TETRA TECH

City of Dawson Aquifer and Wellhead Protection Plan

PRESENTED TO

Government of Yukon, Community Services

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LIMITATIONS OF REPORT

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1.0 INTRODUCTION

Tetra Tech Canada Inc. (Tetra Tech) was retained by the Government of Yukon, Community Services Infrastructure Development Branch (YG-IDB) to prepare an Aquifer and Wellhead Protection Plan (AWHPP) for the City of Dawson (CoD) community water system. This work was authorized by Rick Kent, Senior Program Manager at YG-IDB, under Contract No. C00036879 signed on February 2, 2017.

The objective of this AWHPP is to provide practical protective measures to identify and manage activities and potential risks within the inferred capture zones and recharge areas of the CoD potable water supply wells. This AWHPP will be important to protect and reduce risks: to the health and safety of the community; to the valuable groundwater resource; and to CoD's and YG-IDB's investment in water supply infrastructure. An AWHPP should be a living document and updated regularly based on activities near the community supply wells that might result in additional risks, or when risks have been addressed and mitigated.

This AWHPP was prepared in two phases: a preliminary plan was provided for review and comment following stakeholder meetings and field reconnaissance in February 2017; then, following comment on the preliminary plan and a second field reconnaissance event in summer 2017, this final AWHPP was prepared.

In conjunction with the development of this AWHPP, Tetra Tech has developed a Source Water Emergency Response Plan (SW-ERP) under separate cover. The SW-ERP built on existing emergency response planning and has been incorporated into the findings and risk reduction measures identified in this AWHPP. Correspondingly, where applicable, findings and risk reduction measures detailed in this AWHPP have been reflected in the SW-ERP.

2.0 SCOPE OF SERVICES

Tetra Tech's scope of services for the project included the following tasks:

- Background information review to develop a conceptual hydrogeological model and identify potential risks to the groundwater resource;
- Site visit in winter 2017 to interview CoD Public Works staff, conduct a field review of wellhead completion and water system infrastructure, ground reconnaissance to identify potential sources of groundwater contamination, and groundwater level monitoring at accessible wells;
- Conduct a stakeholder meeting to communicate the goals of the project and gather information or pertinent data that may be available;
- Preparation of a preliminary AWHPP for review and comment by CoD, YG-IDB and Yukon Government Environmental Health Services (EHS) representatives;
- Complete a second site visit in summer 2017 to assess potential sources of groundwater contamination without snow cover and follow up on data gaps identified during the preparation of the preliminary AWHPP;
- Following review of the preliminary AWHPP by CoD, YG-IDB and EHS and receipt of comments, completion of an issued for use AWHPP report; and
- Presentation of the AWHPP and associated risk information posters to stakeholders at a CoD council meeting.

3.0 METHODOLOGY

There are no Yukon-specific guidance documents relating to aquifer and wellhead protection plan development. This AWHPP was developed following guidance provided in the British Columbia Ministry of Environment, Well Protection Toolkit, with the addition of risk-based consideration of potential threats to the security of the water source.

Risk-based AWHPPs are established within a risk framework using risk assessment (hazard and risk identification and presentation) followed by risk management (mitigation, risk transfer, preventive action, monitoring, contingency planning and risk communication). Specific well threats (called risk scenarios) are identified, prioritized, and ranked to provide a management framework based on the actual risk posed by each identified hazard. This AWHPP is intended to provide a risk-based framework for decision making related to directing appropriate action in response to real or perceived threats to the CoD water system, the level and type of that response, and appropriate risk communication throughout the process.

To complete this AWHPP, Tetra Tech obtained and reviewed the following relevant technical and anecdotal information:

- Background geological, hydrogeological, geotechnical, environmental site assessment and infrastructure assessment reports;
- Infrastructure plans and CoD community plans provided by CoD;
- Aerial photographs and satellite imagery, topographic, and geological mapping;
- Meetings with CoD Public Works, YG-IDB and EHS representatives;
- Well supply well pumping rates, water levels and quality data provided by CoD;
- Meteorological, river flow, level and water quality from Environment Canada, Yukon Placer Atlas, and, Yukon River Inter Tribal Watershed Council;
- Long-term groundwater elevations from the Yukon Water Resources Branch;
- Review of the Yukon Contaminated Sites and Spills Report registers and a wide area spill search from Environment Canada;
- Review of historical, current and proposed future land uses;
- Measuring groundwater levels in CoD supply wells and groundwater monitoring wells in the vicinity of the CoD wellfield;
- A visual survey of the wellhead infrastructure and surrounding areas to identify obvious potential contamination sources and pathways; and
- Collection of water quality samples from the CoD groundwater supply wells and the Klondike River in July 2017.

4.0 SITE AND INFRASTRUCTURE BACKGROUND

4.1 Location and History

The CoD is located approximately 530 kilometres (km) northwest of Whitehorse at the confluence of the Yukon and Klondike rivers (Figure 1). The city was established in the late 1800s during the Yukon Gold Rush. At the height of the gold rush in 1898 there were an estimated 40,000 people living in and around Dawson City. A year later, when the rush ended, there were around 8,000 people remaining and by 1902 the population was under 5,000. The population continued to decrease to a minimum of 600-900 through the 1960s and 1970s. With the high price of gold making modern placer mining operations profitable and the growth of the tourism industry, CoD's population has increased over the last 30 years to an estimated 2,200 in September 2016 (Yukon Bureau of Statistics, 2016).

The primary industrial activity in the region over the last 120 years has been placer gold mining in the Klondike River Valley and tributary valleys, mineral exploration and industrial services to support these activities.

For the purpose of this study we have subdivided the CoD and surrounds into three geographic areas, as shown on Figure 1:

1. Downtown Dawson City (referred to in this report as "Dawson City", includes the general area bound by the extents of Front Street, Judge Street and Eight Avenue).
2. Klondike River Valley (including area between the Tr'ondëk Hwëch'in subdivision to Henderson Corner). This includes the Callison Industrial subdivision, Dredge Pond subdivision, the Dawson Airport, Rock Creek, and Guggieville) and tributary valleys extending to the south (to a distance of approximately 2 km south of the Klondike River).
3. West Dawson (opposite Dawson City on the western side of the Yukon River).

4.2 Existing Water Supply, Wastewater, and Stormwater Systems

4.2.1 Water Supply

The CoD owns and operates a public water supply system providing domestic water to the residents of Dawson City. The system consists of four groundwater water supply wells, PW-1N, PW-2N, PW-3N and PW-4N, brought online in October 2015 serving one water treatment system, a buried piped distribution network and a bulk delivery service. The system, which serves approximately 2,000 residents of Dawson City (CoD, 2017), is considered a large public drinking water system (LPDWS) under the Yukon Drinking Water Regulations – Guidelines for Part I – Large Public Drinking Water Systems (YG 2007). Residents and businesses in subdivisions along the Klondike Hwy and in West Dawson are not connected to the City water supply network and have either individual water supply wells or are on trucked water obtained from the Dawson City supply.

Water is pumped from the four groundwater supply wells via a common raw water main to a reservoir pumphouse where it is disinfected through a chlorine gas system. The chlorine gas dosage is manually controlled and adjusted and residual free chlorine is monitored manually by the operator twice per day (Stantec, 2013). After chlorine application, the treated water is stored in two reservoirs (storage capacity of 961 m^3 and 1,352 m^3 respectively), where an uncontrolled contact time is provided before water is pumped into the distribution system (Stantec, 2013).

The water distribution system consists of over 16 km of insulated polyethylene water mains throughout Dawson City, configured in six recirculating loops, with approximately 700 building services and 85 hydrants (Stantec, 2013).

Dawson's cold climate and permafrost conditions require freeze protection (tempering, recirculation and bleeding) of the water distribution system through the winter and spring months. Building services are typically single line services with freeze protection provided by a controlled bleeder system in the serviced building.

Current (2017) and projected (2037) average water demands for the Dawson City distribution network are detailed in Table 4-1.

Table 4-1: Dawson City Average Water Demand (2017 and 2037)

Season	Approximate Water Demand – 2017 (L/s)[1]	Estimated Water Demand – 2037 (L/s)[2]
Winter	34	44
Summer	19	25

[1] Based on information provided by CoD Public Works staff in February, 2017
[2] Assumes a 1.3% annual growth rate (Stantec, 2016)

Table 4-1 shows water demand is strongly seasonal, with increased demand through winter months due to bleeding to prevent freezing of water and wastewater system pipes.

Tetra Tech understand that upgrades to the water treatment plant and treatment system are currently in the design phase, with plans to undertake the upgrade work in the next two years. We understand the treatment system will be designed for a Groundwater Under Direct Influence (GUDI) source with filtration and UV treatment and the system will also be modernised with automatic chlorine analysis and dosage.

4.2.2 City of Dawson Water Supply Wells

The four CoD water supply wells are located on the grassed parkland between Front Street and the Yukon River dyke (Figure 2) and are completed in a relatively shallow unconfined fluvial aquifer.

PW-1N, PW-2N, PW-3N, and PW-4N were drilled, completed and tested in 2014 under the direction of Morrison Hershfield and brought into service in October 2015. The wells were constructed to meet Canadian Groundwater Association Well Construction Guidelines and the American Water Well Association Guidelines. While the Canadian Groundwater Association Well Construction Guidelines are now obsolete, for the purpose of this assessment they are still considered to be applicable for these wells, as there are no specific well construction guidance documents in Yukon.

All four wells are located within 40 m of a sanitary sewer line that runs along Front Street and therefore their siting is not in compliance with the current requirements of the Yukon Drinking Water Regulations – Guidelines for Part I – Large Public Drinking Water Systems (YG 2007). These regulations state that, unless based on the results of a comprehensive hydrogeological study, a drinking water well must be located a minimum distance of 60 m from any part of a sewage disposal system.

The four wells are cycled through duty and standby phases, with two wells typically on duty at any one time. PW-1N and PW-3N are typically pumped in unison (at a combined rate of approximately 50 L/s), then wells PW-2N and PW-4N (at a combined rate of approximately 48 L/s). When one or more wells is offline due to breakdown, repair or other reasons, the well use schedule is amended to meet the required water demand. To protect water sampling lines from freezing, each well sample line is equipped with a raw water bleeder supplied from the common raw water transmission main. Bleed water is discharged directly back into the well (which CoD have identified as a potential means of cross-contamination between wells in the event that one well becomes contaminated).

Logs for the four current water supply wells are included in Appendix B and the construction details of each well is summarized in Table 4-2.

Table 4-2: Dawson City Supply Well Key Details

Well Construction Parameters	Details[1]			
Well ID	**PW-1N**	**PW-2N**	**PW-3N**	**PW-4N**
Date of construction	Completed by Midnight Sun Drilling Ltd. in July 2014	Completed by Midnight Sun Drilling Ltd. in July 2014	Completed by Midnight Sun Drilling Ltd. in July 2014	Completed by Midnight Sun Drilling Ltd. in July 2014
Total well depth	20.1 m bg[2]	18.8 m bg	18.2 m bg	19.0 m bg
Casing	15 3/16" (386 mm) ID Steel Well Casing	15 3/16" (386 mm) ID Steel Well Casing	15 3/16" (386 mm) ID Steel Well Casing	15 3/16" (386 mm) ID Steel Well Casing
Casing depth	16.4 m bgs	15.1 m bg	14.5 m bg	15.3 m bg
Well screen	3.3 m long 120 slot (3.05 mm) stainless steel well screen exposed from approximately 16.87 m bgs to 20.1 m bg	3.4 m long 120 slot (3.05 mm) stainless steel well screen exposed from 15.4 m bgs to 18.8 m bg	3.4 m long 120 slot (3.05 mm) stainless steel v-wire screen exposed from approximately 14.8 m bgs to 18.2 m bg	3.4 m long 120 slot (3.05 mm) stainless steel v-wire screen exposed from 15.6 m bgs to 19.0 m bg
Static water level	6.3 m bg (314.151 m asl) (July 28, 2014)	6.0 m bg (July 22, 2014)	5.09 m bg (314.41 m asl) (July 26, 2014)	5.7 m bg (314.51 m asl) (July 27, 2014)
Sanitary seal	Bentonite surface seal to 5 m bg	Bentonite surface seal to 5 m bg	Bentonite surface seal to 5 m bg	Bentonite surface seal to 5 m bg
Wellhead completion	Pitless unit, vented well cap, wellhead in locked, heated enclosure.	Pitless unit, vented well cap, wellhead in locked, heated enclosure.	Pitless unit, vented well cap, wellhead in locked, heated enclosure.	Pitless unit, vented well cap, wellhead in locked, heated enclosure.
Slab Elevation (m asl[4])[5]	320.74	320.63	320.57	320.64
Top of Casing Elevation (m asl)[4]	321.29	321.14	321.12	321.15
Wellhead stickup	0.55 m ag[3]	0.51 m ag	0.55 m ag	0.52 m ag
Well rated capacity	37 L/s (488 IGPM)	41 L/s (541 IGPM)	42 L/s (554.5 IGPM)	45 L/s (591 IGPM)
Inferred Well GUDI status	GUDI	GUDI	GUDI	GUDI
Well Construction Comments:	Well was constructed to meet Canadian Groundwater Association Well Construction Guidelines and American Water Well Association Guidelines.			

[1] Details from Morrison Hershfield 2014 unless otherwise noted [2] m bg – metres below grade [3] m ag – metres above grade
[4] metres above mean sea level [5] Elevations surveyed by Underhill Geomatics in February 2017.

4.2.3 Existing Drinking Water Protection Measures and Management Activities

There are existing physical, operational and management measures in place to guard the CoD groundwater supply and drinking water system against contamination. These measures include:

- Well construction measures including stick-up of casings above grade, surface seals, locked well enclosures to prevent tampering, heated well enclosures to prevent freezing at the wellheads.
- Water treatment (primary and secondary chlorine disinfection).
- Water quality monitoring including:
    - Monthly monitoring of one of the wells for nutrients, conductivity, pH, total suspended solids, total dissolved solids, fecal coliforms and total coliforms. Several time per year an expanded parameter list is analysed that includes metals, anions and cations;
    - Manual daily chorine monitoring at the Water Treatment Plant (WTP); and
    - Weekly collection of samples for bacteriological testing by water system operators. Samples are shipped to Whitehorse and analyzed by EHS. Samples are collected from sample locations DC1 (the raw water feed prior to water treatment) and DC4 (the community water feed post treatment).
- A SW-ERP with emergency response procedures to minimize health and/or environmental threats and maintain a supply of safe drinking water in the event of an emergency (e.g., discharge from Turner Street outfall, flood conditions, sewer system failure) affecting the drinking water system.
- A Standard Operating Procedure (SOP) for well bleeding to address seasonal water quality results indicating the presence of coliforms.
- At the direction of EHS (EHS 2017), on April 10, 2017, CoD implemented the following preventative measures to address potential seasonal microbiological (bacteria, viruses, protozoa (*Giardia, Cryptosporidium sp.*)) impacts to the raw water supply that have regularly occurred around the time of Yukon River ice breakup:
    - Shutdown well PW-4N (PW-4N is the most southerly well in the network and located closest to the Yukon/Klondike river confluence). Southern water supply wells have historically been the wells most prone to seasonal bacteriological impacts.
    - Increase sampling and bacteriological analysis of raw water to twice weekly.
    - Monitor and record the turbidity of raw water at PW-1N, PW-2N and PW-3N at the time of sampling and twice daily at DC1 (combined raw water).
    - Increase free available chlorine from 0.4 mg/L to 0.6 mg/L chlorine residual at the entrance to the distribution system.

4.2.4 Wastewater system

Existing Wastewater System

Residential and commercial buildings in Dawson City are serviced by a network of sanitary sewer services constructed in 1978 and partially replaced in 1993 (Figure 3). There are no known currently functioning on-site sewage disposal systems with the Dawson City area.

The sanitary sewer system consists of service connections, lateral connections and sewer mains. Lateral connections branch off the sewer main and run along residential side streets while service connections connect laterals to individual properties. During winter and spring months, water is bled through the system to prevent freezing. Within the City area, waste is collected in three drainage basins and flows either via gravity drainage or through a force main to the Wastewater Treatment Plant (WWTP), which is located at the southern end of Fifth Avenue.

Stantec conducted a review of the sanitary sewer condition within the Dawson City area in 2015 (Stantec, 2015) and noted the following issues:

- **Pipe Sags** where some to all of pipe lengths were permanently underwater were prevalent across the entire system. Sewers were installed at slopes of approximately 0.4% and higher, however CCTV video review between 1991 and 2008 showed that that the majority of the gravity sewer pipes have sagged and contain ponded water and are not sloped at the grades indicated in the as-built drawing (Stantec, 2015).
- **Pipe Constrictions** were noted in 64% of pipes observed. Pipe constrictions cause reduced pipe capacity and could result in a pipe blockage that would cause flow to surcharge and to “backup” the system. Constrictions were due to:
  - Pipe deformation/collapse.
  - Pipe joint displacement.
  - Service connection protrusion.
  - Debris accumulation.

Where the invert level of sewer infrastructure is below the groundwater elevation, groundwater ingress into the system through cracks, breaks or displacement in the pipelines or connections may occur. If a sewer pipe is surcharged to a pressure head higher than the surrounding groundwater level, leakage of wastewater may occur at these cracks, breaks and displacements. Long term leakage of wastewater may occur where pipes sag and permanently contain ponded water or where pipe constriction backs up wastewater. Freeze/thaw cycles may result in movement of pipes and enlarging/closing of cracks, breaks and displaced pipes, resulting in fluctuating ingress/seepage rates. CoD Public Works staff consider sanitary manholes within the system, constructed of corrugated steel pipe with cast-in place concrete bases, as the most likely pathway for leakage of wastewater to the subsurface.

The WWTP, which was placed into operation in August of 2012, consists of a high rate aerobic process, applying “deep shaft” VERTREAT process technology, coupled with a flotation clarifier and UV disinfection. The deep shaft treatment system is designed with leak tight aeration shaft casing, comprised of steel and surrounded by cement grout to reduce the risk of groundwater contamination from wastewater breaching from the shafts. The VERTREAT shafts have been demonstrated through use at other sites to be leak free during their operation life (no reported cases of leaks from other systems that have been operating for up to 30 years), and are better protected from damage through seismic activity than above ground installations (EBA, 2009). The aeration shafts are designed to be redundant such that if one reactor requires maintenance, it could be taken off line, and the other reactor used to handle all treatment in the interim.

Following the treatment process, wastewater normally discharges to the Yukon River opposite Church Street, which is downstream of the water supply wells (Figure 3).

A single extension of the sanitary sewer system follows the Klondike Highway approximately 2 km to the south east to the Bonanza Gold Motel and RV Park. The force main serves four lift stations: C-4, Dome Road (currently not in use), Bonanza Gold, and Guggieville. Beyond these serviced areas, properties in the Klondike River Valley are on sewage pump-out or discharge waste to onsite sewage disposal systems.

Turner Street Emergency Outfall

The sanitary sewer system has an emergency outfall located at the Yukon River opposite Turner Street, immediately upstream of the four community water supply wells, which are inferred to draw a large proportion of their water supply from the river. This location serves as an emergency discharge point for raw sewage when the gravity sewer system in the southern end of the city becomes surcharged and wastewater elevations rise sufficiently to flow into the emergency discharge pipe. When in use, up to 2,000 m^3 of raw sewage can be discharged to the Yukon River per day (CoD, 2017). While use of the Turner Street outfall used to happen on a more regular basis due to power outages (N. Carlson, pers.comm.), the emergency discharge is now rarely used, with its last use in December 2014 (following mechanical failure at the WWTP). Over the years, concerns have been raised by CoD, EHS and several environmental consultancy firms in relation to the potential impact of discharge of raw sewage to the river on drinking water quality and the impact to groundwater by the surcharging of the sewer system. EHS recently advised CoD that they want to see alternative steps implemented prior to using the Turner Street outfall to minimize risk to the drinking water supply. CoD, to date, have implemented the following mitigation measures:

- Purchased a 6” portable pump and 300 m of lay flat hose to allow the wastewater treatment plant or blocked pipe sections to be manually bypassed, which is expected to eliminate the need to use the outfall under most circumstances.
- Are investigating re-routing the emergency discharge from Turner Street and tying into the existing Church Street discharge. This work is in preliminary planning stages and is contingent upon invert levels at Church Street being the lowest point in the system (i.e., lower than basements) to prevent backflow and flooding.
- Updated the SW-ERP with emergency response procedures specifically related to discharges form the Turner Street emergency outfall.

Proposed Wastewater System Upgrades

The CoD Public Works staff advised Tetra Tech that the following sanitary sewer system replacements are proposed to be completed in 2018:

- Front Street between the Commissioners Residence and Turner Street.
- Turner Street between Front Street and Fifth Avenue.
- Craig Street from the Hydraulic Tower to Fifth Avenue.
- Fifth Avenue from Craig Street to the wastewater treatment plant.

4.2.5 Storm Water System

The Dawson City storm water drainage network is detailed in Figure 4. The network is gravity drained with flow from east to west and discharge occurs directly to the Yukon River. One CoD storm water drain discharges to the Yukon River upstream of the CoD water supply wells (Figure 4). In addition to the CoD managed storm water system, there are two storm water drains managed and maintained by Yukon Highways and Public Works at the southern end of Dawson City; one located opposite Seventh Avenue and one opposite Dugas Street (Figure 4). These drains capture runoff from the Klondike Hwy (prior to it transitioning to Front Street) and discharge at the confluence of the Yukon and Klondike rivers, also upstream of the water supply wells.

The storm water system can potentially provide rapid transport of contaminants dumped down drains or that enter the system through runoff during rainfall events and/or spills/leaks. Also, and similarly to the sanitary sewage system, where groundwater elevations are above storm water invert elevations, there is the potential for ingress to the pipe through cracks, breaks and displacements in pipes. Where groundwater elevations are below the pipe invert elevation, there is the potential for leakage from the pipework to the subsurface.

Discharge of contaminants to the Yukon or Klondike rivers has the potential to impact upon drinking water quality and therefore the SW-ERP includes emergency response procedures specifically related to discharges from storm water outfalls upstream of the wells.

4.3 Other Groundwater Wells in the Dawson City Area

Other than the four existing wells used for the CoD water supply there are no other known drinking water supply wells within the Dawson City area. Former CoD supply wells PW-1, PW-2 and PW-3, which were in use from 1992 to 2015 and were also located on the grassed strip opposite the Commissioners residence, were removed from service and decommissioned in 2016. PW-4 (YEC-Well), which was located on Front Street between Craig Street and Dugas Street, was used for the Dawson City water supply prior to the use of PW-1 through PW-3, and was kept in an operational state for emergency use until it was removed from service and decommissioned in 2015. All four former water supply wells are believed to have been decommissioned in conformance with the Canadian Ground Water Association Guidelines for Water Well Construction (pers. comm., Geoff Quinsey 2017).

There are a number of existing groundwater monitoring wells/piezometers within Dawson City that have been installed to monitor groundwater elevations and groundwater quality (Figure 2). These monitoring wells/piezometers are all completed to depths of less than 10 m bg and have been completed screening a shallow unconfined aquifer.

Stanley (1992) reported on the installation of a number of observation wells and piezometers along Front Street as part of the 1991/92 water supply well installation program. It is unknown if these wells still exist, if they have been suitably decommissioned or destroyed. CoD Recreation Department staff, who manage maintenance of the parkland the wells are identified as being located on, cannot recall seeing any evidence of these wells within the last few years.

Four groundwater monitoring wells were identified as being installed at the Yukon Energy Corporation (YEC) site on the corner of Fifth Avenue and Dugas Street as part of a 2003 contamination assessment. Inspection of the site in February 2017 and July 2017 could not locate any evidence of the four wells. It is not known if these wells have been buried, decommissioned or destroyed.

4.4 Land Use Zoning

Land use zoning designations based on the CoD Official Community Plan (OCP) from 2012 are included in Appendix C.

Dawson City

There are multiple land use designations in the southern Downtown Dawson City area close to CoD supply wells PW-1N through PW-4N:

- Immediately to the east of the wells is zoned a mixture of urban residential, parks and natural space and institutional (institutional includes a range of activities such as cemeteries, community recreation facilities, hospitals, museums, places of worship, schools and utility infrastructure). Further to the east (beyond Seventh Avenue) is primarily zoned as urban residential with several lots zoned institutional.
- South/southeast of the wells (south of Turner Street) is primarily zoned as urban residential with several lots zoned institutional.

- To the northeast of the wells between Church Street and Princess Street, zoning is a mixture of downtown core (a broad range of mixed uses including community services, financial, multi-family residential, offices, retail, restaurants and tourist accommodations), urban residential and institutional.
- The four water supply wells are located as land zoned as parks and natural space.
- West of the wells is the Yukon River which is un-zoned.

Klondike River Valley

The CoD municipal boundary extends to its furthest point approximately 8 km east of Dawson City up the Klondike River Valley. There are multiple land use designations in the Klondike River Valley including:

- The area between Dawson City and to just east of Upper Bonanza Creek Road is zoned a mix of service commercial, urban residential, institutional, parks and natural space and country residential;
- In general, to the east of Bonanza Creek is zoned industrial south of the Klondike Highway, and country residential north of the highway;
- There is a small pocket zoned country residential south of the highway, just east of the Callison industrial subdivision; and
- To the east of the Callison industrial subdivision, a small pocket is zoned service commercial on the north side of the highway.

5.0 SITE SETTING

5.1.1 Climate

Dawson City experiences a subarctic climate, characterized by long, usually very cold winters, and short, cool to mild summers. Mean minimum / maximum temperatures range from -30°C to -22°C in January and 8°C to 23°C in July. On average, Dawson receives approximately 324 mm of precipitation per annum.

5.1.2 Topography, Terrain and Hydrology

The majority of Dawson City is built on a flat flood plain at the confluence of the Klondike and Yukon rivers, at an elevation of approximately 320 m asl. The City is bordered to the west and south by the Yukon and Klondike rivers and to the east and north by the flanks of the Midnight Dome (a steep sided hill overlooking the City area). East and north of the developed city area, elevations increases rapidly up the flanks of the Midnight Dome from approximately 340 m asl, rising to a peak of approximately 890 m asl, 1.3 km north east of the development limits.

Surface water on the western slopes of the Midnight Dome and within Dawson City generally drains in a westerly direction to collection points within the City and is then discharged to the Yukon and Klondike rivers via the storm water system.

To the east up the Klondike River Valley, relief is relatively flat and consistent through the residential and commercial subdivision areas and out to Henderson Corner, approximately 20 km east of Dawson City. The valley is bounded to the north and south by relatively steep-sided hills, vegetated by boreal forest. Surface water originating on adjacent slopes drains toward the Klondike River, which flows west and discharges to the Yukon River at the southern end of Dawson City.

Environment Canada provides flow and level data for both the Yukon River and Klondike River. The Yukon River station (YT09EB001) is located at the north end of the city (near Judge Street) and the Klondike River station (YT09EA0001) approximately 1.6 km south east of the city, where the Klondike Highway crosses the river (Figure 1). Seasonal flow variations are comparable between the two rivers, with minimum flow from late November through to late April, a rapid increase through to mid-June, correlating with snow melt, then a consistent decrease through summer months to November. Average flows in the Yukon River are in the order of 30 times greater than that of the Klondike River.

Lidar data provided by Yukon Government indicates that during the summer/fall period the Yukon River elevation in the vicinity of Dawson is essentially flat, while the Klondike River increases in elevation over 1.5 m from its confluence with the Yukon River to the vicinity of Eighth Street, 550 m to the east. This gradient may be flattened in the vicinity of the confluence for short periods when downstream ice jams back up the Yukon River or short periods of increased flow in the Yukon River due to events such as heavy rainfall or ice jam release upstream.

A conspicuous unmixed zone occurs at the confluence of the two rivers (see Figure 2), with dark Klondike River water flowing into the murky Yukon River water before mixing. At periods of high flow, the unmixed zone can extend up to 900 m downstream along the Yukon River. Under low river levels, a sand/gravel bar that extends around halfway across the Yukon River is exposed (Figure 2), but the unmixed zone still persists.

5.1.3 Surficial Geology

Dawson City

Figure 5 illustrates the surficial geology of the Dawson City area (YGS, 2014).

The majority of Dawson City is located on a low-lying fluvial terrace at the confluence of the Klondike and Yukon rivers and is underlain by Holocene age (11,000 years ago to present) silt, sand and gravels. Overburden thickness decreases from west to east, with 20 m of overburden at PW-1N (adjacent to the Yukon River) and 9.75 m of overburden encountered at the WWTP on Fifth Avenue. Overburden depth decreases to near zero on the slopes of the Midnight Dome, where bedrock occurs at or very close to surface. North of a defined permafrost boundary (Figure 6), finer grained sands and silts overly gravel, cobble and boulders. These fine grained deposits generally increase in thickness moving to the north. South of the permafrost boundary, the finer grained surficial sediments are generally absent, having been scoured away by the Klondike River (EBA 2009).

Figure 6 shows the location a former slough that runs in a northwest/southeast direction across the study area, as presented in EBA's 1977 report titled *Geotechnical Investigation for Dawson City Utility System*. The majority of the slough was infilled in around 1950, with the only remaining open area at its northwest extent south of the church located on Church Street. The open slough is approximately 3 m deep at this location. Little information is available on the nature of the material used to backfill the slough. J.R. Paine (1995) reported the slough at the northern end of the WWTP as "*an abandoned channel and the fill material in this area can be up to 3 m in thickness*". CoD Public Works staff noted that cars have been removed from the slough just north of the WWTP and that there is a "sinkhole" on the grassed area on Fifth Avenue outside of the museum. Given the alignment of the former slough, it is possible that the sinkhole is associated with the slough and settlement of materials used for infill.

