacts to Groundwater

A groundwater well completed on a lot in any one of WC1, WC3, WC4 or WC5 could potentially be completed in either an overburden or bedrock aquifer. A well completed within the majority of WC2 is expected to be completed in a bedrock aquifer, other than in the southeast section of the area where the potential to install an overburden well exists. Assuming the required setback distance from a well is met and the well is located up-gradient of the sewage disposal system, the risk to groundwater users is considered to be low. In addition, based on the large lot sizes and low density of residential development in the area, the cumulative impact to groundwater from multiple sewage disposal systems is considered to be low.

However, as a precautionary measure, we would recommend that property owners have their well water tested on a regular basis (at minimum yearly) for impact from sewage disposal. Samples should be analyzed at minimum for nitrate, *E.coli* and Total Coliforms and results reviewed by a qualified, experienced professional.

2.3.5.3 Recommendation for Lot Sizes

Consistent with most country residential development in Whitehorse, a 1 hectare minimum lot size is considered appropriate for the developable area in this subdivision.

2.3.6 Geotechnical Considerations

WC1, WC3 and WC5 have fair to good potential for country residential development. However, additional geotechnical data will be required to assess potential for site access, foundation construction and onsite sewage disposal system construction in these areas.

It is the opinion of Tetra Tech that the geotechnical conditions throughout WC2 and WC4 are very problematic and do not support country residential infill development.

2.3.7 Summary and Recommendations

2.3.7.1 Summary

Based upon information collected and reviewed as part of this pre-feasibility level evaluation, it has been determined that WC1, WC3 and WC5 are likely acceptable for residential infill development; however, additional work (as detailed in the recommendations below) should be undertaken to address geotechnical data gaps during subsequent phases of the planning process. Developing residential water supply wells may be “hit or miss” prospect and if successful, potable water from a groundwater supply may require treatment.

2.3.7.2 Recommendations

- It is recommended that two testpits be advanced and two percolation tests be completed in each of WC1, WC2 and WC5 to identify potential geotechnical issues (presence of fine grained, impervious or saturated soils) and determine the actual potential for country residential development.
- To reduce uncertainty in relation to the feasibility of groundwater supply, a test well(s) could be drilled on one or more of the proposed infill areas. Assuming the well(s) is successful, costs could be recovered with the sale of individual lots.

2.4 Hidden Valley

2.4.1 Infill Area Locations

The Hidden Valley assessment consists of one infill area identified for the purpose of this assessment as HV1.

HV1 is approximately 5.11 hectares in size and is located on the south side of Couch Road, just off the Klondike Highway (Figure 1d). Based on minimum lot sizes of 1 hectare, the maximum number of lots that can be placed in this infill area is five.

2.4.2 Geology

2.4.2.1 Surficial Geology

The Whitehorse (105D) 1:250 000 Bedrock Geology mapsheet shows surficial deposits underlying HV1 are unconsolidated silt, sand and gravel of glacial, fluvial, aeolian and lacustrine origins; minor volcanic ash. Lithological descriptions from wells with logs within the Hidden Valley and MacPherson areas (obtained from the GIN) support the mapped description.

2.4.2.2 Bedrock Geology

Review of the Whitehorse (105D) 1:250 000 Bedrock Geology mapsheet indicates HV1 is likely underlain by the Upper Triassic aged (approx. 230 Mya) Mandanna Member described as red, purple, green and grey, medium bedded to massive, arkosic greywacke, mudstone and shale; finely laminated, thick bedded arkosic sandstone; minor interbedded conglomerate and red bioturbated siltstone.

Four water wells in the general vicinity of HV1 have been drilled to bedrock however none of the well logs provided a sufficient description of the bedrock to allow confirmation of the mapping.

2.4.2.3 Permafrost

Permafrost is considered unlikely to be present within HV1, however there is the potential for discontinuous permafrost to be present where there are low permeability, poorly drained areas, sheltered from direct sunlight.

2.4.2.4 Terrain Features

The Hidden Valley site is very flat, therefore, there are no terrain issues.

2.4.2.5 Testpit and Borehole Information

No test hole data was found in Tetra Tech files for the area close to the subject site. However, in Tetra Tech's experience a sandy silt veneer overlying glaciolacustrine silt that extends to an undetermined depth can be present in some locations.

2.4.3 Conceptual Level Hydrogeological Assessment

This hydrogeological overview of the Hidden Valley area is intended to create a conceptual model of the hydrogeological conditions in order to estimate depth to groundwater, provide an overview of the potential for residential water supply, and identify areas where shallow groundwater may be present, all of which are factors that may impact residential development within the infill area.