The sedimentary deposits host discontinuous permafrost, with unfrozen sand and gravel sediments found near the mouth of the Klondike River in the southern end of the City and ice-rich, organic sediments in the northern and eastern portion of the City. To the north and east and up the slopes of the Midnight Dome, surficial material transitions to frost-shattered colluvium over bedrock. Figure 6 shows the approximate extent of permafrost within the City area. The non-permafrost zone is generally coincident with coarser-grained fluvial deposits at the southern end of the City. On both sides of the defined permafrost extent (blue line on Figure 6) is an approximate 100 m to

200 m wide transition zone between non-permafrost and permafrost areas. Within the permafrost transition zone northeast of the defined permafrost boundary, permafrost is likely to be present with likelihood increasing away from the defined boundary. To the south east of the permafrost boundary, permafrost is most likely not present, with the chance of encountering permafrost decreasing moving away from the boundary. Depth to permafrost is approximately 3.5 m to 4.5 m below grade, although this depth will vary seasonally and depend on the active zone thickness. Where present, permafrost extends to the base of the overburden and into bedrock.

While an assessment of the impacts that climate change will have on permafrost in Dawson City is beyond the scope of this project, a general trend of increasing temperatures in arctic and sub-arctic regions would be expected to result in a shift in the permafrost transition zone towards the north and east, and an increased non-permafrost zone in the southern end of the city. We note that based on Tetra Tech's general experience in drilling in the Dawson City area from 1977 to present, to date, climate change has had no clear impact on permafrost as there is little difference between the location of the permafrost zone defined in 2017 when compared against the originally defined zone from 1977 (EBA, 1977).

To protect the city against flooding, a 2.2 km-long dyke has been built along the riverfront from just east of the intersection of Front Street and Eighth Avenue to beyond the ferry terminal at the northern end of town. The dyke ranges in height from approximately 0.5 m to 1.8 m high, and is constructed with a bulk fill material generally consisting of medium to coarse sand and fine to coarse gravel. Based on data provided in the specifications for the dyke construction (Yukon Government 1987) the hydraulic conductivity of the bulk fill material is estimated to be around 10 m/day (~1.2×10^{-4} m/s).

Klondike River Valley

Surficial deposits within the Klondike River Valley consist primarily of serpentine cobble and gravel piles interspersed with numerous small ponds resulting from gold dredging operations (Morrison Hershfield, 2009). The majority of the valley up to the Bear Creek area (Figure 5) has been mined and shows no evidence of permafrost. Areas that remain unmined (such as east of the Callison Subdivision) are underlain by frozen organic sediments overlying alluvial gravel.

5.1.4 Bedrock Geology

The northern end of Dawson City is mapped as being underlain by silvery grey muscovite-chlorite quartz phyllite and micaceous quartzite of the Klondike Group (YG 2017). Metamorphic rocks of the Slide Mountain Group described as brown weathering, variably serpentinized ultramafic rocks with minor dunite, peridotite, harzburgite, diabase and serpentinite is mapped underlying a thin wedge through the middle of the City and volcanic rocks of the Slide Mountain Group including basalt, diorite, gabbro and /greenstone with minor argillite, siltstone, sandstone, tuff, limestone and metachert underlie the southern end of the city. Two thrust faults that define contact between the three groups run in an east/west direction across the southern end of the city. The WWTP is mapped as underlain by volcanic rocks of the Slide Mountain Group, however based on the description of rock encountered during a 2009 drilling program at the WWTP, the borehole most likely intercepted metamorphic rocks of the Slide Mountain Group.

5.2 Hydrogeological Setting

5.2.1 Aquifers

Two key aquifers underly the CoD; a shallow unconfined aquifer within overburden sediments and a deeper bedrock aquifer. The following sections presents a discussion of the conceptual hydrogeology relating to each of these aquifers.

5.2.1.1 Dawson City Aquifer

The four Dawson City community wells are completed in a relatively shallow unconfined sand and gravel aquifer. This aquifer has previously been identified as the Dawson City Aquifer (DCA) by Morrison Hershfield (2014) and, for continuity, Tetra Tech has retained this name. The extent of the DCA is limited to the southern section of the city, where there are inferred to be little to no overlying fine-grained, low permeability sediments and where sand and gravel deposits are unfrozen in close proximity to the Yukon and Klondike rivers (Morrison Hershfield, 2014). This zone generally correlates to that previously defined as non-permafrost (Figure 6).

The DCA is inferred to be hydraulically connected to the Klondike and Yukon rivers and the majority of recharge to the DCA is interpreted to be via horizontal infiltration of surface water from these water bodies (Tetra Tech 2017). To a lesser extent, recharge is expected through vertical infiltration of surface water throughout the city area and on the slopes of the Midnight Dome, and there may be some upwards discharge from the underlying bedrock aquifer to the DCA. Discharge from the DCA is ultimately to the Yukon River. Other than seasonal inflow from shallow groundwater in thawed active zone materials above permafrost areas, little to no horizontal groundwater flow into the DCA is expected from the north and east from the adjacent permafrost zone.

Groundwater Elevation and Flow Direction

Data from eight years of monitoring of Yukon Water Resources observation well YOWN-0803, located approximately 135 m inland from the Yukon River (Figure 2), shows that the depth to groundwater within the DCA can vary seasonally from between approximately 1 m to 6 m bg.

There is insufficient data and monitoring locations to accurately determine seasonal groundwater flow direction within the DCA. However, based on the hydrogeological setting and available groundwater elevations, we infer that shallow groundwater flows in a northwesterly direction from the Klondike River, through the course sedimentary deposits towards the Yukon River (Figure 7).

Aquifer Parameters

Aquifer testing was conducted by Morrison Hershfield during the 2014 drinking water well installation program. The program consisted of a four hour step rate pumping test and an eight hour constant rate pumping test at each of the four newly installed wells. Table 5-1 presents estimated aquifer parameters, as calculated by Morrison Hershfield (2014) and Tetra Tech. Transmissivity results presented in Table 5-1 generally concur with transmissivities calculated by Stanley (average of 1,900 m^2/day) from their 1992 testing program that followed the drilling and installation of former COD supply wells PW-1, PW-2 and PW-3.

Table 5-1: Estimated Aquifer Properties, DCA

	PW-1N	PW-2N	PW-3N	PW-4N	Average
Transmissivity (m^2/day) [1]	1,550	2,600	2,990	2,500	2410
Hydraulic Conductivity [2] (m/d)	119	200	230	192	185

[1] Calculated by Morrison Hershfield, 2014.

[2] Calculated by Tetra Tech based on an aquifer thickness of 13 m.

5.2.1.2 Bedrock Aquifer

A shallow bedrock aquifer immediately underlies the DCA (EBA 2009). Given the nature of the metamorphosed and structurally deformed bedrock, we expect groundwater flow to primarily be in fractures, faults, joints in the rock mass. In addition, brecciated rocks within the two faults crossing the southern end of the city may offer a preferential groundwater flow path. Recharge to the shallow bedrock aquifer underlying the city area likely occurs through outcropping bedrock on the Midnight Dome hill slopes and peak, with flow following the local topography towards the Yukon River. Given that the Yukon River is a major regional discharge feature, a component of recharge would also be expected from upward flow from deeper saturated bedrock. We infer that discharge from the shallow bedrock aquifer flows directly to the Yukon River or to the overlying DCA.

Hydraulic tests (packer tests and pumping tests) were conducted on a deep borehole drilled at the WWTP by Tetra Tech in 2009 to determine the hydraulic conductivity of the different test intervals within the bedrock (EBA 2009). Based on this drilling program, the bulk hydraulic conductivity of the bedrock at intervals between 15.2 m and 30.5 m bgs was estimated to be approximately 5.0 x 10^{-6} m/s based on an 8-hour pumping test. This relatively high K value for bedrock supports the designation of saturated bedrock beneath the DCA as an aquifer.

5.2.1.3 Klondike River Valley Aquifer

The key aquifer of importance to this study in the Klondike River Valley is the shallow unconfined aquifer consisting of relatively clean, highly permeable, sand and gravel deposits, identified for the purpose of this assessment as the Klondike River Valley Aquifer (KRVA). Groundwater flow in these deposits is, in general, expected to flow towards the Klondike River, where, based on general hydrogeological principles, discharge is expected to occur.

5.2.2 Hydrogeological Conceptual Model

Groundwater flow in the relatively shallow unconfined DCA is considered by Tetra Tech to be dominated by surface water recharge that infiltrates through the river bank and sediments from the adjacent Klondike and Yukon rivers. Recharge to the DCA through the bedrock aquifer, surface infiltration or inflow from seasonally thawed active zones in the permafrost areas bounding the DCA to the north and east is expected, although volumes are considered to be minor in proportion to river water recharge. Supporting this, there are strong similarities in the shape of the groundwater and surface water hydrographs for the Klondike River and at monitoring well YOWN-0803 (Figure 5-1; AECOM, 2009). This indicates a hydraulic connection between the DCA and the Klondike River (and by extension the Yukon River), and that this connection extends at least 135 m inland. AECOM (2009) reported a time lag of approximately two days between the surface water level variations and the associated groundwater response in the production wells.

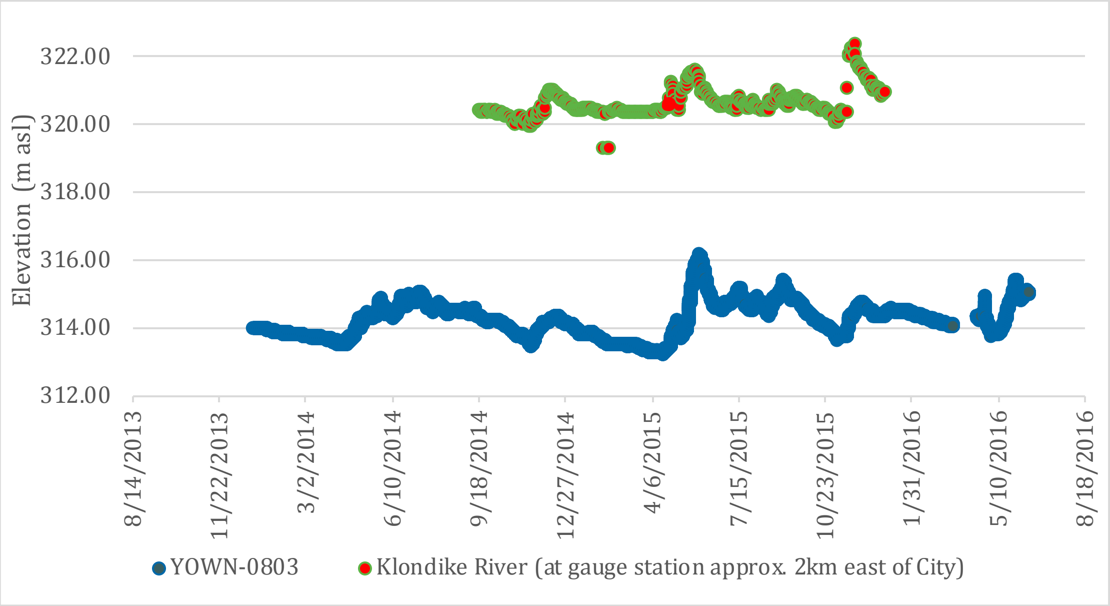

Figure 5-1: Comparison of DCA and Klondike River Elevations (2014 – 2016)

Figure 7 presents a conceptual representation of the typical flow system within the DCA under non-pumping conditions. As shown, based on relative elevations of the Yukon and Klondike rivers, the majority of surface water recharge to the DCA is inferred to occur from the Klondike River, where elevations are typically higher than the Yukon River. Flow is in a northwesterly direction through the highly permeably sands and gravels, and is bounded to the west by the effectively impermeable permafrost boundary. To the north, the permafrost boundary controls the flow direction, resulting in a westerly flow direction towards the Yukon River, where discharge occurs. Groundwater flow direction is likely reversed, at least close to the river banks, following rapid rises in river stage such as during freshet or due to downstream ice blockage. The effect of the dyke on groundwater flow is expected to be minimal as groundwater elevations are generally expected to be below the dyke base. However, during periods of high river and groundwater elevation, the dyke (inferred to have approximately 10 times lower conductivity than surrounding native soils) may partially restrict groundwater recharge.

Under pumping conditions, the flow regime is much the same, however to the north, the hydraulic gradient towards the Yukon River is reversed and flow is induced from the river towards the pumping wells (Figure 8). Morrison Hershfield (2014) reported that shortly after pump start-up, the production wells were found to reach a steady state condition due to the presence of a recharge boundary associated with the Yukon River and the drawdown that occurs shortly after pump start up is the same as the extrapolation of drawdown data that simulates 100 days of sustained pumping. Modelling by Tetra Tech (2017) estimated that the fastest travel time from the Yukon River to the wellfield, under average river elevations, is 37 days and from the Klondike River to the wellfield is 1.6 years.

Data from YOWN-0803, indicates that the depth to groundwater within the DCA can be as little as 1m bg. During times of high groundwater elevation, the infilled slough that runs diagonally across the southern end of the Dawson City area, which has a base approximately 3 m bg, may provide a preferential pathway for shallow groundwater (and contaminant) flow, and travel times may be less than those calculated above. Furthermore, sinkholes (such as on the grassed areas outside the museum) may indicate an area of preferential shallow groundwater flow due to large voids in infill materials.

5.2.3 Aquifer Vulnerability

Aquifer vulnerability is assessed as a measure of the potential for a contaminant introduced at or near ground surface to reach the subject aquifer. Contaminant sources that might impact an aquifer include events such as spills or leaks at surface or from underground piping, tanks or septic fields. Aquifer vulnerability is taken into account when assessing the risk to the aquifer. Morrison Hershfield (2015) used the Groundwater Intrinsic Susceptibility Index (GwISI) method to estimate the vulnerability of the aquifers tapped by each well (Ontario MOE 2001). GwISI scores between 0 and 30 suggest high vulnerability; scores between 30 and 80 suggest medium vulnerability; and scores greater than 80 suggest low vulnerability to surface sources of contamination. Table 5-2 presents the GwISI values as calculated by Morrison Hershfield.

Table 5-2: Groundwater Intrinsic Susceptibility Indices, PW-1N, PW-2N, PW-3N, PW-4N

	PW-1N	PW-2N	PW-3N	PW-4N
GwISI	5.56	6.02	5.87	5.74
Susceptibility	HIGH	HIGH	HIGH	HIGH

Table 5-2 shows that the aquifer that all four water supply wells are completed in has a high susceptibility to contamination introduced at or near ground surface.

6.0 RISK ANALYSIS METHODOLOGY

6.1 Risk Identification Approach

Risk identification can either be done in a qualitative (descriptive assessment of risk elements; receptors; hazards (e.g., contaminants); and likelihood of exposure) or quantitative (based on probabilistic mathematical analysis of the risk elements resulting in a numerical risk ranking). As the site information for this study is primarily qualitative in nature, the qualitative risk approach will yield the most meaningful and communicable project results.

6.2 Responsible Parties

Source water protection is a responsibility typically shared among various stakeholders. For risk-based AWHPPs, the responsible parties are typically the well/water supply system owners responsible for managing the water supply system (i.e., CoD), and the fiduciary bodies responsible for funding the system (i.e., Government of Yukon and CoD).

6.3 Risk Management Team

A risk management team is formed as one of the steps in developing and implementing an AWHPP and comprises representatives from the owner, technical advisors and key stakeholders such as community water users in the area.

We suggest that the risk management team for this AWHPP consist of CoD (the owner and, through its Public Works department, the operator), YG-IDB, and Tetra Tech (the technical advisor).

6.4 Risk Tolerance

For the purposes of implementing a risk-based AWHPP, risk tolerance is defined as a measure of the level of risk deemed acceptable by the owner. A risk-tolerant owner would be prepared to accept or transfer a certain level of risk, while a risk-averse owner would seek to actively mitigate risks to the water supply.

Mr. Louis Gerberding (CoD Superintendent of Public Works) and Mr. Mark Dauphinee (Acting CoD Superintendent of Public Works) expressed that the CoD is overall tolerant of some risk as long as there are mitigation strategies in place for effective risk management, and that the CoD would want to be practical and proactive in relation to risk management. Mr. Gerberding advised that the CoD is currently leaning towards the risk-averse stance in relation to microbiological impacts, based on historical occurrences and requirements of EHS to address impacts. Mr. Gerberding advised that following the commissioning of the new water treatment plant the CoD may be more tolerant of microbiological risk given the mitigation measures the WTP will implement (updated and modernised treatment systems including filtration, automatic chlorine analysis and dosage, UV treatment).

7.0 RISK ASSESSMENT

7.1 Well Capture Zone Assessment

The first technical step in developing an AWHPP is to define the geographic area contributing groundwater to a well, known as the well capture zone. The definition of an accurate well capture zone is a key element in developing an AWHPP. The size and shape of the capture zone depends on the hydrogeological setting and the design and operation of the water wells.

To delineate the capture zone for the four CoD wells, Tetra Tech created a finite difference numerical model of the Dawson City hydrogeological regime (Tetra Tech, 2017). Tetra Tech considered that, given the location of the wells and their proximity to numerous sources of potential contamination (SPC), use of a numerical model was the most suitable method to accurately define capture zones, estimate potential contaminant travel times and provide supporting information for assessing risk. Details of the model development, parameters and output are presented in Appendix D.

Where the modeled well capture zone contacted the permafrost boundary (considered by the model to be an impermeable boundary), a factor of safety was applied to take into account scenarios that could result in migration of contaminants from beyond the permafrost boundary into the well capture zone. The following scenarios were assessed and factors of safety determined:

- Uncertainty in the exact location of the permafrost boundary and the potential for non-permafrost conditions within the transition zone to the north. Half the distance of the permafrost transition zone was chosen as a factor of safety as, to the north and east, the prevalence of permafrost is expected to increase, inhibiting available pathways for groundwater flow and contaminant migration into capture zones. This equates to a distance of between 85 m and 125 m north and east, respectively, of the blue line permafrost boundary on Figure 6.

- Migration of contaminants along sanitary, water and storm water service lines. Service lines are understood to be backfilled with native material rather than bedding sand/gravel which will likely limit migration along these pathways. For the purpose of this assessment, a conservative distance for contamination migration along service lines of 50 m has been assumed.

- Migration of contaminants with overland flow of surface water. Overland flow would be expected to be caught by the storm water system at Fifth Avenue, Sixth Avenue and Seventh Avenue, limiting the possibility of contaminants migrating into the well capture zones.

- Migration of perched groundwater on top of permafrost. Perched groundwater on top of permafrost is expected to be present in the upper silt unit. Tetra Tech (2017) estimated groundwater velocity in the upper silt unit within the permafrost zone to be approximately 30 m in 10 years (3 m/year). For the purpose of this assessment, we have assumed that contaminants in the subsurface that are outside of the 10 year travel time are likely to be naturally attenuated through dispersion, dilution, diffusion and retardation prior to reaching the well permafrost boundary.

- A trend of increasing temperatures in sub-arctic regions is expected to shift the permafrost transition zone to the north and east. As suitable studies assessing future impacts to permafrost in the Dawson City region have not been completed, we consider that for the purpose of this this assessment, a conservative factor of safety of half the permafrost transition zone to the north and east (as detailed above) is suitable to define the current and short-term future permafrost boundary. We note that subsequent updates and iterations of this AWHPP should take into consideration potential effects of climate change on the capture zone, should suitable data be available.

We considered that an appropriate conservative overall factor of safety to be applied to the capture zones should be half the distance between the defined permafrost boundary and the boundary of the permafrost transition zone to the north and east. This distance was selected as it is the most conservative of the five scenarios considered above. 90 day, 1 year and 2 year capture zones, based on estimated 2037 water demands and the factor of safety applied, are shown in Figure 9.

Yukon River Influence

Based on modelling results, Tetra Tech estimates that approximately 90% of water pumped by the wells is drawn from the Yukon River and the capture zone defined to the west. Approximately 5% of water is drawn from the capture zone extending to the east and south and ultimately from the Klondike River. The remaining 5% is from recharge of precipitation, overland flow and horizontal leakage. While geographically the four wells are inferred to draw a significant proportion of their water directly from the Yukon River, review of aerial images indicates that under high water levels, at the confluence of the two rivers, water from the Klondike River flows with little mixing almost mid-way across the Yukon River and water from the two rivers does not appear to fully mix until several hundred metres downstream of the wells (Figure 7-1).

Figure 7-1: Yukon River/Klondike River Confluence – High River Level

Under low river level conditions, a gravel bar at the confluence of the two rivers is exposed to approximately mid-way across the Yukon River (Figure 7-2). The bar diverts Yukon River flow to the west and away from the wells, while the Klondike River flows along several channels through the bar, one aligned almost directly past the wells.

Under these conditions, the majority of water pumped from the wells likely reflects Klondike River water quality. Given the potential for migration of contamination along the Klondike River and tributaries, the well capture zone has been virtually extended to include the Klondike River Valley (up to Rock Creek) and tributary valleys to the south (e.g., Bonanza Creek) that include current and historical placer mining operations (further described below).

Based on these observations, Tetra Tech considers that there is effectively no contribution from Yukon River water (i.e., water sourced form upstream of the confluence) to the four water supply wells and therefore the capture zone does not extend to the southwest along this water body.

Tetra Tech consider this is the most conservative approach to assessing potential impacts to the CoD supply wells given the number of potential contamination sources located within the Klondike River valley and associated tributaries (placer mining, industrial facilities, agricultural land, residential dwellings) and the nature of potential contaminants (hydrocarbons, nutrients, microbiological). In comparison, there are considered to be a very limited number of potential contamination sources that extend for a very limited distance upstream of the wells on the Yukon River.

Figure 7-2: Yukon River/Klondike River Confluence – Low River Level

7.2 Potential Receptors

Potential receptors are users of the CoD municipal water supply system, which includes the residents of Dawson City, local businesses, tourists, transient workers, hospital, school and community centres and residences/businesses on trucked water delivery. There are approximately 2,000 regular users of the CoD municipal water supply (CoD, 2017) with this number increasing to about 3,250 during the peak summer tourism period. Tetra Tech acknowledges that there are non-human users of the CoD water supply, (e.g., pets, livestock), however these users have not been considered in this study.

7.3 Identification of Risk Scenarios

Risk can be defined as the likelihood that a receptor will be exposed to a particular hazard multiplied by the consequence of that exposure. Hazard and receptor must meet to result in exposure, so exposure risk can be defined as occurring where hazard and receptor meet due to an exposure pathway. Eliminating or blocking the pathways for exposure can remove or reduce the chance that an exposure will occur and reduce or eliminate risk. Figure 7-3 illustrates this concept.

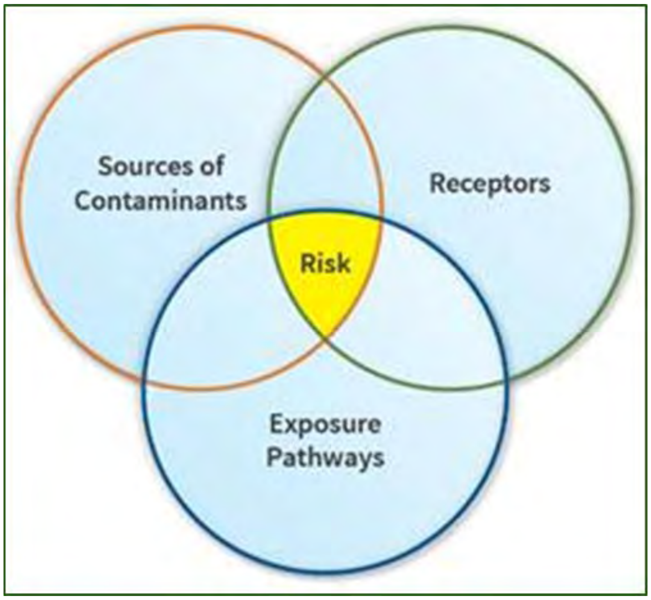

Figure 7-3: Fundamental Concepts of Risk and Risk Management

For the purposes of this AWHPP, risk is defined as the potential for exposure of a receptor (e.g., users of the CoD water system) to a hazard (e.g., contamination in the water) multiplied by the anticipated severity of the consequence of exposure. Hazards are categorized in terms of severity (contaminant toxicity). Risk assessment is the process of evaluating the likelihood of exposure and the hazard severity and evaluating and ranking the potential consequences of the identified risk scenarios.

7.4 Identification of Sources of Potential Contamination within Well Capture Zones

Tetra Tech identified and assessed known SPCs within the well capture zones in order to evaluate the risk these sources pose to community water users. SPCs within well capture zones were identified using several methods:

- Review of current and historic surrounding land uses;
- Requesting an Environment Canada, Environmental Protection Branch Spills search for properties in Dawson City and along the Klondike River Valley with spills records;
- Requesting Government of Yukon, Department of Environment search for properties with contaminated site and spill records in Dawson City and along the Klondike River Valley;
- Meetings and informal discussions with CoD representatives (Louis Gerberding (Superintendent of Public Works), Mark Dauphinee (Acting Superintendent of Public Works), Marc Richard, TC Frank, Henry Procyk, Jake Duncan, Michael Zarowny) to discuss well use, current and former land uses, known hazards and anecdotal information;
- Discussion with former CoD Public Works Superintendent Norm Carlson (now retired);
- Reconnaissance of the Dawson City area (south of Princess Street) and the Klondike River Valley subdivision on February 8, 9 and 10, 2017 and July 23 and 24, 2017;

- Reviewing historical air photos, satellite images and maps of the area for current and former land use;
- Reviewing available contaminated site assessment reports pertaining to Dawson City and along the Klondike River Valley; and
- Reviewing water quality sampling results from CoD and Environment Canada, the Yukon River Intertribal Watershed Council and Tetra Tech's July 2017 monitoring even.

7.4.1 Current Surrounding Land Uses within Well Capture Zone

Dawson City

Current land uses pertinent to this study within the well capture zone of CoD water supply wells PW-1N, PW-2N, PW-3N, and PW-4N are:

- To the east is a mix of developed recreational, commercial and residential land uses. Key identified land uses are:
  - Dawson City hospital (320 m east).
  - Dawson City museum (270 m east).
  - Highways and Public Works (Property Management) Compound (205 m east).
  - Parks Canada open grassed area (150 m east).
  - Residential properties generally east of Sixth Avenue.
- To the south and southeast is a mix of developed recreational, commercial and residential land uses. Key identified land uses are:
  - Dawson City ball field (320 m southeast).
  - Dawson City wastewater treatment plant (210 m southeast).
  - Dawson City water treatment plant (320 m southeast).
  - Dawson City swimming pool (290 m southeast).
  - Yukon Energy Corporation generating station (360 m southeast).
  - RCMP Station (100 m southeast).
  - Residential properties generally southeast of intersection of Turner Street and Fifth Avenue.
- To the northeast is a mix of developed recreational, commercial and residential land uses.
- To the west is the Yukon River.

Klondike River Valley

There are a range of land uses along the Klondike River Valley including residential, commercial and industrial. Key identified land uses include:

- Residential dwellings in the Dredge Pond, Rock Creek, C4 and Guggieville subdivisions.

- A number of commercial gas stations, card locks and fuel storage depots (incl. Fischer Fuels, Dawson City Gas and Tires Super Save Propane and Card Lock, North 60 bulk plant and card lock, AFD bulk plant and card lock).
- Dawson Airport.
- Trans North and Fireweed Helicopters.
- Existing and former placer mines in tributary valleys to the south.
- Quigley Landfill.
- Slinky Mine.
- Former gold processing facility and dredging operational headquarters at Bear Creek.

The majority of the remaining Klondike River catchment comprises undeveloped forested land.

West Dawson

As discussed in Section 7.1, Tetra Tech considers there to be little to no contribution from Yukon River water (i.e., water sourced from upstream of the confluence) to the four water supply wells. Therefore, land uses in West Dawson, which would only impact the Yukon River water quality, have not been assessed in this study.

7.4.2 Historical Surrounding Land Uses

Tetra Tech reviewed aerial/satellite images from 1951, 1961, 1977, 1987, 1995, 2006, 2009, and 2014 and spoke to current and former CoD employees in relation to historical land uses with the potential to contaminate soil and groundwater within the Dawson City and Klondike River Valley areas. Note that where locations are followed by an identifier (e.g., DC01) the identifier refers to locations detailed in Table 1/Figure 10 (DC series) and Table 2/Figure 11 (KRV series).

The following key points are noted in relation to this aerial image review:

Dawson City

- Aerial images from 1951, 1961, 1977 and 1995 are too broad a scale and poor quality to discern changes in land use.
- Development in the 1987 image appears generally similar in nature and extent to in 2014.
- A former White Pass & Yukon Route railway depot was located at the current site of Northern Industrial Supplies (DC49). The railway depot serviced a train line that ran over 50 km from Dawson City to the goldfields from 1906 to 1913. Within Dawson City, the train line ran alongside the Yukon River, following the general alignment of Front Street.
- The Northwest Mounted Police barracks and parade ground was located immediately to the east of the CoD supply wells along Front Street.
- Yukon Government operated a Highways Maintenance Camp (DC36) on the corner of Fifth Avenue and Turner Street. This site is now the location of a two story residential apartment block and the WWTP.
- CoD Public Works staff advised that to their knowledge, other than the removal of several buried cars from the former slough (DC39), there has been no excavation work conducted within the city area that has uncovered material indicative of historical large scale waste disposal.

Klondike River Valley

- Aerial images from 1951, 1961 and 1995 were reviewed, although are at too broad a scale and poor quality to discern changes in land use.

- Images from 2006 and 2014 do not indicate any large scale changes in land usage.

7.4.3 Contaminated Sites and Spills Search, Environment Canada

Contaminated sites searches of all properties within the well capture zones and along the Klondike River Valley were requested from Environment Canada in March and April 2017. At the time of writing, these search results had not yet been provided. Tetra Tech has made multiple efforts to expedite the search, however we were advised by Environment Canada that due to the large number of documents to process and the consultations required, an extension of 150 days beyond the statutory 30-day limit was necessary. Following receipt of the search results, Tetra Tech will review the information provided in light of the AWHPP's conclusions and recommendations, and if necessary, advise YG-IDB if updates to this report are considered necessary.

7.4.4 Contaminated Sites and Spills Search, Government of Yukon

Tetra Tech requested a search for spills and contaminated sites from the Government of Yukon for the Dawson City area, approximately 10 km east up the Klondike River Valley to Bear Creek and approximately 4.5 km up the Bonanza Creek valley. Government of Yukon provided the appended reports on February 9, 2017 and September 21, 2017 (Appendix E). A total of 17 sites were identified within the search area. Of these sites, Environment Yukon identified four as remediated, seven as still being contaminated, one with minor or unlikely contamination and five were identified as having an unknown status. Sites with contaminated or unknown status that are located within inferred well capture zones are detailed below and shown on Figure 10.

Dawson City

- Former Dawson City Hwy Maintenance Camp (DC36). A significant amount of assessment work has been completed on this property, but some areas still have potential contamination remaining. The type and nature of contamination is not detailed in the Environment Yukon report.

  Tetra Tech note that there is understood to be a stockpile of clean, uncontaminated soil that was excavated during the construction of the WWTP remaining on this Site. We understand that along with this uncontaminated soil, a volume of hydrocarbon impacted soil was also excavated and removed from Site to the Yukon Government land treatment facility located on the Top of the World Highway.

- Fifth Avenue and Turner Street (DC35). An underground fuel storage tank (UST) was broken during excavation and an unknown quantity of diesel fuel was spilled which was subsequently remediated. On the same site, during the installation of electrical lines on the property, hydrocarbon odours were detected. An environmental consultant was engaged to assess, excavate and sample the area (future parking lot for apartment complex). Confirmatory sampling indicated residual contamination remains with one sample exceeded the Yukon Contaminated Sites Regulation (CSR) Commercial Land numerical soil standard for Light Extractable Petroleum Hydrocarbons.

- RCMP Station, 415 Front Street (DC37). In 2003, contamination (undefined) was found beneath a modular home that was being removed from the site to facilitate new construction. Excavation and relocation of contaminated material occurred, but confirmatory sampling was not completed in accordance with CSR and minor contamination may remain on site.

- A brown colored substance/plume on the Yukon River was reported to the RCMP on August 17, 2017. Environment Yukon references a spill report stating "speculation is that a barge had gone upstream today with a fuel truck on board", however Environment Yukon states that there was no evidence that the plume was caused by a fuel spill from the barge or fuel truck.

Klondike River Valley

- Old Quigley/Callison Waste Metal Dump (KRV12) that operated from 1975 to 1985. The dump received metal waste and domestic waste. Groundwater sampling in 1994 and 2004 reported concentrations of methoxychlor (pesticide), hydrocarbons and phenols concentrations all below the CSR Aquatic Life standards. The search documentation provided states that Environment Yukon still consider the site to be contaminated.

- YECL Substation, Callison Subdivision (KRV02): In 2003, between 50 L and 100 L of hydraulic oil was spilled in the power plant. The spill was contained and it was prevented from reaching the Yukon River via the sewer system. Current site status is not stated.

- Lot 8, Callison Subdivision (North 60 Bulk Plant) (KRV03): In 2003, 4,000L of diesel fuel was spilled due to an overflowing tank. Fuel was contained and partially cleaned up. Current site status is unknown.

- Lot 1 Callison Subdivision (KRV04): Lot 1 is the site of a decommissioned Land Treatment Facility (LTF) under Mackenzie Petroleum's permit 24-007. The site is deemed to be contaminated with elevated arsenic in soil, however the Environment Yukon report notes that the elevated arsenic concentration may not be associated with the former LTF.

- Lot 1047-2 Quad 116 B/03 (Northern Superior Mechanical) (KRV05): In August 2016 a permit was issued for the relocation of approximately 10 m3 of petroleum hydrocarbon contaminated soil. A characterization sample indicated concentrations of lead above the TCLP trigger of 100 µg/g. Current site status is not stated.

7.4.5 Sources of Potential Contamination in Vicinity of CoD Water Supply Wells

Dawson City

Based on the February 2017 and July 2017 field reconnaissance events, review of surrounding land uses and the contaminated site/spill searches, SPCs and their associated potential contaminants of concern were identified within the Dawson City well capture zone. Both potential biological pathogens and chemical contaminants have been considered in this inventory. The main SPCs and primary contaminants identified in the community within the well capture zone are listed below:

- CoD sanitary sewage system, including wastewater treatment plant (biological, nutrients, “emerging” contaminants [e.g., pharmaceuticals, personal care products])

- Above-ground storage tanks (AST) and USTs (petroleum hydrocarbons). During the visual reconnaissance of the Dawson City area conducted in February and July 2017, Tetra Tech identified approximately 90 ASTs and one UST within the well capture zone

- Fertiliser use (nutrients) on parks and gardens

- Klondike River (biological, hydrocarbons)

A comprehensive list of identified SPCs and associated contaminants is presented in Table 1. Figures 10 and 10a shows the spatial distribution of the identified SPCs in relation to PW-1N, PW-2N, PW-3N, and PW-4N. Tetra Tech notes that there may be other SPCs in Dawson City that have not been included as they are not recorded in available documentation, were not evident at the time of the visual reconnaissance or have not been reported to relevant authorities.

Klondike River Valley

Identified existing and historical SPCs within the Klondike River Valley are detailed in Table 2 and shown on Figure 11. While none of these SPCs are within the calculated well capture zone based on modelling, given the hydraulic connection between the Klondike and Yukon rivers and the pumping wells, the potential exists for contaminants (biological, hydrocarbons, nutrients) sourced from the Klondike River Valley to discharge to the Klondike River, flow with river water to a point adjacent to the wells where bank infiltration occurs, and then migrate to the pumping wells.

The main SPCs and primary contaminants identified along the Klondike River Valley are listed below:

- Above-ground and underground fuel storage tanks (petroleum hydrocarbons).
- Onsite septic disposal systems (biological, nutrients, “emerging” contaminants [e.g., pharmaceuticals, personal care products]).
- Commercial/Industrial activities (solvents, petroleum hydrocarbons, metals).
- Historical mining operations (petroleum hydrocarbons, metals).
- Quigley Landfill (range of organic and inorganic chemicals, metals).
- Former gold processing facility and dredging operational headquarters at Bear Creek (solvents, petroleum hydrocarbons, metals [incl. mercury], polychlorinated biphenyls).

7.4.6 Water Quality Sampling Results

Water quality data from the four current water supply wells (PW-1N, PW-2N, PW-3N, PW-4N), the three former water supply wells (PW-1, PW-2, PW-3), and the Klondike River is provided in Tables 3a, 3b, 3c and 3d. Locations of river sampling locations are provided in Figure 1. In consideration of the identified SPCs and primary contaminants outlined in Section 6.4, Tetra Tech reviewed groundwater quality data from the DCA for indications of impacts from SPCs on water quality.

7.4.6.1 General Water Quality

Apart from biological parameters and a single turbidity exceedance at PW-3N, all other parameters tested for at PW-1N through PW-4N met the aesthetic and health-related parameters of the Guidelines for Canadian Drinking Water Quality (GCDWQ) in samples collected in 2015/16.

7.4.6.2 Nitrate and Chloride

Nitrate and chloride concentrations can be used to determine anthropogenic impacts (such as wastewater, fertilizer use) if an increasing trend is observed, or concentrations are above background concentrations. Nitrate concentrations in all four current water supply wells and three former supply wells between 2004 and 2016 have been a minimum of approximately ten times lower than the GCDWQ Maximum Allowable Concentration (MAC). Concentrations across all wells are similar and have had similar fluctuations in concentration across sample events. The average nitrate concentration in the four water supply wells across the 2015/2016 period was 0.7 mg/L while average concentrations in the Klondike River over a similar time period were 0.1 mg/L. The higher concentration observed in groundwater could be indicative of some anthropogenic influences to the groundwater quality in the DCA.

Across the 13 years that monitoring data was available from the old and new water supply wells, chloride concentrations ranged from 0.82 mg/L to 16 mg/L and had a geometric mean of 3.3 mg/L. Wells located to the north

(PW-1N, PW-2N, PW1, PW2) show a higher average chloride concentration than wells to the south (PW-3N, PW-4N, PW3). There was no chloride concentration data available from the Klondike River. Lower chloride concentrations in the southern wells potentially indicates greater influence from surface water (which would typically have a lower chloride concentration than groundwater due to precipitation runoff) when compared to the more northerly wells.

7.4.6.3 Bacteriological Parameters

Fecal Coliforms and Total Coliforms

Monitoring data from the Klondike River and new and old groundwater supply wells indicate that while the Klondike River sampling results regularly contain fecal coliform (with concentrations up to 57 CFU/mL), detections in groundwater supply wells are uncommon. Tetra Tech reviewed results of 34 bacteriological sampling events from the water supply wells between 2014 and 2017 provided by CoD. There were two positive total coliform results (6%) with a maximum concentration of 2 CFU/mL. There were no positive fecal coliform results in 34 raw water samples collected from the supply wells.

While viruses sourced from the sanitary sewage system are identified as a potential contaminant, laboratory testing of viruses does not occur. The presence/absence of bacteriological contaminants serves as an indicator as to the potential for viruses to be present (i.e. the presence of bacteriological parameters indicates viruses may be present).

Discussion of Bacteriological Detections in Water Supply Wells

Tetra Tech considers that positive bacteriological detections in water sample results at the water supply wells may be due to several mechanisms which are presented below:

1. High bacterial load in the surface water source during the spring (mid-April to early June) breakup period.

   Review of water quality data from the Klondike River water monitoring station YT09EA0001 showed peak fecal coliform concentrations in the spring period (Table 3c). This condition appeared to manifest itself on a yearly basis in the form of bacteria (*E.coli* and Total coliform) observances in old supply well PW-3 and was evident in spring 2016 testing at the new water supply wells. A detailed assessment of the start-date, duration, and intensity of the coliform observances is beyond the scope of this study. Based on the City of Dawson's experience, they have identified the following characteristics in relation to the observances:

   - Occurs during spring freshet;
   - Peaks at and immediately after breakup of the Yukon River ice cover;
   - Connected to rise in the level of the Yukon River; and
   - Most severe during a sudden rise in the level of the Yukon River (e.g., during an ice jam).

   Historically, during use of the old well network (PW1, PW2, and PW3) the majority of total coliform detections during the spring freshet were reported from PW3, the most southerly well in the network. The following key observations are made in relation to bacteriological detections in 2016/17:

   - Water quality testing on six occasions in April 2016 had presence of total coliforms in PW-2N, PW-3N and PW-4N, with multiple wells having total coliform presence detected on several occasions (Marc Richard, pers. comm). There were no detections reported at PW-1N; and
   - PW-1N, PW-3N and PW-4N each reported four positive bacteriological detections between May 24 and September 1, 2017. There were no positive detections for either *E.coli* and Total coliforms in PW-2N is

this period. All detections at PW-1N were between May 24 and June 27, 2017, while the majority of detections at PW-3N and PW-4N were in July and August.

Given that one of key differences between the old and new well networks is that the old configuration did not bleed water from the common raw water transmission main back into the wells, CoD suspected that the total coliform observances in multiple wells may be related to cross-contamination associated with bleeding raw water rather than each of the wells being impacted at the groundwater source. To alleviate the risk of cross-contamination during the spring breakup period, CoD have implemented a bleeder shut down standard operating procedure to stop raw water being bled into wells during this higher risk period. While detailed assessment of the bacteriological observances has not been conducted, more regular total coliform observances at the wells to the south (PW-3 and PW-4N) may offer some insight into the mechanism behind the detections. AECOM (2009) reported that while there is a strong hydraulic connection between the groundwater and surface water systems, the absence of fecal and total coliforms within the raw groundwater samples collected during normal site conditions, particularly when bacteria were regularly present in raw river water samples, suggests that the aquifer system is providing a level of filtration from surface water pathogens.

As shown in Figure 7-1, all four supply wells are approximately the same distance from the river under high river levels, while under low level conditions (Figure 7-2), current supply wells PW-3N and PW-4N (and former supply well PW-3) are located closest to the river confluence and the surface water channel flowing past the wells. Therefore, under high river levels around the spring period, all four wells may be equally susceptible to bacteriological impact from the river. As the river level drops (summer and fall period), southern wells may be more at risk of impact based on the inferred shorter travel time from the channel to the southern wells not providing suitable filtration of bacteriological parameters, resulting in increased positive detections at these wells.

2. Seasonal high groundwater elevations.

   At locations where the sanitary sewer system is leaking, seasonal high groundwater elevations in spring (mid-April to early June) will reduce the natural unsaturated soil absorption and treatment zone (where some natural reduction in bacteria and virus concentrations is expected to occur), potentially resulting in the mobilisation of bacteria and viruses to the DCA.

3. Surcharge of the sanitary sewage system and subsequent use of the Turner Street outfall.

   Coliform observances may be due to wastewater in surcharged sanitary lines (particularly along Front Street) leaking to groundwater and reporting to the wells, or waste water discharged to the river at the Turner Street outfall then entering the groundwater flow system through river bank infiltration and then migrating to the wells. While a detailed assessment of these mechanisms is beyond the scope of this study, the higher incidence of bacteriological observances in former supply well PW-3 suggests that wells in the south of the network are closer to leaking wastewater infrastructure and/or bacteriological contaminants discharged to the river may be subject to decreased travel time and filtration than wells further north (as discussed above).

We note that risks from bacteria and viruses are currently reduced through the water disinfection process, and that according to CoD, there has never been a detection of total coliforms or *E.coli* in the treated water supply (Marc Richard, pers. comm).

Microscopic Particulate Analysis

Microscopic Particulate Analysis (MPA) sampling was conducted at former water supply wells PW1, PW2 and PW3 between May 25 and 26, 2009 and on October 8, 2009. Analytical results indicate that neither *Giardia* nor *Cryptosporidium* were detected in any well on either of the sampling events. MPA sampling of surface water bodies (Yukon or Klondike rivers) was not conducted at the time of well sampling.

7.4.6.4 Organic Compounds

Between 2010 and 2017, samples have been collected from PW-1N through PW-4N and former supply wells PW-1, PW-2 and PW-3 and analyzed for various organic compounds, including petroleum hydrocarbons (PHCs), volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs). All analyzed organic compounds have reported concentrations below the relevant GCDWQ standards and all PHCs and VOCs have been reported at concentrations below laboratory detection limits.

Several PAHs have been detected in water supply wells over the course of the 2010 to 2017 monitoring events including naphthalene (PW-1 (2010), PW-2 (2010), PW-2N (2017)), phenanthrene (PW-2N (2017)) and benzo(g,h,i)perylene (PW-4N (2014)). PAHs are generally generated during the incomplete combustion of organic materials (e.g. coal, oil, petrol, and wood). Anthropogenic sources dominate environmental contamination caused by PAHs, however PAHs do occur naturally in the environment originating from natural sources such as open burning, natural losses or seepage of petroleum or coal deposits, and volcanic activities. We note that the GCDWQ do not specify standards for any of the three PAH compounds detected. The cause of detectable concentrations of these compounds in groundwater is not known, and given they presently have no drinking water guideline value, we consider further source investigation is not warranted. However, continued sampling of the supply wells and review of PAH concentrations should be conducted to identify trends and potentially act as an indicator for risk from other PAHs (such as benzo(a)pyrene which has a drinking water MAC value).

Tetra Tech sampled the Klondike River at the two locations shown on Figure 1 in July 2017 and analyzed them for PHCs, VOCs and PAHs. Analytical results show that all analyzed organic compounds reported concentrations below the relevant GCDWQ standards and concentrations were below laboratory detection limits in both upstream and downstream locations.

Based on anecdotal information, Tetra Tech understand that hydrocarbons (light extractable hydrocarbons, toluene, ethylbenzene, xylenes, volatile petroleum hydrocarbons and naphthalene) have been detected in groundwater between the hospital and the museum, 310 m east of the wells (and within the well capture zone). These hydrocarbons are believed to be associated with a historic UST that has since been removed from the site. There is no other recent information available on hydrocarbon concentrations in the DCA from other monitoring wells within the well capture zones.

7.4.6.5 GUDI Status

While the GUDI status of PW-1N through PW-4N has not been formally assessed, AECOM (2009) undertook a GUDI study to assess the hydraulic connection between the Yukon River and former CoD supply wells PW-1, PW-2 and PW-3.

The GUDI study included a multiphase assessment as outlined within the Assessment Guideline for Well Water or Groundwater under the Direct Influence of Surface Water (YG, 2006). AECOM concluded that given the shallow well screen depth (<15 m), the unconfined nature of the pumped aquifer, the well construction (not in compliance with the CGWA Guidelines for Water Well Construction(1995)), the wells historically showing evidence of impact from surface water, the proximity of the wells to a permanent surface waterbody (<60 m from the Yukon River) and the average time of travel (TOT) time to each production well (15 days), the groundwater drinking source was deemed potentially GUDI. As the average TOT was determined to be below the 90-day threshold specified in YG's assessment guideline (YG 2006), a Phase 2 GUDI assessment was conducted.

The AECOM (2010) Phase 2 assessment made the following conclusions:

- Production wells PW-1, PW-2 and PW-3 have a moderate to strong hydraulic connection to the Yukon and Klondike rivers.
- The absence of fecal and total coliforms within the raw groundwater samples collected during normal site conditions, particularly when bacteria were regularly present in raw river water samples, suggests that the aquifer system is providing a level of filtration from surface water pathogens.
- The occurrence of *E. coli* bacteria over the assessment period in temporal association with issues related to sewer infrastructure malfunction strongly suggests the wells are at times capturing impacted groundwater. This, however, is a wellhead protection issue since the contamination is related to anthropogenic sources and is not specifically related to poor quality water from the Yukon or Klondike rivers (i.e., a GUDI issue).

AECOM assign a GUDI designation to PW-1, PW-2 and PW-3 based on monitoring results and past occurrences of *E. coli* bacterial in raw groundwater following emergency sewage discharges from the Turner Street emergency outfall.

While PW-1, PW-2 and PW-3 have since been decommissioned and replaced by PW-1N through PW-4N, given the similar location, construction, aquifer being targeted and pumping schedule, Tetra Tech, and others (i.e., Morrison Hershfield (2014), YG EHS (2017)), consider the findings of 2009 GUDI assessment applicable to the new water supply wells (i.e., wells PW-1N through PW-4N are GUDI).

GUDI water sources are at higher risk of presence of pathogens associated with surface water (bacteria, viruses and protozoa). We understand that the CoD disinfection system currently includes 4-log removal of bacteria and viruses and treatment objectives for these analytes are met, however the treatment system does not address the potential presence of protozoa. We understand that the CoD and YG-IDB are currently in the planning stages of upgrading the existing WTP to include treatment for protozoa removal (filtration and UV), which is in line with the requirements of the Yukon Drinking Water Regulations – Guidelines for Part I – Large Public Drinking Water Systems (YG 2007) and the GCDWQ.

7.5 Well Capture Zones used for Risk Assessment

For the purposes of this AWHPP, the capture zone of the four water supply wells has been broken down into three zones with different levels of control recommended to safeguard the water supply. These zones are defined based on a conservative estimate of the travel time it will take for a contaminant to reach the well and includes a factor of safety, as discussed in Section 7.1. The well capture zones are defined as follows (the extent of these zones are detailed in Figure 9):

- **90 Day Travel Time (Zone 1)**: Horizontal groundwater travel time of 90 days (corresponding to a distance of between approximately 50 m and 70 m from the wells). The definition of this zone is primarily based upon the Yukon GUDI Assessment Guideline's trigger of 90 days that defines whether a well is considered GUDI or non-GUDI. The 90 day period suggests that this period is sufficient for the renovation of microbiological contaminants (e.g., *E.coli*, *Giardia, Cryptosporidium*, coliforms, or viruses). This inference is supported by studies by Toze (2003), USGS (2017), UNEP (2003) and Morris (undated) that indicate bacteriological and pathogenic viruses typically survive less than 90 days in the subsurface, with concentrations reduced through natural removal by grazing, predation, die-off, and entrapment (filtration) in pore spaces. We note that these studies show that there is variability in survival times and therefore, actual survival times in the DCA may exceed

90 days. The 90 day travel time is not deemed to be a definitive safe distance where microbiological contamination outside of this area is of acceptably low risk to wells, rather it aims to define a reasonable estimate of a the highest exposure likelihood zone for pathogens in well water.

- **One Year Travel Time (Zone 2)**: Horizontal travel time in the source aquifer within this area is estimated to be up to one year from the zone's outer perimeter to the wells.
- **Two Year Travel Time (Zone 3)**: The third zone encompasses the two-year horizontal travel time. As detailed in Appendix D, due to hydrogeological constraints, we do not expect that travel times to the wells anywhere within the DCA would be beyond two years. The two year travel time zone has been extended from the modelled output to follow the river bank in the southwest of the model area given the potential for extreme high elevations in the Yukon River (due to ice jam) influencing groundwater flow to the DCA in this section of the model.

7.6 Risk Evaluation and Mapping

Risk to the well users was evaluated for each of the hazards identified using the Risk Matrix shown in Figure 7-4.

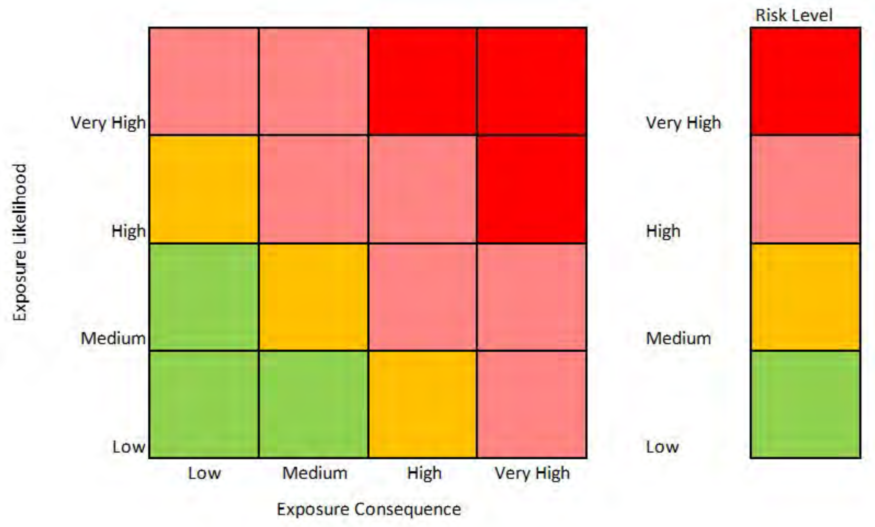

Figure 7-4: Risk Assessment Matrix

The following factors were used to define the categories of exposure likelihood and exposure consequence:

- Magnitude and character of the hazard (point source or non-point source);
- Location (distance from wells);
- Groundwater travel times to the wells;
- Mitigation measures already in place;
- Likelihood of contaminant directly affecting water well; and
- Consequence of the exposure to the hazard for users of the CoD community water supply.

The risk matrix provides the potential risk posed by each of the hazards identified within the well capture zones. An overall risk of “Low”, “Medium”, “High” and “Very High” was assigned to each hazard identified within the well capture zones. The risk levels were based on the combined exposure likelihood and consequence for the potential contaminant. Each combination of hazard, exposure likelihood and consequence is referred to here as a *risk scenario*. Colour-coding the identified risks provides a straight forward and intuitive basis for managing risk scenarios identified on a colour-coded Risk Map (see Figures 10 and 11). We note that this risk evaluation method, by design, does not take into account “post source” barriers/mitigations such as water treatment by either the CoD or individual users. Some risks can be mitigated through monitoring and treatment as is discussed further within this report; however for the purpose of this groundwater source protection plan, the risks to raw water only are considered. Table 7-1 summarizes screening level criteria used for assigning exposure likelihood and exposure consequence ranks to each PSC within the well capture zones.

Table 7-1: Hazard Exposure Likelihood and Consequence Screening Criteria

Likelihood of Exposure to Hazard	**Criteria**
Low	Travel time > 2 years
Medium	Travel time >1 year and up to 2 years
High	Travel time > 90 days and up to 1 year
Very High	Travel time < 90 days
Consequence of Exposure to Hazard[1]	**Criteria**
Low	▪ Does not have any health-based or aesthetic guideline values[2]; or, ▪ not identified as a hazardous substance based on material data safety sheet (MSDS) ; or, ▪ exposure leads to no damage to water supply infrastructure.
Medium	▪ Does not have a health-based guideline value, but has aesthetic objective[2]; or, ▪ no applicable health-based guidelines[2] but chemical has been identified as hazardous/potentially hazardous based on MSDS (e.g., propylene glycol); or, ▪ a potential emerging contaminant of concern; or, ▪ exposure may lead to <$50,000 in repairs or restoration of water supply infrastructure (e.g., well disinfection).
High	▪ Parameter has a health-based guideline value[2] and exposure may result in chronic health hazard (lost times of days to months (e.g., benzene from fuel products, or nitrate from fertilizer or wastewater); or, ▪ exposure results in $50,000 to $100,000 of repair, restoration or replacement costs for damage to water supply infrastructure.
Very High	▪ Parameter has a health-based guideline value[2] and exposure may result in acute health hazard (permanent disabilities or fatalities; e.g., pathogens from wastewater); or, ▪ exposure results in >$100,000 of repair, restoration; or, ▪ replacement costs for damage to water supply infrastructure (e.g., replace well).

[1] Note that where a hazard is composed of multiple constituent chemicals (e.g. gas, heating oil or diesel), the consequence of exposure in relation to health or aesthetic based guideline values is ranked based on individual constituent chemicals that are present (e.g. benzene, xylene, benzo(a)pyrene etc.).

[2] Health-based and aesthetic guideline values based on the Guidelines for Canadian Drinking Water Quality (Health Canada 2014).

Risk can be reduced by

1. Removing the hazard (e.g., replacing diesel fuel with propane), or,
2. Removing the receptor (e.g., cease use of the water system for human consumption), or,
3. Placing barriers within the pathway to exposure (e.g., secondary containment for fuel tanks), or,
4. Some combination of the above.

Exposure likelihood was initially determined based on the travel time from the hazard to the wells. Based on the proximity of all four water supply wells to each other, we have assumed that travel times are effectively the same to any of the four wells.

Where mitigation measures are in place, such as containment tanks, double-walled tanks or storage of chemicals indoors in chemical storage cupboards, exposure likelihood can be decreased proportionally to the mitigation measure in place. For example, a fuel storage tank with a 1.5 year travel time but with secondary containment could have its exposure likelihood reduced from medium to low. Alternatively, the exposure likelihood should be increased where a hazard is deemed to pose an actual and immediate risk of impacting the water source (such as an AST that has been identified as leaking to ground) or fuel tanks that have been observed to be in poor condition and a spill or leak is considered likely.

We note that for the purpose of this assessment, a conservative approach to microbiological contamination has been taken with the 90 day travel time assigned a very high exposure consequence, and the 1 year and 2 year capture zones being assigned a high exposure consequence. This approach has been adopted due to the potential for rapid transport of microbiological contaminants along preferential pathways (e.g., the infilled slough), the potential for the coarse grained DCA limiting filtration, or with high loadings of microbial pathogens in groundwater, even a 99.9% death/inactivation rate may mean that some pathogens could survive in excess of 90 days, thus creating a potential health risk. Risk reduction in this case does not take into account water treatment processes, and are all related to raw water quality. As mentioned previously, risk posed by bacteria and viruses are inherently reduced through required primary disinfection at the WTP.

For the purpose of this assessment, a conservative approach to hydrocarbon transport has also been taken, with no reduction of contaminant concentration along the travel path assumed.

7.6.1 Risk Assessment Rules

To qualitatively assess exposure likelihood and consequence levels, a set of “rules” were established to provide a systematic, rational framework for reducing levels based on mitigation measures in place and evidence of exposure consequence reduction (as described above). Tables 7-2 and 7-3 detail these rules.

Table 7-2: Exposure Likelihood Rules

Rule Number	Rule
1	Exposure Likelihood reduced by one level for each engineered barrier in place (e.g., double-walled tank, spill containment tank, lined and bermed area, SPC located indoors on concrete slab).
2	▪ Fuel tanks that show evidence of leaks or spills are assigned a Very High Exposure Likelihood. ▪ Fuel tanks that have visible corrosion or damage that could potentially result in a leak, or do not have fuel lines and fittings that allow for movement of the tank or adjacent building are assigned a High Exposure Likelihood.