2.4.3.1 Aquifers, Depth to Groundwater, Flow Systems

The GIN shows there are at least 49 wells completed within 1 km of HV1. Of these 49 wells, drilling logs and yields were available from eight wells. Table 2-6 presents a summary of the data provided.

Table 2-6: Drilling Depth and Yield Data – 1 km Radius of HV1*

Parameter	Top of Bedrock (m bg)	Total Depth (m bg)	Distance Drilled in Bedrock (m)	Yield (L/sec)$^{\#}$
Overburden Aquifer (6 wells)				
Mean	-	74	-	1.0
Maximum	-	123	-	1.5
Minimum	-	23	-	0.5
Bedrock Aquifer (2 wells)				
2 wells	94.6 and 60.4	95.4 and 60.4	0.8 and 0.0	Not reported

*Data from GIN 2017 $^{\#}$ Yield estimate likely based on drillers estimate from short term airlifting, not pumping test.

EBA (2007) also conducted a review of well depths and yields in the Hidden Valley and MacPherson areas. Based on data from that study, wells ranged in depth from 23 m to 145 m bg with an average depth of 70 m and an estimated average yield of 0.95 L/s (15 USgpm).

Conservatively assuming six residents per lot and a daily usage of 250 L/day/person, the minimum well yield required to service a lot is approximately 0.02 L/s. Based on the GIN data, this is fifty times less than the mean yield and twenty five times less than the minimum yield of the 14 wells reviewed in the Mary Lake area. We note that the GIN does not provide information on “unsuccessful” wells (i.e. wells that were not completed due to not encountering suitable groundwater supply) and wells may have been drilled with yields below the anticipated daily lot demand.

Based on a review of data provided in EBA (2007) and the GIN, wells in the Hidden Valley and MacPherson subdivisions within 1 km of HV1 appear to target a number of different sand and gravel overburden aquifers that range in depth from approximately 23 m bg to 123 m bg. Aquifers targeted by these wells are likely part of a larger intermediate to regional overburden aquifer system, consisting of fine grained low permeability silts and fine sands interbedded with coarser grained deposits (medium sand to gravel). Coarse grained deposits forming aquifers are likely to be of limited extent and thickness (as evidenced by the various well completion depths (Table 2-6)).

A sedimentary bedrock aquifer is inferred to underlie the overburden aquifer. Sedimentary bedrock aquifers can display a wide range of permeability, dependent upon the degree of primary and secondary porosity present in the rock mass. Two wells in the MacPherson subdivision are completed in the bedrock aquifer, to total depths of 93 m and 73 m bg respectively. A yield of 15 USgpm was estimated for one of these wells, while a yield was not provided for the other (EBA 2007).

EBA (2007) reported that static groundwater elevations were approximately 10 m to 20 m bg in the Hidden Valley area and 40 m to 45 m bg in the MacPherson area. Groundwater flow in both the overburden and bedrock underlying HV1 is expected to be in a generally north/northeasterly direction towards the Yukon River, a major regional groundwater discharge feature.

2.4.3.2 Groundwater Quality

EBA collected samples from two overburden wells in the Hidden Valley area as part of their 2007 hydrogeological assessment. These samples are likely to be generally representative of the overburden aquifer underlying HV1. Samples were analyzed for general water quality parameters and total metals.

Analytical results indicate the water from both wells is moderately hard to hard calcium-bicarbonate type with pH values of 8.2 and 8.3 units. No parameters exceeded their applicable GCDWQ MAC concentration. Turbidity and iron at one well exceeded the GCDWQ AO.

2.4.3.3 Potential for Groundwater Contamination

As with any country residential development, within individual residential lots, groundwater could potentially be impacted by discharge from sewage disposal systems, spills from heating oil tanks, gas tanks and accidental or deliberate disposal of chemicals to ground.

There were no existing large scale potential sources of groundwater contamination located hydraulically up-gradient of the infill area (e.g., landfill, gas station) identified.

2.4.3.4 Potential for Shallow Groundwater Concerns

Based on our data review and May 2017 field inspection, we do not interpret there to be potential for shallow groundwater concerns at HV1.

2.4.3.5 Groundwater Discharge Areas

Based on our data review, we do not interpret there to be any groundwater discharge areas within HV1.