Rule Number	Rule
	▪ Standard single walled tanks in good condition, with seismic restraint, are assigned a Medium Exposure Likelihood. ▪ Where engineered barriers are in place (such as double walled tank, seismic restraints, leak detection), Exposure Likelihood can be reduced by one level for each appropriate barrier. Note that where a risk has been identified, the barrier must be appropriate to a risk in order to reduce Exposure Likelihood (e.g. a leaking tank in a lined, bermed area can have its Exposure Likelihood reduced, however seismic restraints would not result in a reduction of the Exposure Likelihood from the same leaking tank). For the purpose of this assessment, based on a preliminary review of residential and commercial ASTs during the 2017 field reconnaissance events, ASTs appear in generally good condition and a medium exposure likelihood has been assigned to all identified tanks. We note more detailed assessment of individual tanks should be undertaken and this ranking should be reviewed and revised if necessary.
3	Exposure Likelihood for accidental events based on qualitative estimate of event return period*: ▪ <1-year return period – Likelihood Very High ▪ 1- to 5-year return period – Likelihood High ▪ >5- to 20-year return period – Likelihood Medium ▪ > 20-year return period – Likelihood Low
4	If an environmental assessment has been completed by an environmental/engineering professional, level can be amended to a level proportional to the findings (e.g., environmental assessment may indicate hydrocarbon contamination in groundwater at a particular location nominally within the well capture zone will not impact wells, therefore exposure likelihood reduced to low).
5	Exposure Likelihood for spill, leaks, discharges and disposal to the subsurface within the Klondike River Valley reduced from Very High (assumes a travel time of less than 90 days) to Low based on the significant dilution offered by the Klondike River and results of Klondike River water quality testing in July 2017 indicating no observable impact to water quality from the multiple potential contamination sources.
6	Exposure Likelihood for spill, leaks and disposal <100 L directly to the Klondike River or tributary water bodies reduced from Very High (assuming a travel time of less than 90 days) to Low based on the significant dilution offered by the Klondike River.
7	Exposure Likelihood for spill, leaks and disposal >100 L directly to the Klondike River or tributary water bodies reduced from Very High (assuming a travel time of less than 90 days) to Medium based on the significant dilution offered by the Klondike River.
8	Exposure Likelihood is reduced if a Standard Operating Procedure is in place to mitigate potential exposure. (e.g., CoD SOP #1 – Addressing Seasonal Coliform Spikes which directs the cessation of bleeding (and re-circulation of potentially microbiologically contaminated water) during the high risk mid-April to early May period). Exposure Likelihood should be reduced to a level commensurate to the degree of protection an SOP provides.

Note: *Return period* is an expression of the probability that an event will occur at any time within the period duration (e.g., a 2-year return period means that an event could happen *any time* within a two-year window; not that it will recur at regular two year intervals). For this assessment, approximate return periods for accidents (e.g., tanker road spills) were estimated based on historical and anecdotal information from CoD staff and experienced and knowledgeable local contractors (Grenon Enterprises).

Table 7-3: Exposure Consequence Rules

Rule Number	Rule
1	Given the potential health related consequences of microbiological contaminants, exposure consequence has been assigned: ▪ Very High rating for the <90 day, ▪ High risk for >90 days to 2 years capture zones.
2	Where parameters have long term chronic health effects that may take many years to develop (i.e. impacts from ingestion of benzene from fuels spills/leaks), exposure consequence can be can be reduced to an applicable level where routine water quality monitoring of the contaminants of concern allows impacts to water quality to be identified (and appropriate actions to reduce risk to be taken).
3	Exposure consequence can be reduced to applicable level if area has history >5 years of potentially contaminating activity and no impact has been observed at wells (e.g., fertilizer application on grassed areas).
4	Onsite sewage disposal systems within the Klondike River Valley are assumed to be sited, constructed and maintained in compliance with applicable regulations meaning that biological contaminants should be reduced to below health-based guidelines prior to discharge to a surface water body. This reduces hazard consequence from very high to medium.
5	Exposure Consequence for spill, leaks, discharges and disposal to the subsurface within the Klondike River Valley reduced from Very High (assuming a travel time of less than 90 days) to Low based on the significant dilution offered by the Klondike River and results of Klondike River water quality testing in July 2017 indicating no observable impact to water quality from the multiple potential contamination sources.
6	Exposure Consequence for spill, leaks and disposal <100 L directly to the Klondike River or tributary water bodies reduced from Very High (assuming a travel time of less than 90 days) to Low based on the significant dilution offered by the Klondike River.
7	Exposure Consequence for spill, leaks and disposal >100 L directly to the Klondike River or tributary water bodies reduced from Very High (assuming a travel time of less than 90 days) to Medium based on the significant dilution offered by the Klondike River.

The resulting risk ranking for each hazard, as presented in Tables 4 and 5, is colour-coded to represent the estimated level of risk that risk scenario presents to the community water users. For the purpose of this assessment, given the proximity of all four water supply wells to each other, individual risk rankings have not been determined for each well. Rather, if a potential risk is within the capture zone, it is inferred that there will be equal risk of it impacting each of the four water supply wells. Tables 4 and 5, attached, present evaluations of risk scenarios within the capture zone using the risk evaluation method and risk matrix detailed above. The risk rank results are presented on the Risk Map presented as Figure 10. A summary of identified risk rankings within the Dawson City area is provided in Table 7-4.

Table 7-4: Summary of Risk Rankings – Dawson City Aquifer

Risk Rank	Number of Identified Risks in Category
Low	7
Medium	18
High	20
Very High	5
Total Risks Identified	50

Of the 50 identified SPCs, 5 were identified as Very High risk. These SPCs and their associated contaminants are detailed below:

- DC39 – Dawson City Sanitary System (Pathogens);
- DC40 – Turner Street Sanitary Emergency Outfall (Pathogens);
- DC41 – Dawson City Stormwater System (Pathogens);
- DC42 – Stormwater Discharge to Yukon and Klondike rivers upstream of water supply wells (Pathogens); and
- DC43 – Natural microbiological contaminants in the Klondike River (Microbiological).

Tetra Tech note that the CoD currently have in place mitigation measures (a water treatment system) that reduces the actual risk of microbiological impacts (e.g. Total Coliform, *E.coli*) to users from very high to low, and the CoD are planning to implement additional treatment (filtration and UV treatment) within the next few years to reduce the risk of other natural biological contaminants (protozoa including giardia and cryptosporidium).

7.7 Klondike River Valley

Tetra Tech identified a number of SPCs within the Klondike River Valley that have the potential to impact the KRVA, migrate to the Klondike River and, ultimately, to impact the CoD water supply wells via bank recharge to groundwater and flow to the wells. These SPCs, their locations and associated potential contaminants are detailed in Table 2 and shown on Figure 11.

While defining capture zones based on travel times in the DCA and assessing risk based on exposure likelihood and consequence is a practical approach within the Dawson City area, extending this method to the Klondike River Valley and tributary valleys becomes impracticable for the following reasons:

- The size of the Klondike River Valley and wide distribution of SPCs.
- The paucity of hydrogeological information available in the Klondike River Valley.
- The unknown dilution effect of the Klondike River and other surface water bodies.
- Uncertainties in Klondike River travel time.
- Uncertainties on the rates and seasonal variations of bank recharge to groundwater adjacent to the CoD.

Using the risk-based assessment detailed in Section 7.6, in theory a leaking fuel tank located close to the banks of the Klondike River 10 km from Dawson City may technically be within a 90 day travel time of the water supply wells. Under this scenario, that tank leak would present the same level of risk to the CoD wellfield as a leaking fuel tank located 30 m from the wells. This seems illogical and requires a separate approach for risks posed by contaminants flowing downstream in the Klondike River.

Our perspective is that due to mixing and dilution along the Klondike River, the risk posed to the CoD wellfield from a tank on the banks of the Klondike River is likely to be low, and in some cases negligible compared with the risk from a leaking fuel tank, say, 30 m from the wells. To more accurately determine the risk posed to the wellfield from SPCs in the Klondike River Valley, a detailed hydrogeological and hydrological assessment of the Klondike River Valley area would be required that encompasses all potential SPCs and the mechanics of dilution within the Klondike River and bank recharge to groundwater at the CoD, which is beyond the scope of this assessment.

As an alternative for assessing the risk posed by SPCs within the Klondike River Valley, we have applied a qualitative approach that assumes contaminants that migrate via groundwater flow to the Klondike River are likely to be negligible in volume in comparison to the volume of the Klondike River, and that mixing and dilution along the Klondike River will greatly reduce concentrations and therefore the exposure likelihood and exposure consequence. Similarly, concentrations of contaminants directly discharged to the Klondike River or a tributary are expected to be also greatly reduced along surface water flow paths (i.e., Exposure Likelihood rules 4, 5 and 6 and Exposure Consequence rules 4, 5 and 6). To justify this approach, Tetra Tech collected water quality samples from the Klondike River from east of Rock Creek (approximately 20 km upstream of the CoD water supply wells) and from the confluence of the Yukon and Klondike rivers (approximately 400 m upstream of the wells) in July 2017. Analytical results indicated that at the time of sampling, water quality at both locations was very similar, indicating no discernable impact to water quality from the numerous potential contamination sources located along the Klondike Valley and southern tributaries.

Table 5, attached, presents an evaluation of risk scenarios within the Klondike River Valley using the risk evaluation method and Risk Matrix detailed above. The risk rank results are presented on the Risk Map presented as Figure 11.

To validate this risk ranking approach, the CoD source water quality should be regularly monitored for evidence of impacts from potential upstream SPCs, then further assessed and risks mitigated if required (this monitoring is presented below as a recommendation for future work). This could be accomplished by extension of the July 2017 monitoring program to assess concentrations of potential contaminants (hydrocarbons, nitrate, metals) present in groundwater at the CoD water supply wells and surface water in the Klondike River (as it reaches the CoD). If concentrations of potential contaminants were found to exceed water quality criteria or show an increasing trend (based upon professional review) in either groundwater or surface water, steps could then be taken to identify the source of the contaminant(s) and assess and manage the risks. If source water from the Klondike River is suspected of being a source of contamination, detailed water quality monitoring along the Klondike River or tributaries could be carried out to determine the contamination source(s) source, as well as visual inspection of water bodies and on-land sites where contamination is suspected. This approach allows actual risks to the CoD water supply to be evaluated semi-quantitatively in consideration of water quality data and, if identified, known sources of contamination.

We note that a monitoring program is not a substitute for the initial prevention of contamination. In conjunction with the recommended monitoring program, additional mitigation measures including community education and discussion and collaboration with owners of properties deemed to present a higher risk to the water source are presented in the recommendations section of this AWHPP.

8.0 RISK MANAGEMENT

8.1 Risk Management Strategy

Risk management strategies integrate information collected during the capture zone delineation and hazard identification steps and provides workable strategies for preventing, detecting, and responding to wellhead protection risks. The following includes examples of such strategies:

- Endorsing and promoting best management practices (BMPs) in handling, treating, distributing and protecting the water resource. In this context, BMP refers to the best currently available, effective and cost-efficient means toward the ends within the current regulatory framework in Yukon;
- Providing public and landowner information sessions and training;
- Periodic inspections and/or reviews of the AWHPP and wellhead areas; and
- Implementing Action and Management Strategies (provided in Tables 4 and 5).

The risk scenarios identified in this AWHPP are both existing and potential. A number of steps to mitigate certain risks are already underway such as replacement of a number of sanitary sewer lines and manholes in the southern end of Dawson City and upgrading the water treatment system for a GUDI source. Based on the AWHPP assessment, the most appropriate risk management for the CoD water supply system will be a multi-barrier approach including preventative action to reduce risks at sources, mitigation measures such as water treatment, and contingency planning in the event that one of the potential risk scenarios occurs.

In terms of risk communication, the Risk Maps provided with this report and the Risk Information Posters provided as an adjunct to this report can form a concise and convenient basis for communicating risk information to all stakeholders, including the risk management team, water system operators, community organizations, local contractors and residents. Implementation of recommendations in this report, regular scheduled assessment of risks, and review and update of this AWHPP are important to document progress, improve public perception, reduce potential legal liability and possibly reduce insurance costs.

Based on the findings of this AWHPP, we have defined Protection Areas within Dawson City and the Klondike River Valley. The Dawson City-Wellhead Protection Area (DC-WPA) is shown in Figure 12 and has been conservatively defined based on the high to very high risk that can be attributed to microbiological and hydrocarbon contaminants within the Dawson City capture zones, and therefore the necessity to protect the aquifer within this area. The Klondike River Valley – Watershed Protection Area (KRV-WSPA) (Figure 13) has been conservatively defined as the area that encompasses residential, commercial and mining development in the valley and tributary valleys. This broad area has been defined based on the Klondike River watershed, identified SPCs within the watershed, and the current uncertainties in relation to their actual impacts to the CoD water supply.

All existing and future development within the defined WPAs that has the potential to contaminate groundwater and or surface water in the WPAs should be assessed in on-going AWHPP reviews.

8.2 Risk Reduction Planning

Risk reduction planning involves pre-planning actions to respond to risks situated within the capture zone. For example, this would include emergency response actions and communication should a contaminant release occur within a well capture zone.

A list of identified risk reduction and management strategies is provided in Tables 4 and 5.

We note that in conjunction with the development of this AWHPP, Tetra Tech has developed a SW-ERP to address some acute risks to the CoD source water supply. The SW-ERP builds on existing emergency response planning and has been incorporated into the findings and risk reduction measures identified in this AWHPP.

8.3 Risk Monitoring

A Risk Monitoring Plan involves periodic reviewing, auditing and updating of the Risk Maps and Risk Database. Once an AWHPP is in place, continued implementation of the program is essential for it to be worthwhile. The Risk Monitoring Plan entails periodically inspecting the community wells and well sites; periodically inspecting the capture zones for new, moved or absent hazards; working together with the residents and other stakeholders in CoD to identify and create zoning by-laws for the CoD area; reviewing the capture zone areas for new potential risks and updating the status for each identified risk as risk management actions are implemented. The outcome of this would be revised Risk Maps for display or reporting purposes.

Tetra Tech has identified the key areas where risk monitoring will be effective for reducing the risk to the CoD source water. These are included in the Tables 4 and 5 (attached).

At minimum, in addition to the risk reduction measure identified in Tables 4 and 5, yearly inspections should be conducted by a suitably qualified CoD Water Systems Operator and inspections by a suitably experienced engineer/hydrogeologist should be conducted every five years within the WPA to review and identify SPCs that may place any of the four water supply wells or the aquifer at a whole at risk.

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

The following conclusions are made based on this AWHPP study:

- The CoD municipal water supply is provided by four groundwater supply wells PW-1N, PW-2N, PW-3N, and PW-4N. The four wells are completed in a relatively shallow unconfined sand and gravel aquifer (the Dawson City Aquifer “DCA”), which is reported to be susceptible to contamination introduced at or near ground surface and under the direct influence of surface water (GUDI).

- The DCA is considered to be strongly hydraulically connected to the Klondike and Yukon rivers. Tetra Tech modelling indicates that approximately 90% of water pumped by the wells is drawn geographically from the Yukon River channel to the west. Approximately 5% of water is drawn from the capture zones extending to the east and south and ultimately from the Klondike River, and the remaining 5% is from recharge of precipitation, overland flow and horizontal leakage from adjacent silts in the active zone above permafrost. Based on the shallow gravel bar diverting Yukon River flow under low water conditions and lack of mixing at the confluence of the Yukon and Klondike rivers under high water conditions, Tetra Tech considers that water inferred to be pumped from the Yukon River is most likely sourced from the Klondike River and is representative of Klondike River water quality. Therefore, while geographically the capture zone intercepts the Yukon River, Tetra Tech considers that there is effectively no contribution from actual Yukon River water to the CoD drinking water supply.

- Modelling by Tetra Tech (2017) estimated that the fastest travel time from the Yukon River channel to the wellfield, under average river elevations, is 37 days and from the Klondike River to the wellfield (beneath the City of Dawson) is 1.6 years. However, during times of high groundwater elevation, the infilled slough running NW-SE through the middle of the City may provide a preferential pathway for shallow groundwater (and contaminant) flow, and travel times may be less than those calculated above.
- The capture zones of the four CoD water supply wells within Dawson City intercept a number of SPCs including: the City of Dawson Wastewater Treatment Plant; portions of the CoD sanitary sewage system; former contaminated sites, heating fuel tanks at residential and commercial properties; and water sourced from the Klondike River. Given the contamination potential that exists up the Klondike River Valley, and potential for migration of contamination along the Klondike River and tributaries, a wellhead protection area has been has been defined within the Klondike River Valley (up to Henderson Corner) and tributary valleys to the south that include current and historical placer mining operations.
- Raw water quality data from the four current water supply wells indicate that, other than bacteriological exceedances, raw water quality is generally good, with concentrations of general water quality parameters below the aesthetic and health-related parameters of the Guidelines for Canadian Drinking Water Quality (GCDWQ) in samples collected in 2015, 2016 and 2017.
- The former and current wellfield have a history of bacteriological exceedances. Tetra Tech considers these observances are likely related to:
  - High bacterial load in the surface water source (the Klondike River) during the spring breakup period.
  - Surcharge of the sanitary sewage system and subsequent use of the Turner Street outfall.
  - Leakage of wastewater from the sanitary sewage system directly to the DCA. Impacts may be exacerbated during seasonal high groundwater elevations in spring (mid-April to early May) which will reduce the unsaturated soil absorption and treatment zone.
- Wells at the southern end of the wellfield have historically had a higher incidence of bacteriological observances, potentially due to:
  - Southern wells are closest to the Yukon and Klondike river confluence and the channel that flows past the wells, resulting in an inferred shorter travel time from the channel and potentially insufficient filtration.
  - Wells in the south of the field are closer to the Turner Street outfall and potentially surcharged sanitary sewer lines, and potentially closer to leaking sewer lines.
- Recent increases of bacteriological occurrences in new wells in the north end of the wellfield (PW-1N, PW-2N) are likely related to cross-contamination associated with the practice of bleeding raw water between wells to prevent freeze up rather than each of the wells being impacted at the groundwater source.
- The highest identified risks presented to the CoD source water quality are identified as:
  - DC39 – Dawson City Sanitary System (Pathogens);
  - DC32 – Potentially improperly constructed (lacking seismic restraint, poor condition) heating fuel tanks within the 90 day travel time zone (Hydrocarbons);
  - DC40 – Turner Street Sanitary Emergency Outfall (Pathogens);
  - DC41 – Dawson City Stormwater System (Pathogens);

  - DC42 – Stormwater Discharge to Yukon and Klondike rivers upstream of water supply wells (Pathogens); and
  - DC43 – Natural microbiological contaminants in the Klondike River (Microbiological).
- Tetra Tech note that the CoD currently have in place mitigation measures (a water treatment system) that reduces the actual risk of microbiological impacts (e.g. Total Coliform, E.coli) to users from very high to low, and we understand that there has never been indicators such as total coliform or *E.coli* detection in the treated water supply.
- The CoD are planning to implement additional treatment (filtration and UV treatment) within the next few years to reduce the risk of other natural biological contaminants (protozoa including giardia and cryptosporidium).
- The current water treatment process does not have the ability to treat organic contaminants such as hydrocarbons from a fuel or oil spill.
- Tetra Tech collected water quality samples from the Klondike River in July 2017. One sample was collected from east of Rock Creek (approximately 20 km upstream of the CoD water supply wells) and the second the confluence of the Yukon and Klondike rivers (approximately 400 m upstream of the wells). Analytical results indicated that at the time of sampling, water quality at both locations was very similar, indicating no discernable impact to water quality from the numerous potential contamination sources located along the Klondike Valley and southern tributaries.
- Based on the findings of this AWHPP, we have defined protection areas within Dawson City and the Klondike River Valley. The DC-WPA has been conservatively defined based on the risk that can be attributed to microbiological and chemical contaminants within the Dawson City capture zones, and therefore the necessity to protect the aquifer within this area. The KRV-WSPA has been conservatively defined as the area that encompasses residential, commercial and mining development in the valley and tributary valleys. This broad area has been defined based on the SPC within the valley and the uncertainties in relation to their actual impacts to the CoD water supply.

9.2 Recommendations

The following recommendations are made based on this AWHPP:

- A Risk Management Team should be formed to:
  - Consider the risk reduction and source removal options presented in Tables 4 and 5.
  - Periodically review and update the issued for use AWHPP and direct recommended work to ensure this AWHPP is current, relevant and protects the CoD water source adequately.
- Future developments should ensure that regulatory setback requirements are followed as detailed in the Yukon *Public Health and Safety Act*, Drinking Water Regulation, Part 1 Section 9.
- Review and update this AWHPP on a regular basis. Every five years may be sufficient or as required due to changes affecting the well system, activities near the community supply wells that might result in additional risks, or when risks have been addressed and mitigated;
- Incorporate this AWHPP and defined WPAs into the CoD community development planning and future zoning planning, including enforcement of well protection measures.
- Formal recognition and protection status for the identified WPAs.

- All proposed commercial/industrial development within the WPAs that have the potential to contaminate groundwater are assessed by a qualified and experienced engineer/hydrogeologist in the context of this AWHPP and risk reduction measures implemented if required. Higher risk land uses should include a response action plan and remedial action plans as a condition of a development Permit.
- Undertake an education program (through signage, meetings and brochures) to inform the public of the WPA's, the water source and its value to the community, actions that contaminate groundwater in Dawson City or the Klondike River and have the potential to impact the CoD's drinking water source.
- All fuel storage tanks in the WPA should be assessed for general condition, structural integrity/ seismic restraint, evidence of leaks or spills, deficiencies, recommended upgrades noted and the risk revised, if necessary, based on Exposure Likelihood Rule 2
- Where there is bulk storage of fuel in close proximity (<200 m) to the Klondike River (e.g., AFD Petroleum depot, Trans North Helicopters) discussion should be had with property managers/owners to inform them of the potential risk to the CoD water supply, importance of rapid and effective actions including notifying CoD should spills or leaks occur and to request review of mitigation measures in place.
- The CoD should implement water treatment suitable for a GUDI source. *Tetra Tech understands that CoD and YG-IDB are currently in the planning stage for this work.*
- The CoD should upgrade/replace the sanitary sewer system within the DC-WPHA where there is considered to be potential leakage of wastewater that could affect groundwater (such as along Front Street and the Turner Street outfall). *Tetra Tech understands that CoD and YG-IDB are currently in the planning stages for this work.*
- Discussions should be had with local heating fuel providers to discuss the AWHPP, the potential for spills and leaks to impact the drinking water source and the importance of reporting all spills to Environment Yukon and CoD. CoD should investigate the feasibility of fuel delivery contractors providing regular reports on the condition of residential and commercial heating tanks so that CoD can undertake further investigation, if required.
- CoD should establish connections with Environment Yukon so that they are notified immediately of reported spills within the WPA and the appropriate ERP can be initiated, if warranted.
- An alternative to the current bleeding system be developed that eliminates the potential for cross contamination between wells or introduction of contamination to wells.
- A routine monitoring program should be implemented to assess concentrations of potential contaminants (hydrocarbons (LEPH, HEPH, BTEX), propylene glycol, nitrate, metals) present in groundwater at the CoD water supply wells and surface water in the Klondike River (at the same locations as the July 2017 monitoring event). We recommend at minimum, one year of quarterly monitoring of all parameters, followed by semi-annual (freshet and low flow) monitoring of all parameters in subsequent years. The analysis list and sample schedule should be reviewed each year by a qualified and experienced engineer/hydrogeologist and amended based on results and identified potential risks.
- All water wells and monitoring wells within the DC-WPA should be identified and their status assessed. With the permission of the well owner, wells should either be upgraded to current construction standards (if still in use) or decommissioned and abandoned (if unused) in accordance with Environment Yukon Protocol 7 – Groundwater Monitoring Well Installation, Sampling and Decommissioning (monitoring wells).

- Following the assessment and upgrade/decommissioning (where appropriate) of monitoring wells within the DC-WPA, select wells should be incorporated into a routine monitoring program to assess concentrations of potential contaminants (hydrocarbons (LEPH, HEPH, BTEX), propylene glycol, nitrate, metals) present in the DCA. Tetra Tech recommends that if YOWN-0803 and 1200023-MW01 are in a suitable state for monitoring, these two wells should be incorporated into the monitoring program. We note that permission will need to be sought from Environment Yukon Water Resources Branch to access YOWN-0803. We recommend at minimum, one year of semi-annual monitoring of all parameters (spring and late summer), followed by annual (late summer) monitoring of all parameters in subsequent years. The analysis list and sample schedule should be reviewed each year by a qualified and experienced engineer/hydrogeologist and amended based on results and identified potential risks. This review should include consideration of adding additional monitoring wells to suitably assess impact to the DCA and risk to the four drinking water wells. Emergency response procedures in the SW-ERP should continue to be updated as potential risks to the water source are identified.

- CoD should endorse and promote waste minimization and collection programs (e.g., hazardous material collection days) to ensure that new sources of contamination are not introduced in the WPAs.

10.0 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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Oct 11, 201

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TABLES

Table 1: Summary of Potential Sources of Contamination - Dawson City

ID	Site	Address	Easting	Northing	Time Period	Approximate Distance from Wells (m)	Source of Potential Contamination	Potential Contaminants	Zone	Travel Time	Hazard Description
DC01	Residential Dwelling	North side of Turner St b/w 5th and 6th.	576293	7104094	Current	350	44 gal drums, old trucks/cars stored on site.	Petroleum Hydrocarbons, PAHs, solvents, other unknown chemicals	3	1-2 years	Spills, leaks, disposal, releases of oils/solvents to ground, migration of contaminants from this site could potentially introduce hydrocarbons to the DCA and ultimately impact water supply wells.
DC02	Dawson City Swimming Pool	5th Ave	576284	7104165	Current	290	Range of chemicals stored on site used to clean and dose pool, clean facility.	Calcium chloride 77% Sodium Bicarbonate Sodium Thiosulphate Sodium Sulphate (X IT) Sodium Carbonate/Soda Ash Hypochlorite (Briquettes) Hydrochloric Acid/Muriatic Acid Liquid Chlorine/Sodium Hypochlorite Accel Prevention Concentrate/Virox	2	90 days -1 year	Spills, leaks, disposal, releases of chemicals to ground, migration of contaminants from this site could potentially introduce hydrocarbons to the DCA and ultimately impact water supply wells. Chemicals are stored indoors in specific storage areas with mitigates potential for release. None of the listed potential contaminants are listed in the Guidelines for Canadian Drinking Water Quality. Review of MSDS sheets indicate calcium chloride, sodium carbonate, hypochlorite, hydrochloric acid, liquid chlorine, virox are potentially hazardous to human health.
DC03	Waste Water Treatment Plant	5th Ave	576286	7104263	Current	210	Wastewater released to ground due to mechanical failure/human error	Septage; coliform and non-coliform bacteria; viruses; nitrates; heavy metals; synthetic detergents; cooking and motor oils; bleach; pesticides; paints; paint thinner; swimming pool chemicals; septic tank/cesspool cleaner chemicals elevated levels of chloride, sulfate, calcium, magnesium, potassium, and phosphate, emerging contaminants (e.g. antibiotics, anti-inflammatories, lipid regulators, caffeine, carbamazepine and N,N-diethyl-m-toluamide (DEET))	2	90 days -1 year	Mechanical failure or human error at the WWTP has the potential to release raw and/or treated sewage to ground within the WWTP compound. Releases such as theses have occurred in the past, the most recent being two events in 2013 and 2014 where wastewater backed up within the WWTP, over flowed into the interior of the building then under doors to the exterior of the building. Discussions with CoD indicate that these events may have been due to the previous WWTP operators inadequate maintenance schedule. CoD said that now that YG have taken over operation of the WWTP they have more confidence similar events should not occur in the future.
DC04							"Deep Shaft" wastewater treatment system		2	90 days -1 year	Leakage of wastewater (raw, treated or partially treated) from the "deep shaft" treatment process to the DCA or the bedrock aquifer.
DC05							Piezometer at influent sump		2	90 days -1 year	The piezo allows a direct and rapid connection between surface and the DCA. Wastewater overflow and chemical spills could travel directly down the piezo and into the DCA. Chemicals could also be deliberately/inadvertently disposed into the piezo.
DC06							Outside double walled AST Diesel Fuel Tank - 28,000 L	Petroleum Hydrocarbons	2	90 days -1 year	Spills or leaks have potential to rapidly release large volume of diesel to ground, migration of contaminants from this site could potentially introduce large volumes of hydrocarbons to the DCA and ultimately impact water supply wells.
DC07							Indoor double walled AST Diesel Fuel Tank secured to concrete floor- Approx. 1,000 L	Petroleum Hydrocarbons, PAHs	2	90 days -1 year	Potential for spill or leak to migrate outside of building and to subsurface.
DC08							Indoor double walled AST Diesel Fuel Tank secured to concrete floor- Approx. 1,000 L	Petroleum Hydrocarbons, PAHs	2	90 days -1 year	Potential for spill or leak to migrate outside of building and to subsurface.
DC09	Sink hole outside of front of museum	5th Ave	576363	7104304	Historical	265	Unknown, land subsidence may indicate degradation of organic matter, rusting and collapse of metal waste.	Unknown, potential range of organic or inorganic substances	2	90 days -1 year	Nature of backfill material is undocumented and unknown. Potential exists for organic and inorganic substances with potential to contaminate groundwater.
DC10	Ambulance Station	637 Fifth (Corner of 5th Ave and Church St)	576382	7104395	Current	260	2 x 44 gal drums approx. 1/5 to 1/4 full, not labeled placed outside entry and close to vehicle parking area.	Unknown	3	1-2 years	Unknown substance in drums have the potential to being released to ground if tipped or container leaks.
DC11	Former Alexander McDonald Lodge	Corner of 4th Ave and Fifth Ave	576356	7104335	Current	245	1 x 1m3 liquid container outside building on southeast corner	Unknown, property fenced off, unable to enter to assess contents.	3	1-2 years	Unknown substance in container has the potential to being released to ground if container leaks.

Table 1: Summary of Potential Sources of Contamination - Dawson City

ID	Site	Address	Easting	Northing	Time Period	Approximate Distance from Wells (m)	Source of Potential Contamination	Potential Contaminants	Zone	Travel Time	Hazard Description
DC12	Water Treatment Plant	Corner of 5th Ave and Dugas St	576176	7104085	Current	320	Indoor double walled AST Diesel Fuel Tank - Approx. 680 L, placed in spill container	Petroleum Hydrocarbons, PAHs	3	1-2 years	Potential for spill or leak to migrate outside of building and to subsurface.
DC13		Corner of 5th Ave and Dugas St	576163	7104083	Current	0	Outdoor AST Diesel Fuel Tank - 10,000, operator unsure if double walled	Petroleum Hydrocarbons, PAHs	3	1-2 years	Spills or leaks have potential to rapidly release large volume of diesel to ground, migration of contaminants from this site could potentially introduce hydrocarbons to the DCA and ultimately impact water supply wells.
DC14		Corner of 5th Ave and Dugas St	576176	7104085	Current	0	Range of oils, acids, paints, antigels in chemical storage cupboard in workshop	Petroleum Hydrocarbons, hydrocarbons, glycol ether acids	3	1-2 years	Potential for release to ground and migration to DCA.
DC15	Hospital	Sixth Ave	576391	7104239	Current	320	6 x empty drums placed in public area at south end of property, adjacent to ball field	Propylene Glycol	3	1-2 years	Drums are place outside in public area. Drums can degrade with exposure to cold and sunlight. If drums are not washed and chemical residue remains the potential exists for migration of chemicals to subsurface and the DCA if drums leak or are tipped over.
DC16		Sixth Ave	576439	7104218	Current	320	Underground fuel storage tanks located at southwest corner of building	Petroleum Hydrocarbons, PAHs	3	1-2 years	Subsurface leaks from the UST could release large volume of hydrocarbons to DCA prior to being detected. Spills during filling of the UST has potential to release hydrocarbons to the subsurface and the DCA.
DC17	Area between Hospital and Museum	Between 5th Ave and 6th Ave	576411	7104277	Current	310	Soil and groundwater impacted by hydrocarbons from former UST	Petroleum Hydrocarbons, PAHs	3	1-2 years	Existing groundwater and soil contamination. Environmental site assessment concluded that locally, groundwater is not migrating towards the well capture zone.
DC18	Museum	5th Ave	576401	7104291	Current	270	Above ground fuel tank - approximately 10,000 L	Petroleum Hydrocarbons, PAHs	3	1-2 years	Spills during filling and leaks could introduce hydrocarbons to the soil and DCA that could ultimately migrate to the drinking water wells,
DC19	Slough behind church	North end of park area behind Commissioners Residence	576236	7104449	Current	125	Use of Vectobac (biological larvacide in pellet form used for mosquito control)	"VectoBac®" proprietary chemical	1	< 90 days	Vecto Bac is a biological larvacide used to control mosquitos. Safety data sheets state VectoBac is not to be applied directly to treated finished drinking water reservoirs or drinking water receptacles when water is intended for human consumption.
DC20	Ball Park	B/w 5th and 7th Ave	576360	7104188	Current	330	25-10-10 Fertilizer	Nitrogen, Phosphorus, Potassium	2	90 days -1 year	Use of fertilizers can correlate with nitrate contamination in groundwater. Direct application to ground in open grassed areas provided the potential for migration to the DCA, particularly if excessively applied.
DC21	Grassed area behind Commissioners residence	End of 4th St	576265	7104372	Current	150	25-10-10 fertilizer	Nitrogen, Phosphorus, Potassium	2	90 days -1 year	
DC22	Grassed area corner of Church St and Fifth Ave	Corner of Church St and Fifth Ave	576423	7104342	Current	310	25-10-10 fertilizer	Nitrogen, Phosphorus, Potassium	2	90 days -1 year	
DC23	Grassed area along river front between Eighth Ave and Princess St	-	-	-	Current	-	25-10-10 fertilizer	Nitrogen, Phosphorus, Potassium	1	< 90 days	
DC24	YG Property Management Compound	5th Ave (access off 4th Ave)	576283	7104285	Current	200	Approx. 20 x 44 gal drums storing old heating fuel and water. Potential for other unknown hydrocarbons in drums. Placed on pallets within a berm with sealed liner. Three years of accumulated waste.	Petroleum Hydrocarbons, PAHs	2	90 days -1 year	Leaks from corroded/split drums or spills during transport from drums has potential to migrate to the subsurface and to the DCA. Placement of containers in a bermed and lined area provides mitigation against migration to the sub surface.
DC25		5th Ave (access off 4th Ave)	576300	7104287	Current	200	44 gal drum storage - Dowfrost HD 50/50 used for heat transfer fluid for heating and air conditioning systems.	Propylene Glycol	2	90 days -1 year	Leaks from corroded/split drums or spills during transport from drums have the potential to migrate to the subsurface and to the DCA.
DC49		5th Ave (access off 4th Ave)	576272	7104243	Current	200	44 gal drum storage - Dowfrost HD 50/50 used for heat transfer fluid for heating and air conditioning systems, Isopac 80 used as a coagulant and flocculent.	Propylene Glycol, Aluminum Chlorohydrate	2	90 days -1 year	Leaks from corroded/split drums or spills during transport from drums have the potential to migrate to the subsurface and to the DCA.

Table 1: Summary of Potential Sources of Contamination - Dawson City

ID	Site	Address	Easting	Northing	Time Period	Approximate Distance from Wells (m)	Source of Potential Contamination	Potential Contaminants	Zone	Travel Time	Hazard Description
DC26	Yukon Energy Corporation	Corner of 5th and Dugas	576132	7104044	Current	360	Above ground diesel tank - approximately 113,000 L. Single wall, placed in steel containment tank designed to hold tank volume, all within berm.	Petroleum Hydrocarbons, PAHs	3	1-2 years	Spills during filling and leaks could introduce hydrocarbons to the soil and DCA that could ultimately migrate to the drinking water wells. Mitigation measures including tanks being placed in containment tanks and within a bermed containment area reduce potential for impact to DCA. Highest hazard likely to come from spills and leaks during filling the tanks from diesel tanker.
DC27		Corner of 5th and Dugas	576132	7104044	Current	360	Above ground diesel tank - approximately 22,500 L. Single wall, placed in steel containment tank designed to hold tank volume, all within berm.	Petroleum Hydrocarbons, PAHs	3	1-2 years	
DC28		Corner of 5th and Dugas	576134	7104003	Current	360	Engine oil storage in sea can at southeast corner of compound	Petroleum Hydrocarbons, PAHs	3	1-2 years	Impact to groundwater from spilt/leaking containers. Mitigation measures include storage in a sea can lined with high density plastic reduce risk of migration to the sub surface.
DC29	Parks Canada	North side of Turner St between Front St and 5th Ave	576144	7104197	Historical	200	Above ground fuel tank - approximately 5,000 L. Parks Canada staff present advised that the tank is empty and not used. No berm/containment	Petroleum Hydrocarbons, PAHs	2	90 days -1 year	While tank is currently empty potential for future use exists. With no liner or containment, spills or leaks have the potential to migrate to the subsurface.
DC30		North side of Turner St between Front St and 5th Ave	576156	7104201	Historical	200	Leak from a fuel feed line from an above ground storage tank (AST) led to soil contamination in 2001. Characterization samples of the estimated 300 m3 contaminated material excavated were above CSR-CL standards. Env Yukon file holds no record of confirmatory samples or final volume contaminated material removed from the site	Petroleum Hydrocarbons, PAHs	2	90 days -1 year	There is potentially residual hydrocarbon contamination present in soil that may be an ongoing source of groundwater contamination. Given the long term of the contamination (16 years) and hydrocarbons were not detected in groundwater samples collected in 2014, potential for impact is likely low.
DC31		North side of Turner St between Front St and 5th Ave	576150	7104191	Current	200	8 x 44 gal drums, believed to contain propylene glycol for heating/air conditioning. Drums are approx. full to half full.	Propylene Glycol	2	90 days -1 year	Potential exists for migration of chemicals to subsurface and the DCA if drums leak or are tipped over.
DC32	Multiple Locations Within Zone 1	-	-	-	Current	Multiple Locations	Most buildings within the wells capture zone area have AST's for heating fuel located outside and adjacent to the buildings.	Petroleum Hydrocarbons, PAHs	1	< 90 days	Potential for spills or leaks from tanks to migrate to the DCA then to water supply wells
DC33	Multiple Locations Within Zone 2	-	-	-	Current	Multiple Locations	Most buildings within the wells capture zone area have AST's for heating fuel located outside and adjacent to the buildings.	Petroleum Hydrocarbons, PAHs	2	90 days -1 year	Potential for spills or leaks from tanks to migrate to the DCA then to water supply wells
DC34	Multiple Locations Within Zone 3	-	-	-	Current	Multiple Locations	Most buildings within the wells capture zone area have AST's for heating fuel located outside and adjacent to the buildings.	Petroleum Hydrocarbons, PAHs	3	1-2 years	Potential for spills or leaks from tanks to migrate to the DCA then to water supply wells

Table 1: Summary of Potential Sources of Contamination - Dawson City

ID	Site	Address	Easting	Northing	Time Period	Approximate Distance from Wells (m)	Source of Potential Contamination	Potential Contaminants	Zone	Travel Time	Hazard Description
DC35	Former Dawson City Hwy Maintenance Camp	5th Ave	576191	7104170	Current	240	Significant amount of assessment work has been completed on this property, but some areas still have potential contamination remaining	Petroleum Hydrocarbons, PAHs	2	90 days -1 year	There is potentially residual hydrocarbon contamination present in soil that may be an ongoing source of groundwater contamination. Given the long term nature of the contamination and that hydrocarbons were not detected in groundwater samples collected in 2014, potential for impact is unlikely.
DC36	Apartment block at 5th Ave & Turner Street / Former Dawson City Hwy Maintenance Camp	5th Ave & Turner Street	576226	7104257	Current	250	Soil sampling indicates petroleum hydrocarbon contamination	Petroleum Hydrocarbons, PAHs	2	90 days -1 year	There is potentially residual hydrocarbon contamination present in soil that may be an ongoing source of groundwater contamination. Given the long term nature of the contamination and that hydrocarbons were not detected in groundwater samples collected in 2014, potential for impact is low
DC37	RCMP Station, 415 Front Street	RCMP Station, 415 Front Street	576159	7104283	Current	320	Minor undefined contamination (as described in Environment Yukon spill report) may remain onsite.	Unknown	1	< 90 days	Nature of contaminant is unknown. Potential exists for organic and inorganic substances with potential to contaminate groundwater. Given the long term nature of the contamination and that hydrocarbons were not detected in groundwater samples collected in 2014, and tested parameters have been at concentrations below drinking water guidelines, potential for impact is low
DC38	Former slough running NW to SE across southern end of Dawson City.	-	576298	7104372	Historical	183	Several cars removed from slough behind YG Property Management Compound, other potential unknown contaminants.	Petroleum Hydrocarbons, PAHs, propylene glycol, various unknown chemicals	2	90 days -1 year	Nature of backfill material is undocumented and unknown. Potential exists for organic and inorganic substances with potential to contaminate groundwater. Given the long term nature of the contamination and that hydrocarbons were not detected in groundwater samples collected in 2014, and tested parameters have been at concentrations below drinking water guidelines, potential for impact is low
DC39	Dawson City Sanitary System	-	Shown on Figure 5		Current	Multiple Locations	Sanitary Sewer System runs throughout all streets in the City and is connected to al buildings. Leakage has the potential to contaminate groundwater.	Septage; coliform and non-coliform bacteria; viruses; nitrates; heavy metals; synthetic detergents; cooking and motor oils; bleach; pesticides; paints; paint thinner; swimming pool chemicals; septic tank/cesspool cleaner chemicals elevated levels of chloride, sulfate, calcium, magnesium, potassium, and phosphate, emerging contaminants (e.g. antibiotics, anti-inflammatories, lipid regulators, caffeine, carbamazepine and N,N-diethyl-m-toluamide (DEET))	1	< 90 days	Leakage of wastewater from the sanitary sewer lines has the potential to migrate to the DCA then to the drinking water wells. The sanitary system throughout all of Dawson City has been documented to have pipe sags, collapse, deformation, joint displacement, service connection protrusion and debris accumulation, all of which potentially allow the leakage of raw wastewater to the subsurface. CoD staff advised Tetra Tech that manholes are considered to be in poor condition and are likely to provide pathways for wastewater to migrate to the DCA. Where sanitary pipes leak, wastewater may migrate following the fall of the pipeline along excavated trenches backfilled with coarse fill material.
DC40	Turner Street Sanitary Emergency Outfall	End of Turner St	576047	7104232	Current	100	Discharge to the Yukon River form the Turner Street Sanitary Emergency Outfall	Septage; coliform and non-coliform bacteria; viruses; nitrates; heavy metals; synthetic detergents; cooking and motor oils; bleach; pesticides; paints; paint thinner; swimming pool chemicals; septic tank/cesspool cleaner chemicals elevated levels of chloride, sulfate, calcium, magnesium, potassium, and phosphate, emerging contaminants (e.g. antibiotics, anti-inflammatories, lipid regulators, caffeine, carbamazepine and N,N-diethyl-m-toluamide (DEET))	2	90 days -1 year	This location serves as the discharge point for raw sewage when the gravity sewer system in the southern end of the city becomes surcharged and wastewater elevations rise sufficiently to flow into the emergency discharge pipe. Surcharging may exacerbate leakage from sanitary lines and effectively result in a slug of raw wastewater being released from one or more locations to the subsurface and DCA in a short period of time. The Turner St Emergency Outfall is located upstream of the inferred well captures zone that intersects thee Yukon River. When discharged to the Yukon River, contaminants have the potential to be drawn from the river into the well capture zone and migrate to the drinking water wells.
DC41	Dawson City Stormwater System	-	Shown on Figure 4		Current	Multiple Locations	Leakage from the stormwater system that runs throughout Dawson City	Urban runoff; gasoline; oil; other petroleum products. Microbiological contaminants, particularly from canine faces during spring thaw.	Multiple	90 days -1 year	Contaminants in stormwater have the potential to migrate to the subsurface through cracks/breaks in the stormwater lines. Where large concentrated releases of a contaminant enter the stormwater system, there may be potential for impact to the DCA if a pathway exists.
DC42	Stormwater Discharge to Yukon and Klondike Rivers upstream of water supply wells	End of 7th Ave, Dugas St and Turner St	-	-	Current	Multiple Locations	Stormwater Discharge to Yukon and Klondike Rivers upstream of water supply wells	Urban runoff; gasoline; oil; other petroleum products. Microbiological contaminants, particularly from canine faces during spring thaw.	2	90 days -1 year	Contaminants in stormwater have the potential to migrate to the subsurface through cracks/breaks in the stormwater lines. Where large concentrated releases of a contaminant enter the stormwater system, there may be potential for impact to the DCA if a pathway exists.
DC43	Klondike River	-	576063	7104379	Current	40	Water sourced from the Klondike River that enters the Dawson City Aquifer and is within the well capture zones	Natural biological contaminants - protozoa including giardia, cryptosporidium, bacteriological	1	< 90 days	Potential for contaminants to be transported from upstream in the Klondike or Yukon Rivers and be drawn from the river into the well capture zone and migrate to the drinking water wells.
DC44	Potential for multiple locations across capture zone	-	-	-	Current	Multiple Locations	Spills, disposal, leaks, dumping of chemicals in private residences or public places throughout the capture zone.	Hydrocarbons, other unknown chemicals	Multiple	Multiple	Potential for spilled, disposed, leaked, dumped chemicals to migrate to the water table.
DC45	Vehicle accident	-	-	-	Current	Multiple Locations	Vehicle accident and subsequent release of fuel. Trucks with tidy tanks and tankers pose higher potential risk.	Hydrocarbons, other unknown chemicals	Multiple	Multiple	Potential for spilled/leaked fuel to migrate to the water table.
DC46	PW-1N PW-2N PW3N PW4N	-	576137 576124 576112 576100	7104442 7104412 7104385 7104357	Current	0	Bleeding water sourced from the raw water feed to prevent freeze-up	Biological	1	< 90 days	Bleeding using raw water provides the potential for contaminants to be migrated between wells. CoD Public Works staff consider that this is the likely mechanism responsible when there were positive coliform hits of all four wells in 2016, at a time when the bleeding system was operational.
DC47	Multiple	-	-	-	Current	Multiple Locations	Groundwater monitoring wells within the well capture zone	Multiple including hydrocarbons, biological, nutrients.	2	90 days -1 year	Groundwater monitoring wells provide a direct pathway to the DCA. Various chemicals could enter the DCA either through deliberate or inadvertent disposal into the well casing or rapid infiltration between the casing and subsurface if an adequate surface seal is not in place.
DC48	Northern Industrial Supplies (former White Pass and Yukon Route Building)	Corner of Front Street and Harper Street	576241	7104562	Historical	210	Anecdotal information that a spill/leak occurred from a heating fuel tank and was not cleaned up.	Petroleum Hydrocarbons	2	90 days -1 year	Potential for contaminants to migrate to the subsurface and to the DCA.
DC50	Lane at rear of Northern Industrial Supplies	Corner of Front St and Harper St	576266	7104566	Current	230	Car/truck batteries in lane at immediate rear of NIS	Sulfuric acid, lead,	2	90 days -1 year	Potential for contaminants to migrate to the subsurface and to the DCA.

Table 2: Summary of Potential Sources of Contamination - Klondike River Valley

ID	Field ID	Site	Easting	Northing	Time Period	Approximate Distance from Klondike River/ Tributary Creek (m)	Source of Potential Contamination	Potential Contaminants	Hazard Description
KRV01	01	Former gold processing facility and dredging operational headquarters at Bear Creek	585791	7101245	Historic	<100	Leaks, spills, deliberates disposal of various chemicals to water bodies and to ground during former Site operations.	Solvents, petroleum hydrocarbons, metals (incl. mercury), polychlorinated biphenyls	Spills or leaks of hydrocarbons/oils/solvent/other chemicals related to mining t ground, migration of contaminants from this site could potentially introduce hydrocarbons to the KRVA which could migrate to the Klondike River and ultimately impact water supply wells. Mobilization of metals to surface water bodies that could ultimately impact water supply wells.
KRV02	02	YECL Substation, Callison Subdivision	Did not Locate		Historic	-	2003 spill of between 50 and 100L of hydraulic oil.	Hydrocarbons	A spill of hydraulic oil to ground could potentially introduce hydrocarbons to the KRV which could migrate to the Klondike River and ultimately impact CoD water supply wells.
KRV03	03	North 60 Bulk Plant, Callison Subdivision	579084	7102518	Historic	610	In 2003, 4,000L of diesel fuel was spilled due to an overflowing tank. Fuel was contained and partially cleaned up. Current site status is unknown.	Petroleum Hydrocarbons	A spill of fuel to ground could potentially introduce hydrocarbons to the KRVA which could migrate to the Klondike River and ultimately impact CoD water supply wells.
KRV04	04	Lot 1 Callison Subdivision	580755	7102017	Historic	970	Decommissioned Land Treatment Facility (LTF) with potentially elevated arsenic concentrations in soil.	Metals (Arsenic)	Arsenic could potentially leach out of the soil and impact the KRVA which could migrate to the Klondike River and ultimately impact CoD water supply wells.
KRV05	05	Northern Superior Mechanical / NAPA	578010	7102660	Current	275	10 m3 of petroleum hydrocarbon contaminated soil removed from site. Current site status not known	Petroleum Hydrocarbons	Spills, leaks, disposal, releases of hydrocarbons/oils/solvents to ground, migration of contaminants from this site could potentially introduce hydrocarbons to the KRVA, which could migrate to the Klondike River and ultimately impact water supply wells.
KRV06	06				0		Mechanics shop	Petroleum Hydrocarbons; solvents	
KRV07	07	Endurance Automotive and Small Engine	596589		Current	-	Bulk fuel storage tanks, mechanics shop	Petroleum Hydrocarbons; solvents	Spills, leaks, disposal, releases of hydrocarbons/oils/solvents to ground, migration of contaminants from this site could potentially introduce hydrocarbons to the KRVA which could migrate to the Klondike River and ultimately impact water supply wells.
KRV08	08	Public outhouses at campground	592125	7104191	Current	480	Raw waste	Septage; coliform and non-coliform bacteria; viruses; nitrates; heavy metals Septage; coliform and non-coliform bacteria; viruses; nitrates; heavy metals; emerging contaminants (e.g. antibiotics, anti-inflammatories, lipid regulators, caffeine, carbamazepin and N,N-diethyl-m-toluamide (DEET)) Septic tank/cesspool cleaners include synthetic organic chemicals such as 1,1,1 trichloroethane, tetrachloroethylene, carbon tetrachloride, and methylene chloride	Wastewater has the potential to impact the KRVA and migrate to the Klondike River and could ultimately impact water supply wells.
KRV09	09	Airport	591750	7103589	Current	300	Bulk fuel storage tanks, mechanics hangers	Jet fuels; de-icers; diesel fuel; chlorinated solvents; automotive wastes; heating oil; building wastes	Spills, leaks, disposal, releases of hydrocarbons/oils/solvents to ground, migration of contaminants from this site could potentially introduce hydrocarbons to the KRVA which could migrate to the Klondike River and ultimately impact water supply wells.
KRV10	10	Fischer Fuels	587589	7101942	Current	250	Bulk fuel storage tanks	Petroleum Hydrocarbons	Spills or leaks of hydrocarbons to ground, migration of contaminants from this site could potentially introduce hydrocarbons to the KRVA which could migrate to the Klondike River and ultimately impact water supply wells.
KRV11	11	Residential and commercial subdivisions up the Klondike Valley including Callison, Dredge Pond, Rock Creek, Bear Creek,	-	-	Current	-	Most residential and commercial buildings along the Klondike River Valley are believed to onsite sewage disposal systems and above grade storage tanks.	Heating Fuel - hydrocarbons Septage; coliform and non-coliform bacteria; viruses; nitrates; heavy metals; synthetic detergents; cooking and motor oils; bleach; pesticides; paints; paint thinner; swimming pool chemicals; septic tank/cesspool cleaner chemicals elevated levels of chloride, sulfate, calcium, magnesium, potassium, and phosphate, emerging contaminants (e.g. antibiotics, anti-inflammatories, lipid regulators, caffeine, carbamazepine and N,N-diethyl-m-toluamide (DEET)) Septic tank/cesspool cleaners include synthetic organic chemicals such as 1,1,1 trichloroethane, tetrachloroethylene, carbon tetrachloride, and methylene chloride	Spills, leaks, disposal, releases of hydrocarbons/oils/solvents to ground, migration of contaminants from this site could potentially introduce hydrocarbons to the KRVA which could migrate to the Klondike River and ultimately impact water supply wells.
KRV12	12	Quigley Pit (Landfill)	582854	7101473	Current	1600	Deposited domestic and commercial waste	Wide range of organic and inorganic chemicals; metals; oils; wastes from households and businesses	Migration of contaminants from this site could potentially impact the KRVA which could migrate to the Klondike River and ultimately impact water supply wells.

Table 2: Summary of Potential Sources of Contamination - Klondike River Valley

ID	Field ID	Site	Easting	Northing	Time Period	Approximate Distance from Klondike River/ Tributary Creek (m)	Source of Potential Contamination	Potential Contaminants	Hazard Description
KRV13	13	YG Dawson Highway Maintenance Compound	583156	7102104	Current	1000	Bulk fuel storage tanks, mechanics shop, road marking paint, salt	Petroleum Hydrocarbons; solvents	Spills, leaks, disposal, releases of hydrocarbons/oils/solvents to ground, migration of contaminants from this site could potentially introduce hydrocarbons to the KRVA which could migrate to the Klondike River and ultimately impact water supply wells.
KRV14	14	Chief Isaac Mechanical	580289	7101894	Current	1000	Bulk fuel storage tanks, mechanics shop	Petroleum Hydrocarbons; solvents	
KRV15	15	North 60 Public Card Lock	580351	7102084	Current	870	Bulk fuel storage tanks	Petroleum Hydrocarbons	Spills or leaks of hydrocarbons to ground, migration of contaminants from this site could potentially introduce hydrocarbons to the KRVA which could migrate to the Klondike River and ultimately impact water supply wells.
KRV16	16	Fireweed Helicopters	579681	7102575	Current	375	Bulk fuel storage tanks, mechanics hangers	Petroleum Hydrocarbons; solvents	Spills, leaks, disposal, releases of hydrocarbons/oils/solvents to ground, migration of contaminants from this site could potentially introduce hydrocarbons to the KRVA which could migrate to the Klondike River and ultimately impact water supply wells.
KRV17	17	AFD Public Card Lock	577943	7102680	Current	170	Bulk fuel storage tanks	Petroleum Hydrocarbons	Spills or leaks of hydrocarbons to ground, migration of contaminants from this site could potentially introduce hydrocarbons to the KRVA which could migrate to the Klondike River and ultimately impact water supply wells.
KRV18	18	Dawson City Gas and Tires	577794	7102606	Current	0	Bulk fuel storage tanks, mechanics shop	Petroleum Hydrocarbons	Spills, leaks, disposal, releases of hydrocarbons/oils/solvents to ground, migration of contaminants from this site could potentially introduce hydrocarbons to the KRVA which could migrate to the Klondike River and ultimately impact water supply wells.
KRV19	19	Trans North Helicopters	576597	7103615	Current	60	Bulk fuel storage tanks, mechanics hangers	Petroleum Hydrocarbons; solvents	
KRV20	20	Historic and existing Placer Mines i Klondike River Valley tributary valleys	-	-	Historic and Current	<10 m to 1 km+	Heavy machinery, runoff from mine, fuel storage	Petroleum Hydrocarbons, metals, sediment	Spills or leaks of hydrocarbons/oils/solvent/other chemicals related to mining t ground, migration of contaminants from this site could potentially introduce hydrocarbons to the KRVA which could migrate to the Klondike River and ultimately impact water supply wells. Mobilization of metals to surface water bodies that could ultimately impact water supply wells.
KRV21	21	Mackenzie Petroleum/Chief Isaac Petroleum/ Super Save Propane and card lock	580797	7102025	Current	950	Bulk fuel storage tanks	Petroleum Hydrocarbons	Spills or leaks of hydrocarbons to ground, migration of contaminants from this site could potentially introduce hydrocarbons to the KRVA which could migrate to the Klondike River and ultimately impact water supply wells
KRV22	22	Total Crawler Services	580416	7102202	Current	750	Mechanics shop, leaking vehicles and equipment	Petroleum Hydrocarbons; solvents	Spills, leaks, disposal, releases of hydrocarbons/oils/solvents to ground, migration of contaminants from this site could potentially introduce hydrocarbons to the KRVA which could migrate to the Klondike River and ultimately impact water supply wells.
KRV23	23	Heavy machinery and truck storage and fuel tanks on lot.	578706	7102631	Current	270	Leaking vehicles and equipment, tanks	Petroleum Hydrocarbons	
KRV24	24	Heavy machinery and truck storage.	579038	7102621	Current	470	Leaking vehicles and equipment, tanks	Petroleum Hydrocarbons	
KRV25	25	Mechanics	580352	7102197	Current	750	Mechanics shop	Petroleum Hydrocarbons; solvents	
KRV26	26	Slinky Mine	578266	7103258	Current	200	Heavy machinery, runoff from mine, fuel storage	Petroleum Hydrocarbons, metals, sediment	Spills or leaks of hydrocarbons/oils/solvent/other chemicals related to mining t ground, migration of contaminants from this site could potentially introduce hydrocarbons to the KRVA which could migrate to the Klondike River and ultimately impact water supply wells. Mobilization of metals to surface water bodies that could ultimately impact water supply wells.
KRV27	27	Klondike River	-	-	Current	-	Wildlife	Giardia, Cryptosporidium	Potential for contaminants to be transported from upstream in the Klondike Rivers and be drawn from the river into the well capture zone and migrate to the drinking water wells.
KRV28	-	Various	-	-	Current	>20	Accidental or deliberate spill, leak, disposal to ground	Petroleum Hydrocarbons, Wastewater	Spills, leaks or discharge of hydrocarbons to ground, migration of contaminants from this site could potentially introduce hydrocarbons to the KRVA which could migrate to the Klondike River and ultimately impact water supply wells.
KRV29	-	Various	-	-	Current	<20	Accidental or deliberate spill, leak, disposal to ground or directly to Klondike River or tributary - less than 100 L.	Petroleum Hydrocarbons, Wastewater	Potential for contaminants to be transported from upstream in the Klondike River and be drawn from the river into the well capture zone and migrate to the drinking water wells.
KRV30	-	Various	-	-	Current	<20	Accidental or deliberate spill, leak, disposal to ground or directly to Klondike River or tributary - more than 100 L.	Petroleum Hydrocarbons, Wastewater	Potential for contaminants to be transported from upstream in the Klondike River and be drawn from the river into the well capture zone and migrate to the drinking water wells.