2.4.3.6 Potential Problem Areas

Based on our data review and May 2017 field inspection, there were no potential problem areas identified within the HV1 infill development area.

2.4.4 Onsite Water Supply Feasibility

2.4.4.1 Groundwater Supply Evaluation

Based on the number of existing wells within the Hidden Valley subdivision (at least 49) and the average yield of wells reported by EBA (2007) (0.95 L/s (15 USgpm)), we consider there is a relatively high likelihood that a well could be completed successfully in the overburden aquifer underlying HV1. We note that a wells success will be dependent upon intercepting suitable coarse grained materials and of suitable lateral extent to provide a long term yield. The targeting of the bedrock aquifer by two wells in MacPherson potentially indicates that intersecting a productive overburden aquifer is not guaranteed.

Information from one of the two wells completed in the bedrock aquifer in MacPherson suggests that there is the potential for productive wells to be completed in this aquifer. We note however that while sedimentary rock aquifers have the potential to be highly permeable and provide large quantities of water, they also have the potential to have a very low yield, insufficient even for domestic water supply.

2.4.4.2 Considerations for Water Well Installation Costs

Costs to install water wells typically depend on a variety of factors including depth, type of installation, size of well, location and problems encountered during drilling. It is anticipated that the water wells will be drilled by a local contractor, access will be provided, the wells will be typically sized domestic supply wells (approximately 150 mm diameter) and installed according to typical domestic well design. The largest factor in well installation costs is typically the total well depth. Bedrock wells are often deeper due to the need to encounter fractures to obtain sufficient flow for water supply. Wells in the surrounding Hidden Valley and MacPherson subdivisions are on average around 70 m deep, with a maximum depth of 145 m, and similar conditions and depths may be encountered within HV1. Based on information provided by a local drilling contractor (Brian McDougal, Impact Well Drilling) wells in the Hidden Valley area, on average, cost approximately $22,500 to $27,500.

2.4.5 Onsite Sewage Disposal Feasibility

2.4.5.1 Locating of Sewage Disposal Systems

Sewage disposal systems must be located in compliance with the Yukon *Public Health and Safety Act* (1999) which require they are: 5 m from a lot boundary, road or driveway, 6 m from any building and 30 m from any source for potable water or high water level of any water body.

It is also best practice to locate sewage disposal systems down or cross-hydraulic hydraulic gradient of existing or potential locations of groundwater supply wells to minimize the potential for impact.

2.4.5.2 Lot Density and Impacts to Groundwater

A groundwater well completed on a lot in HV1 could potentially be completed in either an overburden or bedrock aquifer. Given the vertical separation and sequence of low permeability till that is inferred to extend from ground to targeted overburden and bedrock aquifers, there is likely to be little impact to groundwater from sewage disposal systems. The relatively large size of the blocks (2.47 acres) also means that there is likely to be significant horizontal separation between wells and sewage disposal systems, further decreasing the potential impact to water supply wells.

However, as a precautionary measure, we would recommend that property owners have their well water tested on a regular basis (at minimum yearly) for impact from sewage disposal. Samples should be analyzed at minimum for nitrate, *E.coli* and Total Coliforms and results reviewed by a qualified, experienced professional.

2.4.5.3 Recommendation for Lot Sizes

A minimum lot size of 1 hectare is considered appropriate.

2.4.6 Geotechnical Considerations

The presence of fine grained soils throughout this site is the biggest geotechnical concern as it will effect septic system absorption field sizing, perimeter insulation requirements around all foundation elements to minimize potential for seasonal frost heave and driveway construction on weaker subgrade soils.

2.4.7 Summary and Recommendations

2.4.7.1 Summary

Based upon information collected and reviewed as part of this pre-feasibility level evaluation, it has been determined that the Hidden Valley site is considered acceptable for country residential infill development; however, additional work (as detailed in the recommendations below) should be undertaken to address geotechnical data gaps during subsequent phases of the planning process. While we consider there to be a relatively high probability of encountering an aquifer suitable to provide a domestic water supply, we note that the potential exists for an unsuccessful well.

2.4.7.2 Recommendations

- This site is fairly large, therefore it is recommended that three testpits be excavated to assess frost susceptibility and in each of the three testpits, a percolation test should be completed to support absorption field sizing.

- To reduce uncertainty in relation to the feasibility of groundwater supply, a test well(s) could be drilled on one or more of the proposed infill areas. Assuming the well(s) is successful, costs could be recovered with the sale of individual lots.