Table 3a: Groundwater Analytical Results

Chem_Group	ChemName	output unit	EQL	Canadian Drinking Water AO	Canadian Drinking Water MAC	PW-1	PW-1N							PW-2		PW-2N						
						7/19/2010	7/28/2014	7/28/2014	11/8/2015	2/17/2016	4/11/2016	9/21/2016	7/24/2017	6/9/2010	7/19/2010	7/25/2014	7/28/2014	11/8/2015	2/17/2016	4/11/2016	9/21/2016	7/24/2017
Physical Parameters	pH	pH Units	0.1	7.0- 10.5		-	7.69	7.69	7.69	8.03	7.37	7.62	-	-	-	7.52	7.52	7.73	8.03	7.39	7.66	-
	Electrical Conductivity (EC)	µS/cm	2			-	325	325	518	394	406	546	-	-	-	310	310	392	359	343	424	-
	Total Dissolved Solids (TDS) (Filtered)	µg/L	10000	500000		-	206,000	206,000	334,000	222,000	236,000	334,000	-	-	-	195,000	195,000	252,000	210,000	204,000	274,000	-
	Total Suspended Solids (TSS)	µg/L	1000			<2000	-	-	-	-	-	-	-	<2000	<2000	-	-	-	-	-	-	-
	Hardness as CaCO3	µg/L	500			-	168,000	168,000	258,000	183,000	198,000	267,000	182,000	-	-	163,000	163,000	195,000	158,000	165,000	205,000	164,000
	Alkalinity (total as CaCO3)	mg/L	2			-	103	103	183	130	133	185	-	-	-	93.1	93.1	124	111	98.4	134	-
	Alkalinity (pp as CaCO3)	µg/L				-	-	-	<500	<500	<500	<500	-	-	-	-	-	<500	<500	<500	<500	-
	Bicarbonate	µg/L				-	-	-	223,000	159,000	162,000	225,000	-	-	-	-	-	151,000	135,000	120,000	164,000	-
	Carbonate	µg/L				-	-	-	<500	<500	<500	<500	-	-	-	-	-	<500	<500	<500	<500	-
	Hydroxide	µg/L				-	-	-	<500	<500	<500	<500	-	-	-	-	-	<500	<500	<500	<500	-
	Bromide	µg/L	50			-	-	<50	-	-	-	-	-	-	-	<50	-	-	-	-	-	-
	Chloride (Cl)	µg/L	500	250000		-	-	3060	-	-	-	-	-	-	-	2340	-	-	-	-	-	-
	Chloride (Cl) (Filtered)	µg/L		250000		-	3060	-	13,000	4900	4000	16,000	-	-	-	-	2340	10,000	2500	860	8900	-
	Fluoride (F)	µg/L	20		1500	-	94	94	68	60	64	60	-	-	-	81	81	73	61	73	66	-
	Sulphate (SO4)	µg/L	500	500000		-	-	60,700	-	-	-	-	-	-	-	62,900	-	-	-	-	-	-
	Sulphate (SO4) (Filtered)	µg/L		500000		-	60,700	-	65,700	71,600	71,700	69,000	-	-	-	-	62,900	63,100	72,200	74,700	60,000	-
	Colour	Col. Unit	5	15		-	<5	<5	<5	7.3	<5	<5	-	-	-	<5	<5	<5	6.1	<5	<5	-
	Turbidity	NTU	0.1		1	-	0.41	0.41	0.19	<0.1	<0.1	0.19	-	-	-	0.19	0.19	0.2	<0.1	<0.1	0.22	-
Nutrients	Ammonia as N	µg/L	5			-	-	<5	-	-	-	-	-	-	-	<5	-	-	-	-	-	-
	Nitrate (as N)	µg/L	5		10000	-	365	365	1140	641	525	1580	161	-	-	418	418	1100	534	374	1330	273
	Nitrite (as N)	µg/L	1		1000	-	<1	<1	<5	<5	<5	<5	-	-	-	<1	<1	<5	<5	<5	<5	-
	Nitrate and Nitrite (as N)	µg/L				-	365	-	1140	641	525	1580	-	-	-	-	418	1100	534	374	1330	-
	Nitrogen (Total)	µg/L	50			-	-	394	-	-	-	-	-	-	-	434	-	-	-	-	-	-
Metals	Aluminum Total	ug/L	3			-	20.4	-	<3	<3	<3	3.9	-	-	-	-	10.3	<3	<3	<3	<3	-
	Antimony	µg/L	0.2		6	<0.2	<0.05	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.2	<0.2	<0.5	<0.05	<0.5	<0.5	<0.5	<0.5	<0.5
	Arsenic	µg/L	0.2		10	<0.2	<0.05	<0.5	0.24	0.15	0.16	0.2	<1	<0.2	<0.2	<0.5	<0.05	0.12	<0.1	0.1	0.11	<1
	Beryllium	µg/L	0.04			<0.04	-	<1	-	-	-	-	<5	<0.04	<0.04	<1	-	-	-	-	-	<5
	Bismuth	µg/L	1			<1	-	<200	-	-	-	-	-	<1	<1	<200	-	-	-	-	-	-
	Boron	µg/L	4		5000	12	<100	<100	<50	<50	<50	<50	<100	53	10	<100	<100	<50	<50	<50	<50	<100
	Cadmium	µg/L	0.01		5	0.03	0.021	0.021	0.039	0.027	0.027	0.04	<0.05	0.02	0.03	0.024	0.024	0.029	0.025	0.023	0.024	<0.05
	Calcium	µg/L	50			45,300	45,100	45,100	69,600	48,400	54,000	72,200	49,800	40,100	42,900	45,100	45,100	51,500	41,900	45,100	55,900	45,500
	Chromium	µg/L	0.4		50	1.1	<1	<1	<1	<1	<1	<1	<0.5	1	1.2	<1	<1	<1	<1	<1	<1	<0.5
	Cobalt	µg/L	0.02			0.06	<0.3	<0.3	<0.5	<0.5	<0.5	<0.5	<0.5	0.05	0.04	<0.3	<0.3	<0.5	<0.5	<0.5	<0.5	<0.5
	Copper	µg/L	1	1000		2	1.3	1.3	1.83	2.5	1.7	2.05	5	13	5	1.9	1.9	1.77	1.82	1.1	1.2	4.6
	Iron	µg/L	10	300		29	<30	<30	12.9	<5	<5	7.9	<30	12	18	<30	<30	9	<5	<5	51.2	<30
	Lead	µg/L	0.1		10	0.4	<0.5	<0.5	0.45	0.22	<0.2	0.23	<1	0.5	0.2	<0.5	<0.5	0.23	<0.2	<0.2	<0.2	<1
	Lithium	µg/L	1			3	-	<5	-	-	-	-	<50	2	2	<5	-	-	-	-	-	<50
	Magnesium	µg/L	50			13,300	12,400	12,400	20,400	15,000	15,400	21,000	13,900	10,800	12,300	12,200	12,200	16,100	13,000	12,700	15,900	12,100
	Manganese	µg/L	0.2	50		108	0.73	0.73	1.5	5.4	5.8	4.2	<10	0.5	49.3	1.13	1.13	1.1	1.2	<1	9.2	<10
	Mercury	µg/L	0.01		1	-	0.014	0.014	<0.01	<0.01	<0.002	<0.01	<0.2	-	-	0.022	0.022	0.012	<0.01	<0.002	<0.01	<0.2
	Molybdenum	µg/L	0.1			0.5	<1	<1	<1	<1	<1	<1	<1	0.3	0.4	<1	<1	<1	<1	<1	<1	<1
	Nickel	µg/L	1			2	<1	<1	<1	<1	<1	1.2	<5	<1	<1	<1	<1	<1	<1	<1	<1	<5
	Phosphorus	µg/L	10			<10	-	<300	-	-	-	-	-	<10	<10	<300	-	-	-	-	-	-
	Potassium	µg/L	100			700	<2000	<2000	1050	930	963	1110	<2000	600	500	<2000	<2000	912	773	775	866	<2000
	Selenium	µg/L	0.1		50	<0.6	0.71	0.71	0.59	0.91	0.86	0.57	<1	0.7	<0.6	0.75	0.75	0.85	0.89	0.97	0.84	<1
	Silicon	µg/L	50			3620	-	3350	-	-	-	-	-	3070	3430	3240	-	-	-	-	-	-
	Silver	µg/L	0.01			<0.01	<0.02	<0.02	0.02	<0.02	<0.02	<0.02	<0.05	<0.01	<0.01	<0.02	<0.02	0.032	<0.02	<0.02	<0.02	<0.05
	Sodium	µg/L	20	200000		3940	3400	3400	6090	4770	4620	5960	4700	2950	3480	3100	3100	4190	3600	3220	4080	3200
	Strontium	µg/L	1			217	-	218	-	-	-	-	-	206	211	217	-	-	-	-	-	-
	Sulphur (Elemental)	µg/L	100			19,200	-	-	-	-	-	-	-	-	18,600	-	-	-	-	-	-	-
	Sulphur as S	µg/L	100			-	-	-	22,900	21,500	23,900	23,000	-	17,200	-	-	-	23,400	21,900	26,900	21,700	-
	Tellurium	µg/L	0.1			<0.1	-	-	-	-	-	-	-	<0.1	<0.1	-	-	-	-	-	-	-
	Thallium	µg/L	0.01			<0.01	-	<0.2	-	-	-	-	<0.2	<0.01	<0.01	<0.2	-	-	-	-	-	<0.2
	Thorium	µg/L	0.4			<0.4	-	-	-	-	-	-	-	<0.4	<0.4	-	-	-	-	-	-	-
	Tin	µg/L	0.1			0.2	-	<0.5	-	-	-	-	-	<0.1	<0.1	<0.5	-	-	-	-	-	-
	Titanium	µg/L	1			9	-	<10	-	-	-	-	<50	<1	2	<10	-	-	-	-	-	<50
	Uranium	µg/L	0.2		20	0.7	0.57	0.57	2.13	0.81	0.97	2.13	0.8	<0.4	0.5	0.52	0.52	0.88	0.64	0.74	1.15	0.71
	Vanadium	µg/L	0.1			0.2	<1	<1	<5	<5	<5	<5	<30	0.2	0.2	<1	<1	<5	<5	<5	<5	<30
	Zinc	µg/L	1	5000		20	<50	<50	5	<5	<5	<5	8.5	19	6	<50	<50	<5	<5	<5	<5	<5
	Zirconium	µg/L	0.1			0.2	-	-	-	-	-	-	-	<0.1	<0.1	-	-	-	-	-	-	-
Biological	Total Coliforms	MPN/100mL	1			-	<1	-	<1	<1	<1	<1	-	-	-	-	<1	<1	<1	<1	<1	-
	E. Coli	MPN/100mL	1			-	<1	-	<1	<1	<1	<1	-	-	-	-	<1	<1	<1	<1	<1	-
BTEXS & MTBE	Benzene	µg/L	0.5		5	<1	-	<0.5	-	-	-	-	<0.5	-	<1	<0.5	-	-	-	-	-	<0.5
	Toluene	µg/L	0.45	24	60	<1	-	<0.5	-	-	-	-	<0.45	-	<1	<0.5	-	-	-	-	-	<0.45
	Ethylbenzene	µg/L	0.5	1.6	140	<1	-	<0.5	-	-	-	-	<0.5	-	<1	<0.5	-	-	-	-	-	<0.5
	Xylenes (m & p)	µg/L	0.5			-	-	<0.5	-	-	-	-	<0.5	-	-	<0.5	-	-	-	-	-	<0.5
	Xylene (o)	µg/L	0.5			-	-	<0.5	-	-	-	-	<0.5	-	-	<0.5	-	-	-	-	-	<0.5
	Xylenes Total	µg/L	0.75	20	90	<1	-	<0.75	-	-	-	-	<0.75	-	<1	<0.75	-	-	-	-	-	<0.75
	Styrene	µg/L	0.5			<1	-	<0.5	-	-	-	-	<0.5	-	<1	<0.5	-	-	-	-	-	<0.5
	MTBE	µg/L	0.5	15		<1	-	<0.5	-	-	-	-	<0.5	-	<1	<0.5	-	-	-	-	-	<0.5
Hydrocarbons	EPH10-19	µg/L	250			-	-	-	-	-	-	-	<250	-	-	-	-	-	-	-	-	<250
	EPH19-32	µg/L	250			-	-	-	-	-	-	-	<250	-	-	-	-	-	-	-	-	<250
	LEPH	µg/L	100			<100	-	-	-	-	-	-	<250	<100	<100	-	-	-	-	-	-	<250
	HEPH	µg/L	100			<100	-	-	-	-	-	-	<250	<100	<100	-	-	-	-	-	-	<250
	VH6-10	µg/L	50			<50	-	-	-	-	-	-	-	-	<50	-	-	-	-	-	-	-
	VPHw	µg/L	50			<50	-	-	-	-	-	-	-	-	<50	-	-	-	-	-	-	-
Glycols	Diethylene glycol	µg/L	5000			-	-	-	-	-	-	-	<5000	-	-	-	-	-	-	-	-	<5000
	Ethylene glycol	µg/L	5000			-	-	-	-	-	-	-	<5000	-	-	-	-	-	-	-	-	<5000
	Propylene glycol	µg/L	5000			-	-	-	-	-	-	-	<5000	-	-	-	-	-	-	-	-	<5000
	Triethylene Glycol	µg/L	5000			-	-	-	-	-	-	-	<5000	-	-	-	-	-	-	-	-	<5000
Polycyclic Aromatic Hydrocarbon	Acenaphthene	µg/L	0.05			<0.1	-	<0.05	-	-	-	-	<0.05	<0.1	<0.1	<0.05	-	-	-	-	-	<0.1
	Acenaphthylene	µg/L	0.05			<0.1	-	<0.05	-	-	-	-	<0.05	<0.1	<0.1	<0.05	-	-	-	-	-	<0.05
	Acridine	µg/L	0.05			<0.05	-	<0.05	-	-	-	-	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-	<0.05
	Anthracene	µg/L	0.05			<0.1	-	<0.05	-	-	-	-	<0.05	<0.1	<0.1	<0.05	-	-	-	-	-	<0.06
	Benz(a)anthracene	µg/L	0.01			<0.01	-	<0.05	-	-	-	-	<0.05	<0.01	<0.01	<0.05	-	-	-	-	-	<0.05
	Benzo(a)pyrene	µg/L	0.005		0.04	<0.01	-	<0.01	-	-	-	-	<0.005	<0.01	<0.01	<0.01	-	-	-	-	-	<0.006
	Benzo(b)fluoranthene	µg/L	0.01			<0.01	-	<0.05	-	-	-	-	-	<0.01	<0.01	<0.05	-	-	-	-	-	-
	Benzo(b+j)fluoranthene	µg/L	0.05			-	-	-	-	-	-	-	<0.05	-	-	-	-	-	-	-	-	<0.05
	Benzo(g,h,i)perylene	µg/L	0.05			<0.1	-	<0.05	-	-	-	-	<0.05	<0.1	<0.1	<0.05	-	-	-	-	-	<0.05
	Benzo(k)fluoranthene	µg/L	0.02			<0.02	-	<0.05	-	-	-	-	<0.05	<0.02	<0.02	<0.05	-	-	-	-	-	<0.05
	Chrysene	µg/L	0.05			<0.1	-	<0.05	-	-	-	-	<0.05	<0.1	<0.1	<0.05	-	-	-	-	-	<0.05
	Dibenz(a,h)anthracene	µg/L	0.005			<0.01	-	<0.05	-	-	-	-	<0.005	<0.01	<0.01	<0.05	-	-	-	-	-	<0.005
	Fluoranthene	µg/L	0.05			<0.1	-	<0.05	-	-	-	-	<0.05	<0.1	<0.1	<0.05	-	-	-	-	-	<0.05
	Fluorene	µg/L	0.05			<0.1	-	<0.05	-	-	-	-	<0.05	<0.1	<0.1	<0.05	-	-	-	-	-	<0.05
	Indeno(1,2,3-c,d)pyrene	µg/L	0.05			<0.1	-	<0.05	-	-	-	-	<0.05	<0.1	<0.1	<0.05	-	-	-	-	-	<0.05
	Naphthalene	µg/L	0.05			0.1	-	<0.05	-	-	-	-	<0.05	<0.1	0.1	<0.05	-	-	-	-	-	0.119
	Phenanthrene	µg/L	0.05			<0.1	-	<0.05	-	-	-	-	<0.05	<0.1	<0.1	<0.05	-	-	-	-	-	0.084
	Pyrene	µg/L	0.02			<0.02	-	<0.05	-	-	-	-	<0.05	<0.02	<0.02	<0.05	-	-	-	-	-	<0.05
	Quinoline	µg/L	0.05			<3.4	-	<0.05	-	-	-	-	<0.05	<3.4	<3.4	<0.05	-	-	-	-	-	<0.06
Volatile Organic Compounds (VO	Bromodichloromethane	µg/L	1			-	-	<1	-	-	-	-	-	-	-	<1	-	-	-	-	-	-
	Bromoform	µg/L	1			-	-	<1	-	-	-	-	-	-	-	<1	-	-	-	-	-	-
	Carbon tetrachloride	µg/L	0.5		2	-	-	<0.5	-	-	-	-	-	-	-	<0.5	-	-	-	-	-	-
	Chlorobenzene	µg/L	1	30	80	-	-	<1	-	-	-	-	-	-	-	<1	-	-	-	-	-	-
	Chloroethane	µg/L	1			-	-	<1	-	-	-	-	-	-	-	<1	-	-	-	-	-	-
	Chloroform	µg/L	1			-	-	<1	-	-	-	-	-	-	-	<1	-	-	-	-	-	-
	Chloromethane	µg/L	5			-	-	<5	-	-	-	-	-	-	-	<5	-	-	-	-	-	-
	Dibromochloromethane	µg/L	1			-	-	<1	-	-	-	-	-	-	-	<1	-	-	-	-	-	-
	1,2-Dichlorobenzene	µg/L	0.7	3	200	-	-	<0.7	-	-	-	-	-	-	-	<0.7	-	-	-	-	-	-
	1,3-Dichlorobenzene	µg/L	1			-	-	<1	-	-	-	-	-	-	-	<1	-	-	-	-	-	-
	1,4-Dichlorobenzene	µg/L	1	1	5	-	-	<1	-	-	-	-	-	-	-	<1	-	-	-	-	-	-
	1,1-Dichloroethane	µg/L	1			-	-	<1	-	-	-	-	-	-	-	<1	-	-	-	-	-	-
	1,2-Dichloroethane	µg/L	1		5	-	-	<1	-	-	-	-	-	-	-	<1	-	-	-	-	-	-
	1,1-Dichloroethene	µg/L	1		14	-	-	<1	-	-	-	-	-	-	-	<1	-	-	-	-	-	-
	1,2-Dichloroethene (cis)	µg/L	1			-	-	<1	-	-	-	-	-	-	-	<1	-	-	-	-	-	-
	1,2-Dichloroethene (trans)	µg/L	1			-	-	<1	-	-	-	-	-	-	-	<1	-	-	-	-	-	-
	1,2-Dichloropropane	µg/L	1			-	-	<1	-	-	-	-	-	-	-	<1	-	-	-	-	-	-
	1,3-Dichloropropene	µg/L	1.41			-	-	<1.4	-	-	-	-	-	-	-	<1.4	-	-	-	-	-	-
	1,3-Dichloropropene [cis]	µg/L	1			-	-	<1	-	-	-	-	-	-	-	<1	-	-	-	-	-	-
	1,3-Dichloropropene [trans]	µg/L	1			-	-	<1	-	-	-	-	-	-	-	<1	-	-	-	-	-	-
	Methylene Chloride	µg/L	5		50	-	-	<5	-	-	-	-	-	-	-	<5	-	-	-	-	-	-
	1,1,1,2-Tetrachloroethane	µg/L	1			-	-	<1	-	-	-	-	-	-	-	<1	-	-	-	-	-	-
	1,1,2,2-Tetrachloroethane	µg/L	1			-	-	<1	-	-	-	-	-	-	-	<1	-	-	-	-	-	-
	Tetrachloroethene	µg/L	1		10	-	-	<1	-	-	-	-	-	-	-	<1	-	-	-	-	-	-
	1,1,1-Trichloroethane	µg/L	1			-	-	<1	-	-	-	-	-	-	-	<1	-	-	-	-	-	-
	1,1,2-Trichloroethane	µg/L	1			-	-	<1	-	-	-	-	-	-	-	<1	-	-	-	-	-	-
	Trichloroethene	µg/L	1		5	-	-	<1	-	-	-	-	-	-	-	<1	-	-	-	-	-	-
	Trichlorofluoromethane	µg/L	1			-	-	<1	-	-	-	-	-	-	-	<1	-	-	-	-	-	-
	Vinyl chloride	µg/L	1		2	-	-	<1	-	-	-	-	-	-	-	<1	-	-	-	-	-	-

RDL = Reportable Detection Limit
Shaded - Exceeds the Guidelines for Canadian Drinking Water Quality Value - Maximum Allowable Concentration
Red - Exceeds the Guidelines for Canadian Drinking Water Quality Value - Aesthetic Objective

Table 3a: Groundwater Analytical Results

Chem_Group	ChemName	output unit	EQL	Canadian Drinking Water AO	Canadian Drinking Water MAC	PW-3		PW-3N							PW-4N						
						6/9/2010	7/19/2010	7/26/2014	7/28/2014	11/8/2015	2/17/2016	4/11/2016	9/21/2016	7/24/2017	7/27/2014	7/28/2014	11/8/2015	2/17/2016	4/11/2016	9/21/2016	7/24/2017
Physical Parameters	pH	pH Units	0.1	7.0- 10.5		-	-	7.83	7.83	7.84	8.06	7.56	7.73	-	7.77	7.77	7.83	8.09	7.56	7.73	-
	Electrical Conductivity (EC)	µS/cm	2			-	-	292	292	343	326	338	357	-	290	290	305	336	338	337	-
	Total Dissolved Solids (TDS) (Filtered)	µg/L	10000	500000		-	-	186,000	186,000	232,000	194,000	214,000	228,000	-	202,000	202,000	212,000	200,000	210,000	216,000	-
	Total Suspended Solids (TSS)	µg/L	1000			<2000	<2000	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Hardness as CaCO3	µg/L	500			-	-	151,000	151,000	165,000	148,000	163,000	184,000	157,000	149,000	149,000	152,000	154,000	164,000	162,000	155,000
	Alkalinity (total as CaCO3)	mg/L	2			-	-	91.2	91.2	102	92.3	95.1	110	-	86.8	86.8	87.7	97.9	95.4	101	-
	Alkalinity (pp as CaCO3)	µg/L				-	-	-	-	<500	<500	<500	<500	-	-	-	<500	<500	<500	<500	-
	Bicarbonate	µg/L				-	-	-	-	125,000	113,000	116,000	134,000	-	-	-	107,000	119,000	116,000	124,000	-
	Carbonate	µg/L				-	-	-	-	<500	<500	<500	<500	-	-	-	<500	<500	<500	<500	-
	Hydroxide	µg/L				-	-	-	-	<500	<500	<500	<500	-	-	-	<500	<500	<500	<500	-
	Bromide	µg/L	50			-	-	<50	-	-	-	-	-	-	<50	-	-	-	-	-	-
	Chloride (Cl)	µg/L	500	250000		-	-	1470	-	-	-	-	-	-	1470	-	-	-	-	-	-
	Chloride (Cl) (Filtered)	µg/L		250000		-	-	-	1470	3800	2700	630	4700	-	-	1470	2300	1900	640	3900	-
	Fluoride (F)	µg/L	20		1500	-	-	87	87	71	73	83	72	-	98	98	78	73	85	67	-
	Sulphate (SO4)	µg/L	500	500000		-	-	60,400	-	-	-	-	-	-	58,700	-	-	-	-	-	-
	Sulphate (SO4) (Filtered)	µg/L		500000		-	-	-	60,400	60,300	79,100	73,000	61,000	-	-	58,700	63,100	75,900	74,700	59,000	-
	Colour	Col. Unit	5	15		-	-	<5	<5	<5	<5	<5	11.4	-	<5	<5	<5	<5	<5	5.9	-
	Turbidity	NTU	0.1		1	-	-	1.2	1.2	0.14	<0.1	<0.1	1.29	-	0.33	0.33	<0.1	<0.1	0.11	0.17	-
Nutrients	Ammonia as N	µg/L	5			-	-	<5	-	-	-	-	-	-	<5	-	-	-	-	-	-
	Nitrate (as N)	µg/L	5		10000	-	-	346	346	762	276	245	918	287	316	316	426	267	202	864	253
	Nitrite (as N)	µg/L	1		1000	-	-	<1	<1	<5	<5	<5	<5	-	<1	<1	<5	<5	<5	<5	-
	Nitrate and Nitrite (as N)	µg/L				-	-	-	346	762	276	245	918	-	-	316	426	267	202	864	-
	Nitrogen (Total)	µg/L	50			-	-	372	-	-	-	-	-	-	349	-	-	-	-	-	-
Metals	Aluminum Total	ug/L	3			-	-	-	44.3	<3	<3	<3	<3	-	-	11.2	3.4	<3	<3	<3	-
	Antimony	µg/L	0.2		6	<0.2	<0.2	<0.5	<0.05	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.05	<0.5	<0.5	<0.5	<0.5	<0.5
	Arsenic	µg/L	0.2		10	0.3	<0.2	<0.5	<0.05	0.13	<0.1	0.13	0.17	<1	<0.5	<0.05	0.21	0.22	0.29	0.25	<1
	Beryllium	µg/L	0.04			<0.04	<0.04	<1	-	-	-	-	-	<5	<1	-	-	-	-	-	<5
	Bismuth	µg/L	1			<1	<1	<200	-	-	-	-	-	-	<200	-	-	-	-	-	-
	Boron	µg/L	4		5000	37	7	<100	<100	<50	<50	<50	<50	<100	<100	<100	<50	<50	<50	<50	<100
	Cadmium	µg/L	0.01		5	0.01	0.01	0.02	0.02	0.031	0.022	0.023	0.026	<0.05	0.025	0.025	0.026	0.02	0.021	0.029	<0.05
	Calcium	µg/L	50			35,600	38,000	41,000	41,000	43,600	38,900	43,800	49,400	43,200	40,000	40,000	41,800	39,800	43,700	44,800	42,000
	Chromium	µg/L	0.4		50	<0.4	1	<1	<1	<1	<1	<1	<1	<0.5	<1	<1	<1	<1	<1	<1	<0.5
	Cobalt	µg/L	0.02			0.04	<0.02	<0.3	<0.3	<0.5	<0.5	<0.5	<0.5	<0.5	<0.3	<0.3	<0.5	<0.5	<0.5	<0.5	<0.5
	Copper	µg/L	1	1000		5	1	1.6	1.6	1.06	1.93	1.92	1.77	4.7	2.1	2.1	1.46	1.52	1.46	2.71	4
	Iron	µg/L	10	300		<10	<10	50	50	11.7	<5	<5	143	<30	<30	<30	9.6	<5	5.9	57.6	<30
	Lead	µg/L	0.1		10	0.3	0.2	<0.5	<0.5	0.2	<0.2	<0.2	0.71	<1	<0.5	<0.5	0.5	<0.2	<0.2	0.98	<1
	Lithium	µg/L	1			2	2	<5	-	-	-	-	-	<50	<5	-	-	-	-	-	<50
	Magnesium	µg/L	50			9950	10,900	11,400	11,400	13,500	12,400	13,000	14,800	11,900	11,500	11,500	11,600	13,200	13,400	12,300	12,100
	Manganese	µg/L	0.2	50		0.3	0.3	1.36	1.36	<1	<1	<1	7	<10	0.64	0.64	<1	<1	<1	1.6	<10
	Mercury	µg/L	0.01		1	-	-	<0.01	<0.01	0.016	<0.01	0.0029	<0.01	<0.2	0.012	0.012	<0.01	<0.01	0.0031	<0.01	<0.2
	Molybdenum	µg/L	0.1			0.5	0.5	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Nickel	µg/L	1			2	<1	<1	<1	<1	<1	<1	<1	<5	<1	<1	<1	<1	<1	<1	<5
	Phosphorus	µg/L	10			<10	17	<300	-	-	-	-	-	-	<300	-	-	-	-	-	-
	Potassium	µg/L	100			500	400	<2000	<2000	816	651	696	779	<2000	<2000	<2000	694	601	601	634	<2000
	Selenium	µg/L	0.1		50	<0.6	<0.6	0.71	0.71	0.78	0.84	0.87	0.94	<1	<1	<1	0.83	0.86	0.83	0.94	<1
	Silicon	µg/L	50			2830	3100	3100	-	-	-	-	-	-	3050	-	-	-	-	-	-
	Silver	µg/L	0.01			<0.01	<0.01	<0.02	<0.02	0.02	<0.02	<0.02	<0.02	<0.05	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.05
	Sodium	µg/L	20	200000		2480	2630	2900	2900	3430	2970	3050	3250	3200	2700	2700	3040	3100	3150	2940	3400
	Strontium	µg/L	1			196	199	203	-	-	-	-	-	-	207	-	-	-	-	-	-
	Sulphur (Elemental)	µg/L	100			-	17,400	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Sulphur as S	µg/L	100			14,500	-	-	-	22,300	22,600	27,300	21,900	-	-	-	22,100	24,300	26,300	19,500	-
	Tellurium	µg/L	0.1			<0.1	<0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Thallium	µg/L	0.01			<0.01	<0.01	<0.2	-	-	-	-	-	<0.2	<0.2	-	-	-	-	-	<0.2
	Thorium	µg/L	0.4			<0.4	<0.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Tin	µg/L	0.1			<0.1	<0.1	<0.5	-	-	-	-	-	-	<0.5	-	-	-	-	-	-
	Titanium	µg/L	1			<1	3	<10	-	-	-	-	-	<50	<10	-	-	-	-	-	<50
	Uranium	µg/L	0.2		20	0.6	0.6	0.56	0.56	0.73	0.98	1.31	1.08	0.88	0.79	0.79	0.69	1.26	1.58	0.9	0.9
	Vanadium	µg/L	0.1			0.2	0.2	<1	<1	<5	<5	<5	<5	<30	<1	<1	<5	<5	<5	<5	<30
	Zinc	µg/L	1	5000		9	4	<50	<50	<5	<5	<5	<5	<5	<50	<50	<5	<5	<5	<5	<5
	Zirconium	µg/L	0.1			<0.1	<0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biological	Total Coliforms	MPN/100mL	1			-	-	<1	<1	<1	<1	<1	<1	-	-	<1	<1	<1	14	<1	-
	E. Coli	MPN/100mL	1			-	-	<1	<1	<1	<1	<1	<1	-	-	<1	<1	<1	<1	<1	-
BTEXS & MTBE	Benzene	µg/L	0.5		5	-	<1	<0.5	-	-	-	-	-	<0.5	<0.5	-	-	-	-	-	<0.5
	Toluene	µg/L	0.45	24	60	-	<1	<0.5	-	-	-	-	-	<0.45	<0.5	-	-	-	-	-	<0.45
	Ethylbenzene	µg/L	0.5	1.6	140	-	<1	<0.5	-	-	-	-	-	<0.5	<0.5	-	-	-	-	-	<0.5
	Xylenes (m & p)	µg/L	0.5			-	-	<0.5	-	-	-	-	-	<0.5	<0.5	-	-	-	-	-	<0.5
	Xylene (o)	µg/L	0.5			-	-	<0.5	-	-	-	-	-	<0.5	<0.5	-	-	-	-	-	<0.5
	Xylenes Total	µg/L	0.75	20	90	-	<1	<0.75	-	-	-	-	-	<0.75	<0.75	-	-	-	-	-	<0.75
	Styrene	µg/L	0.5			-	<1	<0.5	-	-	-	-	-	<0.5	<0.5	-	-	-	-	-	<0.5
	MTBE	µg/L	0.5	15		-	<1	<0.5	-	-	-	-	-	<0.5	<0.5	-	-	-	-	-	<0.5
Hydrocarbons	EPH10-19	µg/L	250			-	-	-	-	-	-	-	-	<250	-	-	-	-	-	-	<250
	EPH19-32	µg/L	250			-	-	-	-	-	-	-	-	<250	-	-	-	-	-	-	<250
	LEPH	µg/L	100			<100	<100	-	-	-	-	-	-	<250	-	-	-	-	-	-	<250
	HEPH	µg/L	100			<100	<100	-	-	-	-	-	-	<250	-	-	-	-	-	-	<250
	VH6-10	µg/L	50			-	<50	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	VPHw	µg/L	50			-	<50	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Glycols	Diethylene glycol	µg/L	5000			-	-	-	-	-	-	-	-	<5000	-	-	-	-	-	-	<5000
	Ethylene glycol	µg/L	5000			-	-	-	-	-	-	-	-	<5000	-	-	-	-	-	-	<5000
	Propylene glycol	µg/L	5000			-	-	-	-	-	-	-	-	<5000	-	-	-	-	-	-	<5000
	Triethylene Glycol	µg/L	5000			-	-	-	-	-	-	-	-	<5000	-	-	-	-	-	-	<5000
Polycyclic Aromatic Hydrocarbon	Acenaphthene	µg/L	0.05			<0.1	<0.1	<0.05	-	-	-	-	-	<0.05	<0.05	-	-	-	-	-	<0.05
	Acenaphthylene	µg/L	0.05			<0.1	<0.1	<0.05	-	-	-	-	-	<0.05	<0.05	-	-	-	-	-	<0.05
	Acridine	µg/L	0.05			<0.05	<0.05	<0.05	-	-	-	-	-	<0.05	<0.05	-	-	-	-	-	<0.05
	Anthracene	µg/L	0.05			<0.1	<0.1	<0.05	-	-	-	-	-	<0.05	<0.05	-	-	-	-	-	<0.05
	Benz(a)anthracene	µg/L	0.01			<0.01	<0.01	<0.05	-	-	-	-	-	<0.05	<0.05	-	-	-	-	-	<0.05
	Benzo(a)pyrene	µg/L	0.005		0.04	<0.01	<0.01	<0.01	-	-	-	-	-	<0.005	<0.01	-	-	-	-	-	<0.005
	Benzo(b)fluoranthene	µg/L	0.01			<0.01	<0.01	<0.05	-	-	-	-	-	-	<0.05	-	-	-	-	-	-
	Benzo(b+j)fluoranthene	µg/L	0.05			-	-	-	-	-	-	-	-	<0.05	-	-	-	-	-	-	<0.05
	Benzo(g,h,i)perylene	µg/L	0.05			<0.1	<0.1	<0.05	-	-	-	-	-	<0.05	0.054	-	-	-	-	-	<0.05
	Benzo(k)fluoranthene	µg/L	0.02			<0.02	<0.02	<0.05	-	-	-	-	-	<0.05	<0.05	-	-	-	-	-	<0.05
	Chrysene	µg/L	0.05			<0.1	<0.1	<0.05	-	-	-	-	-	<0.05	<0.05	-	-	-	-	-	<0.05
	Dibenz(a,h)anthracene	µg/L	0.005			<0.01	<0.01	<0.05	-	-	-	-	-	<0.005	<0.05	-	-	-	-	-	<0.005
	Fluoranthene	µg/L	0.05			<0.1	<0.1	<0.05	-	-	-	-	-	<0.05	<0.05	-	-	-	-	-	<0.05
	Fluorene	µg/L	0.05			<0.1	<0.1	<0.05	-	-	-	-	-	<0.05	<0.05	-	-	-	-	-	<0.05
	Indeno(1,2,3-c,d)pyrene	µg/L	0.05			<0.1	<0.1	<0.05	-	-	-	-	-	<0.05	<0.05	-	-	-	-	-	<0.05
	Naphthalene	µg/L	0.05			<0.1	<0.1	<0.05	-	-	-	-	-	<0.05	<0.05	-	-	-	-	-	<0.05
	Phenanthrene	µg/L	0.05			<0.1	<0.1	<0.05	-	-	-	-	-	<0.05	<0.05	-	-	-	-	-	<0.05
	Pyrene	µg/L	0.02			<0.02	<0.02	<0.05	-	-	-	-	-	<0.05	<0.05	-	-	-	-	-	<0.05
	Quinoline	µg/L	0.05			<3.4	<3.4	<0.05	-	-	-	-	-	<0.05	<0.05	-	-	-	-	-	<0.05
Volatile Organic Compounds (VO	Bromodichloromethane	µg/L	1			-	-	<1	-	-	-	-	-	-	<1	-	-	-	-	-	-
	Bromoform	µg/L	1			-	-	<1	-	-	-	-	-	-	<1	-	-	-	-	-	-
	Carbon tetrachloride	µg/L	0.5		2	-	-	<0.5	-	-	-	-	-	-	<0.5	-	-	-	-	-	-
	Chlorobenzene	µg/L	1	30	80	-	-	<1	-	-	-	-	-	-	<1	-	-	-	-	-	-
	Chloroethane	µg/L	1			-	-	<1	-	-	-	-	-	-	<1	-	-	-	-	-	-
	Chloroform	µg/L	1			-	-	<1	-	-	-	-	-	-	<1	-	-	-	-	-	-
	Chloromethane	µg/L	5			-	-	<5	-	-	-	-	-	-	<5	-	-	-	-	-	-
	Dibromochloromethane	µg/L	1			-	-	<1	-	-	-	-	-	-	<1	-	-	-	-	-	-
	1,2-Dichlorobenzene	µg/L	0.7	3	200	-	-	<0.7	-	-	-	-	-	-	<0.7	-	-	-	-	-	-
	1,3-Dichlorobenzene	µg/L	1			-	-	<1	-	-	-	-	-	-	<1	-	-	-	-	-	-
	1,4-Dichlorobenzene	µg/L	1	1	5	-	-	<1	-	-	-	-	-	-	<1	-	-	-	-	-	-
	1,1-Dichloroethane	µg/L	1			-	-	<1	-	-	-	-	-	-	<1	-	-	-	-	-	-
	1,2-Dichloroethane	µg/L	1		5	-	-	<1	-	-	-	-	-	-	<1	-	-	-	-	-	-
	1,1-Dichloroethene	µg/L	1		14	-	-	<1	-	-	-	-	-	-	<1	-	-	-	-	-	-
	1,2-Dichloroethene (cis)	µg/L	1			-	-	<1	-	-	-	-	-	-	<1	-	-	-	-	-	-
	1,2-Dichloroethene (trans)	µg/L	1			-	-	<1	-	-	-	-	-	-	<1	-	-	-	-	-	-
	1,2-Dichloropropane	µg/L	1			-	-	<1	-	-	-	-	-	-	<1	-	-	-	-	-	-
	1,3-Dichloropropene	µg/L	1.41			-	-	<1.4	-	-	-	-	-	-	<1.4	-	-	-	-	-	-
	1,3-Dichloropropene [cis]	µg/L	1			-	-	<1	-	-	-	-	-	-	<1	-	-	-	-	-	-
	1,3-Dichloropropene [trans]	µg/L	1			-	-	<1	-	-	-	-	-	-	<1	-	-	-	-	-	-
	Methylene Chloride	µg/L	5		50	-	-	<5	-	-	-	-	-	-	<5	-	-	-	-	-	-
	1,1,1,2-Tetrachloroethane	µg/L	1			-	-	<1	-	-	-	-	-	-	<1	-	-	-	-	-	-
	1,1,2,2-Tetrachloroethane	µg/L	1			-	-	<1	-	-	-	-	-	-	<1	-	-	-	-	-	-
	Tetrachloroethene	µg/L	1		10	-	-	<1	-	-	-	-	-	-	<1	-	-	-	-	-	-
	1,1,1-Trichloroethane	µg/L	1			-	-	<1	-	-	-	-	-	-	<1	-	-	-	-	-	-
	1,1,2-Trichloroethane	µg/L	1			-	-	<1	-	-	-	-	-	-	<1	-	-	-	-	-	-
	Trichloroethene	µg/L	1		5	-	-	<1	-	-	-	-	-	-	<1	-	-	-	-	-	-
	Trichlorofluoromethane	µg/L	1			-	-	<1	-	-	-	-	-	-	<1	-	-	-	-	-	-
	Vinyl chloride	µg/L	1		2	-	-	<1	-	-	-	-	-	-	<1	-	-	-	-	-	-