3.0 CLOSURE

We trust this report meets your present requirements. If you have any questions or comments, please contact the undersigned.

Respectfully submitted,
Tetra Tech Canada Inc.

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FIGURES

Q:\Whitehorse\Data\0201drawings\Whitehorse\ENW-WENW\ENWWENW03041-01 Infill Area Suitability Assessment\ENW.WENW03041-01 Fig.1-R0.dwg [FIGURE 1A] May 10, 2017 - 1:54:36 pm (BY: BUCHAN, CAMERON)

LEGEND

— - EXTENT OF INFILL AREAS

0 250m

Scale: 1:7,500 @ 8.5"x11"

CLIENT

City of Whitehorse

TETRA TECH

INFILL AREA SUITABILITY ASSESSMENT
WHITEHORSE, YUKON

MARY LAKE INFILL AREAS

PROJECT NO.	DWN	CKD	REV	
ENW.WENW03041-01	CB	AS	0	Figure 1a
OFFICE	DATE			
EBA-WHSE	May 8, 2017			

LEGEND

- EXTENT OF INFILL AREA

0 250m

Scale: 1:5,000 @ 8.5"x11"

CLIENT

City of Whitehorse

TETRA TECH

INFILL AREA SUITABILITY ASSESSMENT WHITEHORSE, YUKON

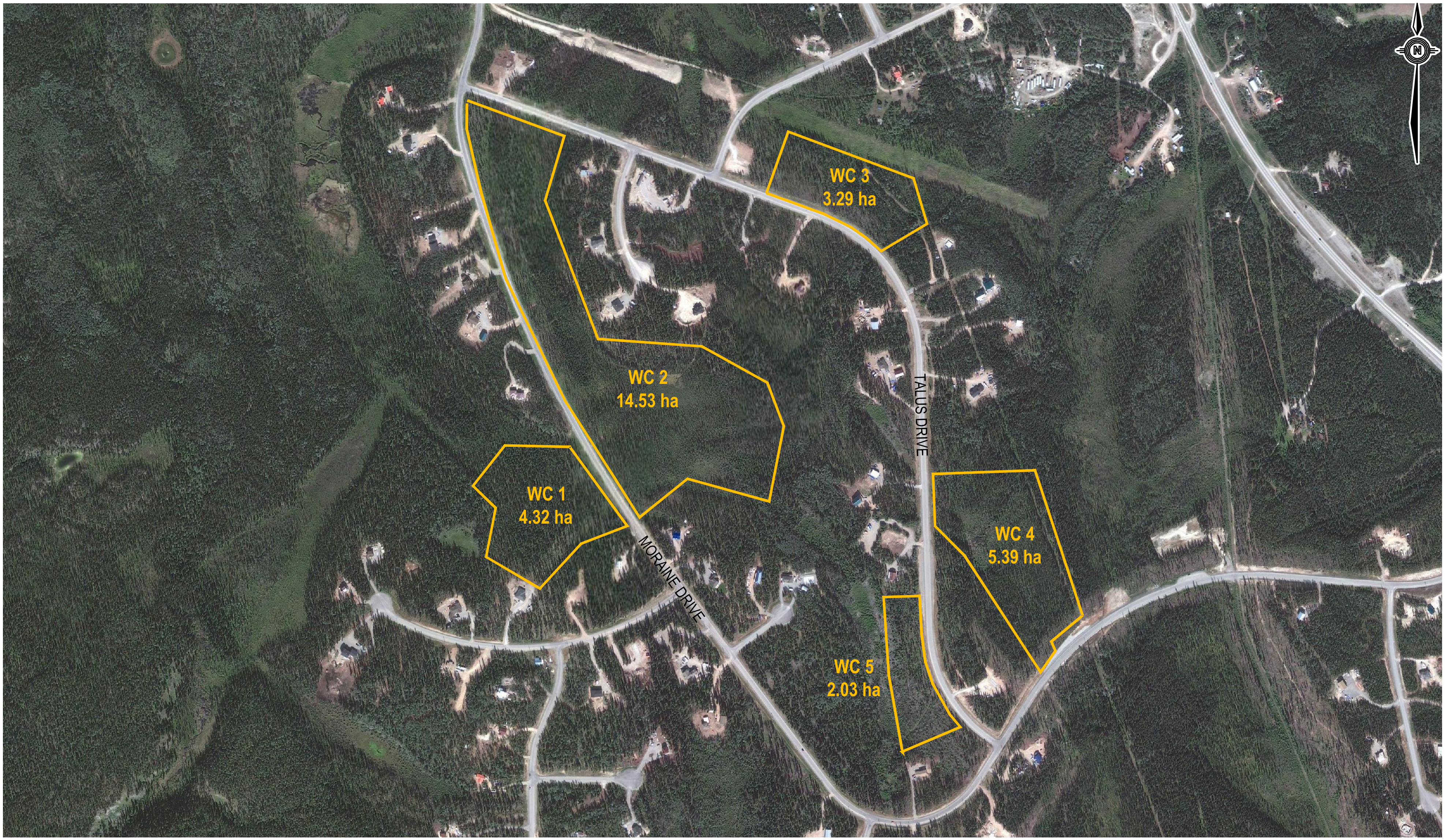
COWLEY CREEK INFILL AREA

PROJECT NO.	DWN	CKD	REV
ENW.WENW03041-01	CB	AS	0

OFFICE	DATE
EBA-WHSE	May 8, 2017

Figure 1b

Q:\Whitehorse\Data\0201drawings\Whitehorse\ENW-WENW\ENWWENW03041-01 Infill Area Suitability Assessment\ENW.WENW03041-01 Fig.1-R0.dwg [FIGURE 1C] May 10, 2017 - 1:55:13 pm (BY: BUCHAN, CAMERON)



LEGEND

▬ - EXTENT OF INFILL AREAS

0 500m

Scale: 1:10,000 @ 8.5"x11"

CLIENT

City of Whitehorse

TETRA TECH

INFILL AREA SUITABILITY ASSESSMENT
WHITEHORSE, YUKON

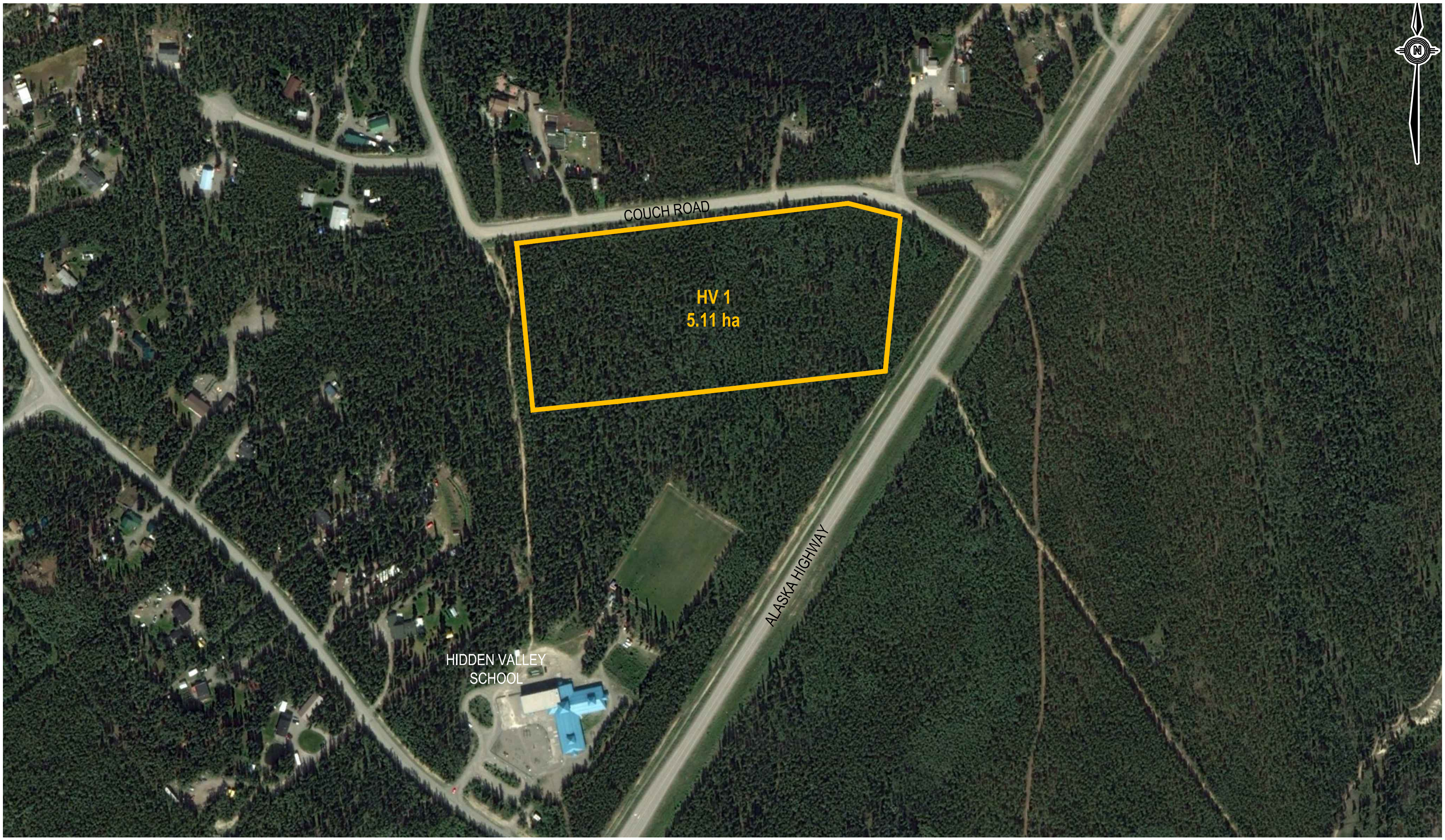
WHITEHORSE COPPER INFILL AREAS

PROJECT NO.	DWN	CKD	REV
ENW.WENW03041-01	CB	AS	0

OFFICE	DATE
EBA-WHSE	May 8, 2017

Figure 1c

Q:\Whitehorse\Data\0201drawings\Whitehorse\ENW-WENW\ENWWENW03041-01 Infill Area Suitability Assessment\ENW.WENW03041-01 Fig.1-R0.dwg [FIGURE 1D] May 10, 2017 - 1:55:30 pm (BY: BUCHAN, CAMERON)



LEGEND

🟨 - EXTENT OF INFILL AREA

0 250m

Scale: 1:5,000 @ 8.5"x11"

CLIENT

City of Whitehorse

TETRA TECH

INFILL AREA SUITABILITY ASSESSMENT
WHITEHORSE, YUKON

HIDDEN VALLEY INFILL AREA

PROJECT NO.	DWN	CKD	REV
ENW.WENW03041-01	CB	AS	0

OFFICE	DATE
EBA-WHSE	May 8, 2017

Figure 1d

APPENDIX A

TETRA TECH'S GENERAL CONDITIONS

GENERAL CONDITIONS

GEOENVIRONMENTAL REPORT

This report incorporates and is subject to these "General Conditions".

1.1 USE OF REPORT AND OWNERSHIP

This report pertains to a specific site, a specific development, and a specific scope of work. It is not applicable to any other sites, nor should it be relied upon for types of development other than those to which it refers. Any variation from the site or proposed development would necessitate a supplementary investigation and assessment.

This report and the assessments and recommendations contained in it are intended for the sole use of TETRA TECH's client. TETRA TECH does not accept any responsibility for the accuracy of any of the data, the analysis or the recommendations contained or referenced in the report when the report is used or relied upon by any party other than TETRA TECH's Client unless otherwise authorized in writing by TETRA TECH. Any unauthorized use of the report is at the sole risk of the user.