RDL = Reportable Detection Limit
Shaded - Exceeds the Guidelines for Canadian Drinking Water Quality Value - Maximum Allowable Concentration
Red - Exceeds the Guidelines for Canadian Drinking Water Quality Value - Aesthetic Objective

Table 3b: Klondike River Water Quality, July 2017

Chem_Group	ChemName	output unit	EQL	Canadian Drinking Water AO	Canadian Drinking Water MAC	KLONDIKE RIVER D/S	KLONDIKE RIVER U/S
						7/24/2017	7/24/2017
	Hardness as CaCO3	µg/L	500			154,000	155,000
	Nitrate (as N)	µg/L	5		10000	45.4	51.9
Metals	Aluminum	µg/L	5	100[#1]		122	82
	Antimony	µg/L	0.2		6	<0.5	<0.5
	Arsenic	µg/L	0.2		10	<1	<1
	Barium	µg/L	1		1000	68	68
	Beryllium	µg/L	0.04			<5	<5
	Boron_	µg/L	4		5000	<100	<100
	Cadmium	µg/L	0.01		5	<0.05	<0.05
	Calcium	µg/L	50			42,000	42,500
	Chromium	µg/L	0.4		50	<0.5	<0.5
	Cobalt	µg/L	0.02			<0.5	<0.5
	Copper	µg/L	1	1000		1	1.1
	Iron	µg/L	10	300		194	148
	Lead	µg/L	0.1		10	<1	<1
	Lithium	µg/L	1			<50	<50
	Magnesium	µg/L	50			12,000	11,900
	Manganese	µg/L	0.2	50		21	17
	Mercury	µg/L	0.01		1	<0.2	<0.2
	Molybdenum	µg/L	0.1			<1	<1
	Nickel	µg/L	1			<5	<5
	Potassium	µg/L	100			<2000	<2000
	Selenium	µg/L	0.1		50	<1	<1
	Silver	µg/L	0.01			<0.05	<0.05
	Sodium	µg/L	20	200000		2700	2600
	Thallium	µg/L	0.01			<0.2	<0.2
	Titanium	µg/L	1			<50	<50
	Uranium	µg/L	0.2		20	0.72	0.63
	Vanadium	µg/L	0.1			<30	<30
	Zinc	µg/L	1	5000		<5	<5
BTEXS & MTBE	Benzene	µg/L	0.5		5	<0.5	<0.5
	Toluene	µg/L	0.45	24	60	<0.45	<0.45
	Ethylbenzene	µg/L	0.5	1.6	140	<0.5	<0.5
	Xylenes (m & p)	µg/L	0.5			<0.5	<0.5
	Xylene (o)	µg/L	0.5			<0.5	<0.5
	Xylenes Total	µg/L	0.75	20	90	<0.75	<0.75
	Styrene	µg/L	0.5			<0.5	<0.5
	MTBE	µg/L	0.5	15		<0.5	<0.5
Hydrocarbons	EPH10-19	µg/L	250			<250	<250
	EPH19-32	µg/L	250			<250	<250
	LEPH	µg/L	100			<250	<250
	HEPH	µg/L	100			<250	<250
Glycols	Diethylene glycol	µg/L	5000			<5000	<5000
	Ethylene glycol	µg/L	5000			<5000	<5000
	Propylene glycol	µg/L	5000			<5000	<5000
	Triethylene Glycol	µg/L	5000			<5000	<5000
Polycyclic Aromatic Hydrocarbor	Acenaphthene	µg/L	0.05			<0.05	<0.05
	Acenaphthylene	µg/L	0.05			<0.05	<0.05
	Acridine	µg/L	0.05			<0.05	<0.05
	Anthracene	µg/L	0.05			<0.05	<0.05
	Benz(a)anthracene	µg/L	0.01			<0.05	<0.05
	Benzo(a)pyrene	µg/L	0.005		0.04	<0.005	<0.005
	Benzo(b+j)fluoranthene	µg/L	0.05			<0.05	<0.05
	Benzo(g,h,i)perylene	µg/L	0.05			<0.05	<0.05
	Benzo(k)fluoranthene	µg/L	0.02			<0.05	<0.05
	Chrysene	µg/L	0.05			<0.05	<0.05
	Dibenz(a,h)anthracene	µg/L	0.005			<0.005	<0.005
	Fluoranthene	µg/L	0.05			<0.05	<0.05
	Fluorene	µg/L	0.05			<0.05	<0.05
	Indeno(1,2,3-c,d)pyrene	µg/L	0.05			<0.05	<0.05
	Naphthalene	µg/L	0.05			<0.05	<0.05
	Phenanthrene	µg/L	0.05			<0.05	<0.05
	Pyrene	µg/L	0.02			<0.05	<0.05
	Quinoline	µg/L	0.05			<0.05	<0.05

RDL = Reportable Detection Limit

Shaded - Exceeds the Guidelines for Canadian Drinking Water Quality Value - Maximum Allowable Concentration

Red - Exceeds the Guidelines for Canadian Drinking Water Quality Value - Aesthetic Objective

Table 3c: Klondike River Water Quality (Microbiological)

Sample Date	Coliforms Fecal	Unit
8/23/2005	22	CFU/100ML
9/7/2005	11	CFU/100ML
5/17/2006	30	CFU/100ML
9/11/2006	11	CFU/100ML
10/11/2006	15	CFU/100ML
11/6/2006	Coliroms	CFU/100ML
1/9/2007	2	CFU/100ML
2/5/2007	4	CFU/100ML
5/22/2007	12	CFU/100ML
6/5/2007	32	CFU/100ML
10/29/2007	1	CFU/100ML
2/27/2008	1	CFU/100ML
3/17/2008	1	CFU/100ML
6/24/2008	2	CFU/100ML
9/24/2008	3	CFU/100ML
3/2/2009	1	CFU/100ML
4/15/2009	1	CFU/100ML
6/23/2009	3	CFU/100ML
8/31/2009	1	CFU/100ML
9/30/2009	7	CFU/100ML
3/1/2010	1	CFU/100ML
6/22/2010	1	CFU/100ML
2/28/2011	1	CFU/100ML
5/4/2011	48	CFU/100ML
7/25/2011	22	CFU/100ML
9/19/2011	1	CFU/100ML
2/6/2012	1	CFU/100ML
5/22/2012	8	CFU/100ML
7/17/2012	3	CFU/100ML
8/13/2012	15	CFU/100ML
9/18/2012	4	CFU/100ML
10/17/2012	5	CFU/100ML
2/11/2013	1	CFU/100ML
5/21/2013	14	CFU/100ML
10/22/2013	1	CFU/100ML
1/20/2014	<1	CFU/100ML
2/19/2014	<1	CFU/100ML
3/25/2014	<1	CFU/100ML
7/7/2014	<1	CFU/100ML
8/11/2014	4	CFU/100ML
9/9/2014	3	CFU/100ML
10/6/2014	5	CFU/100ML
3/9/2015	1	CFU/100ML
3/30/2015	<1	CFU/100ML
4/28/2015	57	CFU/100ML
6/1/2015	1	CFU/100ML
7/6/2015	2	CFU/100ML
8/4/2015	3	CFU/100ML
9/14/2015	9	CFU/100ML
10/6/2015	4	CFU/100ML
2/10/2016	<1	CFU/100ML
3/7/2016	<1	CFU/100ML
3/30/2016	<1	CFU/100ML
6/1/2016	<1	CFU/100ML
7/4/2016	8	CFU/100ML
8/29/2016	5	CFU/100ML
10/12/2016	1	CFU/100ML
11/7/2016	<1	CFU/100ML
2/14/2017	<1	CFU/100ML

Table 4: Evaluation of Risk Scenarios - Dawson City

ID	Site	Source of Potential Contamination	Exposure Likelihood	Exposure Consequence	Risk Rank	Notes on Existing Risk Mitigation Measures and Application of Risk Assessment Rules	Risk Reduction Options to Consider	SPC Removal Options to Consider
DC01	Residential Dwelling	44 gal drums, old trucks/cars stored on site.	Medium	High	High	No known engineered risk mitigation measures in place.	Request owner allows an inventory of potentially hazardous chemicals onsite. If hazardous material identified and deemed a potential risk to groundwater, request owner instigate mitigation measures or remove. Spills/leaks to be reported to Yukon Spills line and to CoD If appropriate, implement appropriate ERP/s (contamination of water source, oil spill)	-
DC02	Dawson City Swimming Pool	Range of chemicals stored on site used to clean and dose pool, clean facility.	Low	Medium	Low	Exposure likelihood reduced from high to low based on two engineered mitigation measures in place (chemicals stored indoors, chemicals stored in specific storage areas)	Regular (6 monthly at minimum) assessment of storage containers and storage locations to ensure spills/leaks are not occurring. Spills/leaks to be reported to Yukon Spills line and to CoD If appropriate, implement appropriate ERP/s (contamination of water source)	-
DC03	Waste Water Treatment Plant	Wastewater released to ground due to mechanical failure/human error	High	High	High	No known engineered risk mitigation measures in place.	Regular maintenance of plant. Appropriate and thorough training of staff. SOP's in place to reduce chance of mechanical failure or human error. Use of portable 6" pump and hose to bypass the WWTP if required to eliminate overflow. Spills/leaks/overflows to be reported to Yukon Spills line and to CoD If appropriate, implement appropriate ERP/s (contamination of water source, sewer system failure)	-
DC04		"Deep Shaft" wastewater treatment system	Low	High	Medium	Exposure likelihood reduced from high to low based on one engineered barrier (shaft design - leak tight aeration shaft casing, comprised of steel and surrounded by cement grout to reduce the risk of groundwater contamination from wastewater breaching from the shafts) and as there have been no documented cases of leaks from other systems that have been operating for up to 30 years.	Regular maintenance of plant. Routine testing of "deep shaft" for leakage. Appropriate and thorough training of staff. SOP's in place to reduce chance of mechanical failure or human error, identify problems and how to manage them. Leaks to be reported to Yukon Spills line and to CoD If appropriate, implement appropriate ERP/s (contamination of water source, sewer system failure)	-
DC05		Piezometer at influent sump	High	High	High	No known engineered risk mitigation measures in place.	Replace the existing piezometer cap with a lockable cap that can completely seal the piezo from inflow of liquid from surface. Implement a SOP for the access of the piezo that includes ensuring the cap is replaced, sealed and locked immediately after use. Staff to be trained on importance of keeping piezometer sealed and potential implications to drinking water if wastewater or chemicals flow into open piezometer. Spills/leaks to be reported to Yukon Spills line and to CoD If appropriate, implement appropriate ERP/s (contamination of water source, sewer system failure)	Decommission the piezometer
DC06		Outside double walled AST Diesel Fuel Tank - 28,000 L	Medium	Medium	Medium	Exposure likelihood reduced from high to medium based on one engineered barrier (double walled) Exposure consequence reduced from high to medium based on water quality sampling conducted in 2014 and 2017 reporting chemicals with chronic long term health hazards associated with fuels had concentrations below laboratory detection limits, and under the assumption that CoD will implement recommended routine hydrocarbon sampling at all four water supply wells.	Place fuel tank in a spill containment tank or within lined/bermed area. Spills/leaks to be reported to Yukon Spills line and to CoD If appropriate, implement appropriate ERP/s (oil spill)	-
DC07		Indoor double walled AST Diesel Fuel Tank secured to concrete floor- Approx. 1,000 L	Low	Medium	Low	Exposure likelihood reduced from high to low based on two engineered barriers (double walled, located indoors on concrete slab) Exposure consequence reduced from high to medium based on water quality sampling conducted in 2014 and 2017 reporting chemicals with chronic long term health hazards associated with fuels had concentrations below laboratory detection limits, and under the assumption that CoD will implement recommended routine hydrocarbon sampling at all four water supply wells.	Place fuel tank in a spill containment tank Spills/leaks to be reported to Yukon Spills line and to CoD If appropriate, implement appropriate ERP/s (oil spill)	-
DC08		Indoor double walled AST Diesel Fuel Tank secured to concrete floor- Approx. 1,000 L	Low	Medium	Low	Exposure likelihood reduced from high to low based on two engineered barriers (double walled, located indoors on concrete slab) Exposure consequence reduced from high to medium based on water quality sampling conducted in 2014 and 2017 reporting chemicals with chronic long term health hazards associated with fuels had concentrations below laboratory detection limits, and under the assumption that CoD will implement recommended routine hydrocarbon sampling at all four water supply wells.	Place fuel tank in a spill containment tank Spills/leaks to be reported to Yukon Spills line and to CoD If appropriate, implement appropriate ERP/s (oil spill)	-
DC09	Sink hole outside of front of museum	Unknown, land subsidence may indicate degradation of organic matter, rusting and collapse of metal waste.	High	High	High	No known engineered risk mitigation measures in place.	Undertake investigation program to assess the cause of subsidence. If buried waste is present, remove if considered to be a potential source of groundwater contamination.	If buried waste is present, remove if considered to be a potential source of groundwater contamination.
DC10	Ambulance Station	2 x 44 gal drums approx. 1/5 to 1/4 full, not labeled placed outside entry and close to vehicle parking area.	Medium	High	High	No known engineered risk mitigation measures in place.	Determine contents of drums. If drums contain chemicals that may detrimentally impact groundwater, place drums in containment tank or in lined, bermed area. Spills/leaks to be reported to Yukon Spills line and to CoD	Remove drums from site and locate/dispose of in accordance with applicable guidelines, dependent on contents.
DC11	Former Alexander McDonald Lodge	1 x 1m3 liquid container outside building on southeast corner	Medium	High	High	No known engineered risk mitigation measures in place.	Determine contents of container. If container contain chemicals that may detrimentally impact groundwater, place in containment tank or in lined, bermed area Spills/leaks to be reported to Yukon Spills line and to CoD	Remove container from site and locate/dispose of in accordance with applicable guidelines, dependent on contents.
DC12	Water Treatment Plant	Indoor double walled AST Diesel Fuel Tank - Approx. 680 L, placed in spill container	Low	Medium	Low	Exposure likelihood low given travel time < 2 years with three engineered barriers in place (double walled tank, placed in spill container, indoors and on concrete floor). Exposure consequence reduced from high to medium based on water quality sampling conducted in 2014 and 2017 reporting chemicals with chronic long term health hazards associated with fuels had concentrations below laboratory detection limits, and under the assumption that CoD will implement recommended routine hydrocarbon sampling at all four water supply wells.	Spills/leaks to be reported to Yukon Spills line and to CoD If appropriate, implement appropriate ERP/s (oil spill)	-
DC13		Outdoor AST Diesel Fuel Tank - 10,000, operator unsure if double walled	Medium	Medium	Medium	No known engineered risk mitigation measures in place. Exposure consequence reduced from high to medium based on water quality sampling conducted in 2014 and 2017 reporting chemicals with chronic long term health hazards associated with fuels had concentrations below laboratory detection limits, and under the assumption that CoD will implement recommended routine hydrocarbon sampling at all four water supply wells.	Place the fuel tank in a spill containment tank. Replace tank with double walled tank if not already. Spills/leaks to be reported to Yukon Spills line and to CoD If appropriate, implement appropriate ERP/s (oil spill)	-
DC14		Range of oils, acids, paints, antigels in chemical storage cupboard in workshop	Low	Medium	Medium	Exposure likelihood low given travel time < 2 years with three engineered barriers in place (double walled tank, placed in spill container, indoors and on concrete floor).	Spills/leaks to be reported to Yukon Spills line and to CoD If appropriate, implement appropriate ERP/s (oil spill)	-
DC15	Hospital	6 x empty drums placed in public area at south end of property, adjacent to ball field	Low	Medium	Medium	No known engineered risk mitigation measures in place. Exposure likelihood reduce to low as drums are empty.	Ensure all drums are washed and cleaned prior to storage. Spills/leaks to be reported to Yukon Spills line and to CoD. Do not store in publically accessible location as this may encourage dumping of other used drums.	Dispose/return drums immediately after use
DC16		Underground fuel storage tanks located at southwest corner of building	High	Medium	High	Exposure likelihood increased from medium to high based on potential for leaks from underground storage tanks to go unnoticed for long periods and result in large scale contamination. Exposure consequence reduced from high to medium based on water quality sampling conducted in 2014 and 2017 reporting chemicals with chronic long term health hazards associated with fuels had concentrations below laboratory detection limits, and under the assumption that CoD will implement recommended routine hydrocarbon sampling at all four water supply wells.	Regular assessment of UST condition to detect leakage and loss of product. Spills/leaks to be reported to Yukon Spills line and to CoD. If appropriate, implement appropriate ERP/s (oil spill, contamination of water source)	-
DC17	Area between Hospital and Museum	Soil and groundwater impacted by hydrocarbons from former UST	Low	Medium	Low	Exposure likelihood reduced from medium to low as site has been assessed with no free phase hydrocarbons present and dissolved phase appears to be migrating north west away from wells.	Implement recommendations made in Tetra Tech (2016).	-
DC18	Museum	Above ground fuel tank - approximately 10,000 L	Medium	Medium	Medium	No known engineered risk mitigation measures in place. Exposure consequence reduced from high to medium based on water quality sampling conducted in 2014 and 2017 reporting chemicals with chronic long term health hazards associated with fuels had concentrations below laboratory detection limits, and under the assumption that CoD will implement recommended routine hydrocarbon sampling at all four water supply wells.	Place tank in spill container or bermed/lined area. Spills/leaks to be reported to Yukon Spills line and to CoD. If appropriate, implement appropriate ERP/s (oil spill, contamination of water source)	-