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Where TETRA TECH submits both electronic file and hard copy versions of reports, drawings and other project-related documents and deliverables (collectively termed TETRA TECH's instruments of professional service); only the signed and/or sealed versions shall be considered final and legally binding. The original signed and/or sealed version archived by TETRA TECH shall be deemed to be the original for the Project.

Both electronic file and hard copy versions of TETRA TECH's instruments of professional service shall not, under any circumstances, no matter who owns or uses them, be altered by any party except TETRA TECH. The Client warrants that TETRA TECH's instruments of professional service will be used only and exactly as submitted by TETRA TECH.

Electronic files submitted by TETRA TECH have been prepared and submitted using specific software and hardware systems. TETRA TECH makes no representation about the compatibility of these files with the Client's current or future software and hardware systems.

1.1 NOTIFICATION OF AUTHORITIES

In certain instances, the discovery of hazardous substances or conditions and materials may require that regulatory agencies and other persons be informed and the client agrees that notification to such bodies or persons as required may be done by TETRA TECH in its reasonably exercised discretion.

1.2 INFORMATION PROVIDED TO TETRA TECH BY OTHERS

During the performance of the work and the preparation of the report, TETRA TECH may rely on information provided by persons other than the Client. While TETRA TECH endeavours to verify the accuracy of such information when instructed to do so by the Client, TETRA TECH accepts no responsibility for the accuracy or the reliability of such information which may affect the report.