Table 4: Evaluation of Risk Scenarios - Dawson City

ID	Site	Source of Potential Contamination	Exposure Likelihood	Exposure Consequence	Risk Rank	Notes on Existing Risk Mitigation Measures and Application of Risk Assessment Rules	Risk Reduction Options to Consider	SPC Removal Options to Consider
DC19	Slough behind church	Use of Vectobac (biological larvacide in pellet form used for mosquito control)	Very High	Low	High	No known engineered risk mitigation measures in place.	Ensure that application of VectoBac is applied by qualified/trained professionals in compliance with directions for use taking into account location of water supply wells.	Discontinue use of VectoBac at location.
DC20	Ball Park	25-10-10 Fertilizer	High	Low	Medium	No known engineered risk mitigation measures in place. Exposure consequence reduced from high to low as area has history of fertilizer use and nitrate concentrations in groundwater supply wells are on average more than ten times lower than MAC and maximum concentration is over six times lower than MAC.	Application rates to be determined by qualified professional to ensure over fertilization does not occur.	Discontinue application
DC21	Grassed area behind Commissioners residence	25-10-10 fertilizer	High	Low	Medium			
DC22	Grassed area corner of Church St and Fifth Ave	25-10-10 fertilizer	High	Low	Medium			
DC23	Grassed area along river front between Eighth Ave and Princess St	25-10-10 fertilizer	Very High	Low	High			
DC24	YG Property Management Compound	Approx. 20 x 44 gal drums storing old heating fuel and water. Potential for other unknown hydrocarbons in drums. Placed on pallets within a berm with sealed liner. Three years of accumulated waste.	Medium	High	High	Exposure likelihood reduced from high to medium based on one engineered barrier (drums placed in lined, bermed containment area)	Remove drums on a frequent basis - i.e. yearly Spills/leaks to be reported to Yukon Spills line and to CoD If appropriate, implement appropriate ERP/s (oil spill, contamination of water source)	Do not store drums onsite.
DC25		44 gal drum storage - Dowfrost HD 50/50 used for heat transfer fluid for heating and air conditioning systems.	High	Medium	High	No known engineered risk mitigation measures in place.	Store drums in lined, bermed area. Spills/leaks to be reported to Yukon Spills line and to CoD Remove drums on a frequent basis - i.e. yearly If appropriate, implement appropriate ERP/s (oil spill, contamination of water source)	Do not store drums onsite.
DC49		44 gal drum storage - Dowfrost HD 50/50 used for heat transfer fluid for heating and air conditioning systems, Isopac 80 used as a coagulant and flocculent.	High	Medium	High	No known engineered risk mitigation measures in place.	Store drums in lined, bermed area. Spills/leaks to be reported to Yukon Spills line and to CoD Remove drums on a frequent basis - i.e. yearly If appropriate, implement appropriate ERP/s (oil spill, contamination of water source)	Do not store drums onsite.
DC26	Yukon Energy Corporation	Above ground diesel tank - approximately 113,000 L. Single wall, placed in steel containment tank designed to hold tank volume, all within berm.	Low	Medium	Low	Exposure likelihood reduced from medium to low based on one engineered barrier (drums placed in steel spill containment area) Exposure consequence reduced from high to medium based on water quality sampling conducted in 2014 and 2017 reporting chemicals with chronic long term health hazards associated with fuels had concentrations below laboratory detection limits, and under the assumption that CoD will implement recommended routine hydrocarbon sampling at all four water supply wells.	Regular inspection (daily) of tanks and truck discharge location to ensure spills or leaks are not occurring Spills/leaks to be reported to Yukon Spills line and to CoD If appropriate, implement appropriate ERP/s (oil spill, contamination of water source)	-
DC27		Above ground diesel tank - approximately 22,500 L. Single wall, placed in steel containment tank designed to hold tank volume, all within berm.	Low	Medium	Low	Exposure likelihood reduced from medium to low based on one engineered barrier (drums placed in steel spill containment area) Exposure consequence reduced from high to medium based on water quality sampling conducted in 2014 and 2017 reporting chemicals with chronic long term health hazards associated with fuels had concentrations below laboratory detection limits, and under the assumption that CoD will implement recommended routine hydrocarbon sampling at all four water supply wells.	Regular inspection (daily) of tanks and truck discharge location to ensure spills or leaks are not occurring Spills/leaks to be reported to Yukon Spills line and to CoD If appropriate, implement appropriate ERP/s (oil spill, contamination of water source)	-
DC28		Engine oil storage in sea can at southeast corner of compound	Low	Medium	Low	Exposure likelihood reduced from medium to low based on one engineered barrier (drums placed in steel spill containment area) Exposure consequence reduced from high to medium based on water quality sampling conducted in 2014 and 2017 reporting chemicals with chronic long term health hazards associated with fuels had concentrations below laboratory detection limits, and under the assumption that CoD will implement recommended routine hydrocarbon sampling at all four water supply wells.	Spills/leaks to be reported to Yukon Spills line and to CoD If appropriate, implement appropriate ERP/s (oil spill, contamination of water source)	-
DC29	Parks Canada	Above ground fuel tank - approximately 5,000 L. Parks Canada staff present advised that the tank is empty and not used. No berm/containment	Medium	Medium	Medium	No known engineered risk mitigation measures in place. Exposure consequence reduced from high to medium based on water quality sampling conducted in 2014 and 2017 reporting chemicals with chronic long term health hazards associated with fuels had concentrations below laboratory detection limits, and under the assumption that CoD will implement recommended routine hydrocarbon sampling at all four water supply wells.	If tank is to be used in the future, place in spill containment tank. Spills/leaks to be reported to Yukon Spills line and to CoD	Remove tank from site
DC30		Leak from a fuel feed line from an above ground storage tank (AST) led to soil contamination in 2001. Characterization samples of the estimated 300 m3 contaminated material excavated were above CSR-CL standards. Env Yukon file holds no record of confirmatory samples or final volume contaminated material removed from the site	High	Medium	High	No known engineered risk mitigation measures in place. Exposure consequence reduced from high to medium based on water quality sampling conducted in 2014 and 2017 reporting chemicals with chronic long term health hazards associated with fuels had concentrations below laboratory detection limits, and under the assumption that CoD will implement recommended routine hydrocarbon sampling at all four water supply wells.	Undertake assessment of residual contamination	If residual contamination is present, remediate to below appropriate standards.
DC31		8 x 44 gal drums, believed to contain propylene glycol for heating/air conditioning. Drums are approx. full to half full.	High	Medium	High	No known engineered risk mitigation measures in place.	Place drums in lined, bermed enclosure or spill containment tank. Spills/leaks to be reported to Yukon Spills line and to CoD. If appropriate, implement appropriate ERP/s (oil spill, contamination of water source)	Remove drums from site and store/dispose of in accordance with appropriate regulations.
DC32	Multiple Locations Within Zone 1	Most buildings within the wells capture zone area have AST's for heating fuel located outside and adjacent to the buildings.	Medium	Medium	Medium	For the purpose of this assessment it is assumed that all tanks are single walled, in generally good condition and with no mitigation measures in place (further work should be conducted to assess individual tanks and the risk rank amended accordingly). Exposure consequence reduced from high to medium based on water quality sampling conducted in 2014 and 2017 reporting chemicals with chronic long term health hazards associated with fuels had concentrations below laboratory detection limits, and under the assumption that CoD will implement recommended routine hydrocarbon sampling at all four water supply wells.	All tanks in Zone 1 are replaced/upgraded to be double lined in spill container Educate owner on assessing the state of fuel tank and connections, appropriate location of tank and construction of stands. Spills/leaks to be reported to Yukon Spills line and to CoD CoD or YG to conduct monthly assessments of tanks in Zone 1. Implement scheme to encourage owners to report spills and replace tanks without substantial financial burden. If appropriate, implement appropriate ERP/s (oil spill, contamination of water source) Investigate feasibility of fuel delivery companies advising CoD of "at risk" tanks	Replace heating fuel with propane
DC33	Multiple Locations Within Zone 2	Most buildings within the wells capture zone area have AST's for heating fuel located outside and adjacent to the buildings.	Medium	Medium	Medium	For the purpose of this assessment it is assumed that all tanks are single walled, in generally good condition and with no mitigation measures in place (further work should be conducted to assess individual tanks and the risk rank amended accordingly). Exposure consequence reduced from high to medium based on water quality sampling conducted in 2014 and 2017 reporting chemicals with chronic long term health hazards associated with fuels had concentrations below laboratory detection limits, and under the assumption that CoD will implement recommended routine hydrocarbon sampling at all four water supply wells.	All tanks in Zone 2 are replaced/upgraded to be double lined Educate owner on assessing the state of fuel tank and connections, appropriate location of tank and construction of stands. Spills/leaks to be reported to Yukon Spills line and to CoD CoD or YG to conduct yearly assessments of tanks in Zone 2. Implement scheme to encourage owners to report spills and replace tanks without substantial financial burden. If appropriate, implement appropriate ERP/s (oil spill, contamination of water source) Investigate feasibility of fuel delivery companies advising CoD of "at risk" tanks	-
DC34	Multiple Locations Within Zone 3	Most buildings within the wells capture zone area have AST's for heating fuel located outside and adjacent to the buildings.	Medium	Medium	Medium	For the purpose of this assessment it is assumed that all tanks are single walled, in generally good condition and with no mitigation measures in place (further work should be conducted to assess individual tanks and the risk rank amended accordingly). Exposure consequence reduced from high to medium based on water quality sampling conducted in 2014 and 2017 reporting chemicals with chronic long term health hazards associated with fuels had concentrations below laboratory detection limits, and under the assumption that CoD will implement recommended routine hydrocarbon sampling at all four water supply wells.	All tanks in Zone 3 are replaced/upgraded to be double lined Educate owner on assessing the state of fuel tank and connections, appropriate location of tank and construction of stands. Spills/leaks to be reported to Yukon Spills line and to CoD. CoD or YG to conduct yearly assessments of tanks in Zone 3. Implement scheme to encourage owners to report spills and replace tanks without substantial financial burden. If appropriate, implement appropriate ERP/s (oil spill, contamination of water source) Investigate feasibility of fuel delivery companies advising CoD of "at risk" tanks	-

Table 4: Evaluation of Risk Scenarios - Dawson City

ID	Site	Source of Potential Contamination	Exposure Likelihood	Exposure Consequence	Risk Rank	Notes on Existing Risk Mitigation Measures and Application of Risk Assessment Rules	Risk Reduction Options to Consider	SPC Removal Options to Consider
DC35	Former Dawson City Hwy Maintenance Camp	Significant amount of assessment work has been completed on this property, but some areas still have potential contamination remaining	High	Medium	High	No known engineered risk mitigation measures in place. Exposure consequence reduced from high to medium based on water quality sampling conducted in 2014 and 2017 reporting chemicals with chronic long term health hazards associated with fuels had concentrations below laboratory detection limits, and under the assumption that CoD will implement recommended routine hydrocarbon sampling at all four water supply wells.	Undertake environmental assessment of residual contamination to determine presence, extent and mobility.	If residual contamination is present, remediate to below appropriate standards.
DC36	Apartment block at 5th Ave & Turner Street / Former Dawson City Hwy Maintenance Camp	Soil sampling indicates petroleum hydrocarbon contamination	High	Medium	High	No known engineered risk mitigation measures in place. Exposure consequence reduced from high to medium based on water quality sampling conducted in 2014 and 2017 reporting chemicals with chronic long term health hazards associated with fuels had concentrations below laboratory detection limits, and under the assumption that CoD will implement recommended routine hydrocarbon sampling at all four water supply wells.	Undertake environmental assessment of residual contamination to determine presence, extent and mobility.	If residual contamination is present, remediate to below appropriate standards.
DC37	RCMP Station, 415 Front Street	Minor undefined contamination (as described in Environment Yukon spill report) may remain onsite.	Medium	High	High	No known engineered risk mitigation measures in place. Exposure likelihood reduced from Very High to Medium as hydrocarbon sampling of the four wells in 2014 indicated no hydrocarbon impact to groundwater	Undertake environmental assessment of residual contamination to determine presence, extent and mobility.	If residual contamination is present, remediate to below appropriate standards.
DC38	Former slough running NW to SE across southern end of Dawson City.	Several cars removed from slough behind YG Property Management Compound, other potential unknown contaminants.	High	High	High	No known engineered risk mitigation measures in place.	Undertake investigation program to assess nature of slough backfill. If buried waste is present, remove if considered to be a potential source of groundwater contamination.	If present, remove buried waste that may be impacting groundwater quality.
DC39	Dawson City Sanitary System	Sanitary Sewer System runs throughout all streets in the City and is connected to al buildings. Leakage has the potential to contaminate groundwater.	Very High	Very High	Very High	No engineered barriers in place.	Upgrade sanitary lines to reduce/eliminate the potential for leakage (CoD are currently in the planning process to replace the sanitary sewer in the vicinity of the wells along Front St, Turner St and Fifth Ave). If appropriate, implement appropriate ERP/s (contamination of water source, sewer backup event, sewer system failure)	-
DC40	Turner Street Sanitary Emergency Outfall	Discharge to the Yukon River form the Turner Street Sanitary Emergency Outfall	High	Very High	Very High	No engineered barriers in place.	Implement mitigation measures already in place including use of portable pump and lay flat hosing to bypass points of mechanical failure and blockage. Re-route the Turner St emergency outfall along 5th Ave to Church St then discharge to the river at the end of Church St. CoD is currently undertaking a feasibility assessment to determine if this is a viable option. Investigate potential for hydraulic control of contamination plume migrating from the south - e.g. pumping PW-4N continuously at high rates and discharging to waste (Yukon River). This may hydraulically control a plume from the south, while drinking water supplies are obtained from northern wells (PW-1N and PW-2N). Suspend raw water bleeding at wells for frost protection when discharge occurs until bacteriological testing indicates it is safe to resume bleeding. If appropriate, implement appropriate ERP/s (contamination of water source, sewer backup event, sewer system failure, flood event or discharge at the Turner Street sanitary sewer outfall)	-
DC41	Dawson City Stormwater System	Leakage from the stormwater system that runs throughout Dawson City	High	Very High	Very High	No engineered barriers in place.	Encourage public to clean up dog faces, especially over winter to avoid high concentrations during spring thaw. Public education over appropriate substances to discharge to or wash down stormwater drains If appropriate, implement appropriate ERP/s (contamination of water source, contaminant discharge at the Turner Street storm sewer outfall)	-
DC42	Stormwater Discharge to Yukon and Klondike Rivers upstream of water supply wells	Stormwater Discharge to Yukon and Klondike Rivers upstream of water supply wells	High	Very High	Very High	No engineered barriers in place.	Encourage public to clean up dog faces, especially over winter to avoid high concentrations during spring thaw. Public education over appropriate substances to discharge to or wash down stormwater drains If appropriate, implement appropriate ERP/s (contamination of water source, contaminant discharge at the Turner Street storm sewer outfall)	-
DC43	Klondike River	Water sourced from the Klondike River that enters the Dawson City Aquifer and is within the well capture zones	Very High	Very High	Very High	Observances of microbiological contaminants in wells in the spring breakup period indicate a very high exposure likelihood.	Follow SOP for addressing seasonal coliform spikes and directions related to addressing seasonal coliform spike provided by Environmental Health Services dated April5, 2017. Suspend raw water bleeding at wells for frost protection at spring breakup and when Turner St Outfall discharge occurs until bacteriological testing indicates it is safe to resume. During spring breakup, there have historically been bacteriological hits on wells to the south (former supply well PW-3). Investigate potential to suspend use of southern wells or use southern wells to hydraulically control water migrating along the inferred shorter travel path from the river and then discharge it to waste (Yukon River). Education of public and businesses about discharging contaminants to ground and directly to the Klondike River and tributaries and the potential for impact to drinking water supplies. Incorporate UV Disinfection into the treatment system (proposed upgrades to the WTP include UV Disinfection) If appropriate, implement appropriate ERP/s (contamination of water source)	-
DC44	Potential for multiple locations across capture zone	Spills, disposal, leaks, dumping of chemicals in private residences or public places throughout the capture zone.	Low	High	Medium	Classified as low as deliberate, large scale dumping of chemicals within the Dawson City area is considered to be unlikely	Placement of signs advising within wellhead protection zone. Restrict public parking within 30 m of all water supply wells. CoD Staff to conduct regular visual assessment of potential contaminants and contamination within capture zones as part of regular work routine. Public information sessions, pamphlets distributed via mail with rates advising of potentially contaminating activities, mitigation measures, disposal options, spill hotline number. Spills/leaks to be reported to Yukon Spills line and to CoD. If appropriate, implement appropriate ERP/s (contamination of water source, oil spill)	-
DC45	Vehicle accident	Vehicle accident and subsequent release of fuel. Trucks with tidy tanks and tankers pose higher potential risk.	Low	High	Medium	Classified as low as no know vehicle accidents resulting in large scale release of fuel know of in Dawson City	Rapid implementation of response plan when potentially contaminating events occur. Spills/leaks to be reported to Yukon Spills line and to CoD. Investigate potential for hydraulic control of contaminate plume, dependent upon location of source. If appropriate, implement appropriate ERP/s (contamination of water source, oil spill)	-
DC46	PW-1N PW-2N PW3N PW4N	Bleeding water sourced from the raw water feed to prevent freeze-up	Medium	Very High	High	Standard Operating Procedure in place to reduce likelihood of cross contamination occurring	Implement Standard Operating Procedure for Addressing Seasonal Coliform Spikes at spring breakup. Suspend raw water bleeding at wells for frost protection when Turner St Outfall discharge occurs until bacteriological testing indicates it is safe to resume.	Investigate and implement alternative bleeding method that eliminates flow of water between wells.
DC47	Multiple	Groundwater monitoring wells within the well capture zone	High	High	High	Some wells have risk mitigation measured in place (locked) although majority can be accessed by public or subject to infiltration.	The condition of all identified groundwater monitoring wells should be assessed and the potential to provide a pathway to the DCA determined. Where wells provide a pathway for contamination, with the approval of the well/property owner, wells should be upgraded to be in compliance with best practice or decommissioned. All groundwater monitoring wells should be locked/secured to prevent unauthorized access	Decommission wells that are no longer in use or needed.
DC48	Northern Industrial Supplies (former White Pass and Yukon Route Building)	Anecdotal information that a spill/leak occurred from a heating fuel tank and was not cleaned up.	High	High	High	No known engineered risk mitigation measures in place. Exposure consequence reduced from high to medium based on water quality sampling conducted in 2014 and 2017 reporting chemicals with chronic long term health hazards associated with fuels had concentrations below laboratory detection limits, and under the assumption that CoD will implement recommended routine hydrocarbon sampling at all four water supply wells.	Contact owner to discuss historical spills onsite. If a spill has previously occurred, review actions to clean up contamination. Undertake environmental assessment if residual contamination is believed to exist to determine presence, extent and mobility.	If residual contamination is present, remediate to below appropriate standards.
DC50	Lane at rear of Northern Industrial Supplies	Car/truck batteries in lane at immediate rear of NIS	Low	High	Medium	No known engineered risk mitigation measures in place. Exposure likelihood reduced from high to low based on significant dilution expected if acid was to reach the water table.	Store batteries in spill container	Remove batteries from location and dispose of in appropriate manner.

Table 5: Evaluation of Risk Scenarios - Klondike River Valley

ID	Site	Source of Potential Contamination	Exposure Likelihood (revised based on mitigation measures and/or rules)	Exposure Consequence	Risk Rank	Notes on Existing Risk Mitigation Measures and Reduction of Exposure Likelihood	Risk Reduction Options to Consider
KRV01	Former gold processing facility and dredging operational headquarters at Bear Creek	Leaks, spills, deliberates disposal of various chemicals to water bodies and to ground during former Site operations.	Low	Low	Low	Exposure likelihood and consequence reduced to low based on the significant dilution offered by the Klondike River	Continued environmental assessment and remediation, where required.
KRV02	YECL Substation, Callison Subdivision	2003 spill of between 50 and 100L of hydraulic oil.	Low	Low	Low	Exposure likelihood and consequence reduced to low based on the significant dilution offered by the Klondike River	
KRV03	North 60 Bulk Plant, Callison Subdivision	In 2003, 4,000L of diesel fuel was spilled due to an overflowing tank. Fuel was contained and partially cleaned up. Current site status is unknown.	Low	Low	Low	Exposure likelihood and consequence reduced to low based on the significant dilution offered by the Klondike River	
KRV04	Lot 1 Callison Subdivision	Decommissioned Land Treatment Facility (LTF) with potentially elevated arsenic concentrations in soil.	Low	Low	Low	Exposure likelihood and consequence reduced to low based on the significant dilution offered by the Klondike River	
KRV05	Northern Superior Mechanical / NAPA	10 m3 of petroleum hydrocarbon contaminated soil removed from site. Current site status not known	Low	Low	Low	Exposure likelihood and consequence reduced to low based on the significant dilution offered by the Klondike River	
KRV06		Mechanics shop	Low	Low	Low	Exposure likelihood and consequence reduced to low based on the significant dilution offered by the Klondike River	
KRV07	Endurance Automotive and Small Engine	Bulk fuel storage tanks, mechanics shop	Low	Low	Low	Exposure likelihood and consequence reduced to low based on the significant dilution offered by the Klondike River	
KRV08	Public outhouses at campground	Raw waste	Low	Low	Low	Exposure likelihood and consequence reduced to low based on the significant dilution offered by the Klondike River	
KRV09	Airport	Bulk fuel storage tanks, mechanics hangers	Low	Low	Low	Exposure likelihood and consequence reduced to low based on the significant dilution offered by the Klondike River	
KRV10	Fischer Fuels	Bulk fuel storage tanks	Low	Low	Low	Exposure likelihood and consequence reduced to low based on the significant dilution offered by the Klondike River	
KRV11	Residential and commercial subdivisions up the Klondike Valley including Callison, Dredge Pond, Rock Creek, Bear Creek,	Most residential and commercial buildings along the Klondike River Valley are believed to onsite sewage disposal systems and above grade storage tanks.	Low	Low	Low	Exposure likelihood and consequence reduced to low based on the significant dilution offered by the Klondike River	
KRV12	Quigley Pit (Landfill)	Deposited domestic and commercial waste	Low	Low	Low	Routine groundwater and surface water monitoring program in place. Exposure likelihood and consequence reduced to low based on the significant dilution offered by the Klondike River.	
KRV13	YG Dawson Highway Maintenance Compound	Bulk fuel storage tanks, mechanics shop, road marking paint, salt	Low	Low	Low	Exposure likelihood and consequence reduced to low based on the significant dilution offered by the Klondike River	
KRV14	Chief Isaac Mechanical	Bulk fuel storage tanks, mechanics shop	Low	Low	Low	Exposure likelihood and consequence reduced to low based on the significant dilution offered by the Klondike River	
KRV15	North 60 Public Card Lock	Bulk fuel storage tanks	Low	Low	Low	Exposure likelihood and consequence reduced to low based on the significant dilution offered by the Klondike River	
KRV16	Fireweed Helicopters	Bulk fuel storage tanks, mechanics hangers	Low	Low	Low	Exposure likelihood and consequence reduced to low based on the significant dilution offered by the Klondike River	

Table 5: Evaluation of Risk Scenarios - Klondike River Valley

ID	Site	Source of Potential Contamination	Exposure Likelihood (revised based on mitigation measures and/or rules)	Exposure Consequence	Risk Rank	Notes on Existing Risk Mitigation Measures and Reduction of Exposure Likelihood	Risk Reduction Options to Consider
KRV17	AFD Public Card Lock	Bulk fuel storage tanks	Low	Low	Low	Exposure likelihood and consequence reduced to low based on the significant dilution offered by the Klondike River	Discussion should be had with property managers/owners to inform them of the potential risk to the CoD water supply, importance of rapid and effective actions including notifying CoD should spills or leaks occur and to request review of mitigation measures in place.
KRV18	Dawson City Gas and Tires	Bulk fuel storage tanks, mechanics shop	Low	Low	Low	Exposure likelihood and consequence reduced to low based on the significant dilution offered by the Klondike River	Undertake education program (through signage, meetings and brochures) informing owner that the area lies upstream of the CoD drinking water capture zone and actions that contaminate groundwater or the Klondike River in these upstream areas have the potential to impact drinking water supplies in the CoD.
KRV19	Trans North Helicopters	Bulk fuel storage tanks, mechanics hangers	Low	Low	Low	Exposure likelihood and consequence reduced to low based on the significant dilution offered by the Klondike River	Discussion should be had with property managers/owners to inform them of the potential risk to the CoD water supply, importance of rapid and effective actions including notifying CoD should spills or leaks occur and to request review of mitigation measures in place.
KRV20	Historic and existing Placer Mines in Klondike River Valley tributary valleys	Heavy machinery, runoff from mine, fuel storage	Low	Low	Low	Exposure likelihood and consequence reduced to low based on the significant dilution offered by the Klondike River	Undertake education program (through signage, meetings and brochures) informing owner that the area lies upstream of the CoD drinking water capture zone and actions that contaminate groundwater or the Klondike River in these upstream areas have the potential to impact drinking water supplies in the CoD.
KRV21	Chief Isaac Petroleum/ Super Save	Bulk fuel storage tanks	Low	Low	Low	Exposure likelihood and consequence reduced to low based on the significant dilution offered by the Klondike River	
KRV22	Total Crawler Services	Mechanics shop, leaking vehicles and equipment	Low	Low	Low	Exposure likelihood and consequence reduced to low based on the significant dilution offered by the Klondike River	
KRV23	Heavy machinery and truck storage and fuel tanks on lot.	Leaking vehicles and equipment, tanks	Low	Low	Low	Exposure likelihood and consequence reduced to low based on the significant dilution offered by the Klondike River	
KRV24	Heavy machinery and truck storage.	Leaking vehicles and equipment, tanks	Low	Low	Low	Exposure likelihood and consequence reduced to low based on the significant dilution offered by the Klondike River	
KRV25	Mechanics	Mechanics shop	Low	Low	Low	Exposure likelihood and consequence reduced to low based on the significant dilution offered by the Klondike River	
KRV26	Slinky Mine	Heavy machinery, runoff from mine, fuel storage	Low	Low	Low	Exposure likelihood and consequence reduced to low based on the significant dilution offered by the Klondike River	
KRV27	Klondike River	Wildlife	Low	Low	Low	Exposure likelihood and consequence reduced to low based on the significant dilution offered by the Klondike River	
KRV28	Various	Accidental or deliberate spill, leak, disposal to ground	Low	Low	Low	Exposure likelihood and consequence reduced to low based on the significant dilution offered by the Klondike River	
KRV29	Various	Accidental or deliberate spill, leak, disposal to ground or directly to Klondike River or tributary - less than 100 L.	Low	Low	Low	Exposure likelihood and consequence reduced to low based on the significant dilution offered by the Klondike River	
KRV30	Various	Accidental or deliberate spill, leak, disposal to ground or directly to Klondike River or tributary - more than 100 L.	Low	Medium	Low	Exposure likelihood reduced to low based on the significant dilution offered by the Klondike River. Exposure consequence reduced to medium based on the significant dilution offered by the Klondike River	

FIGURES

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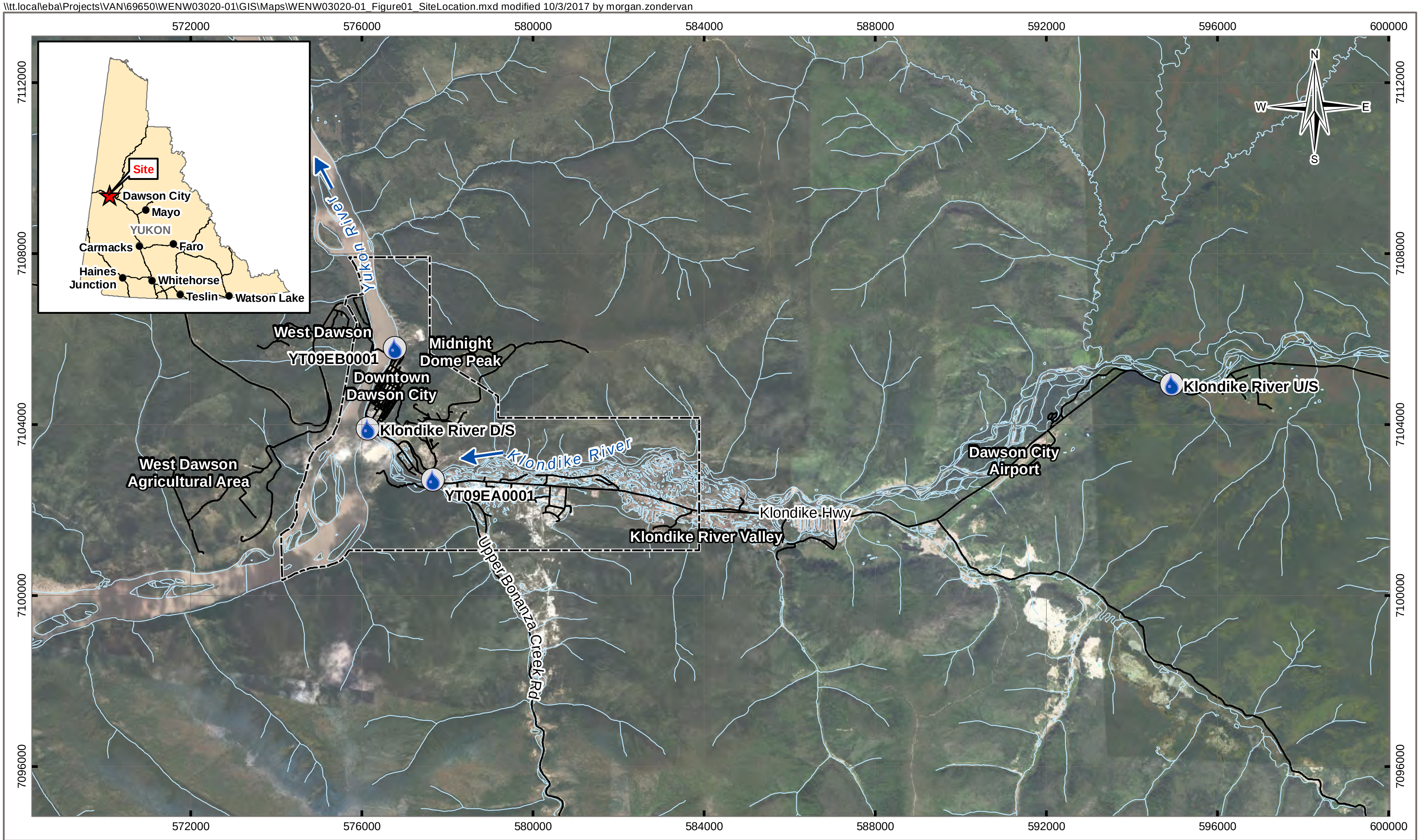

LEGEND

- Surface Water Quality Sample/Flow Location
- Road
- Watercourse
- Waterbody
- Dawson City Municipal Boundary
- River Flow Direction

NOTES
Base data source: Imagery from Google (2016)
CanVec 1:50,000 (2016)

STATUS
ISSUED FOR USE

Scale: 1:125,000
2 1 0 2
Kilometres

PROJECTION	DATUM
UTM Zone 7	NAD83

FILE NO.
WENW03020-01_Figure01_SiteLocation.mxd

CLIENT
Yukon Government

TETRA TECH

DAWSON CITY AQUIFER AND WELLHEAD PROTECTION PLAN

Site Location

OFFICE	DWN	CKD	APVD	REV
Tt-VANC	MEZ	SL	AS	0

DATE
October 3, 2017

PROJECT NO.
ENW.WENW03020-01

Figure 1

W:\Projects\VAN\69650\WENW03020-01\GIS\Maps\WENW03020-01_Figure02_SitePlan.mxd modified 10/6/2017 by morgan.zondervan

LEGEND

⊕ Monitoring Well

⊕ Water Supply Well

💧 Surface Water Quality Sample/Flow Monitoring Location

→ River Flow Direction

NOTES
Base data source: Imagery from mapservices.gov.yk (2003/2014)

STATUS
ISSUED FOR USE

Scale: 1:10,000
200 100 0 200
Metres

PROJECTION
UTM Zone 7

DATUM
NAD83

FILE NO.
WENW03020-01_Figure02_SitePlan.mxd

CLIENT
Yukon Government

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DAWSON CITY AQUIFER AND WELLHEAD PROTECTION PLAN

Site Plan and Well Locations

OFFICE	DWN	CKD	APVD	REV
Tt-VANC	MEZ	SL	AS	0

DATE
October 6, 2017

PROJECT NO.
ENW.WENW03020-01

Figure 2

LEGEND

⊕ Water Supply Well

○ Outfall Manhole

○ Sanitary Manhole

— Sanitary Main

— Wastewater Effluent Outfall

→ River Flow Direction

NOTES
Base data source: Imagery from mapservices.gov.yk (2003/2014)
Sewer Network from Mammoth Mapping (2007)

STATUS
ISSUED FOR USE

DAWSON CITY AQUIFER AND WELLHEAD PROTECTION PLAN

Sanitary Sewer System

PROJECTION
UTM Zone 7

DATUM
NAD83

CLIENT
Yukon Government

Scale: 1:4,500
50 25 0 50
Metres

TETRA TECH

FILE NO.
WENW03020-01_Figure03_Sewer.mxd

OFFICE	DWN	CKD	APVD	REV
Tt-VANC	MEZ	SL	AS	0

DATE
October 11, 2017

PROJECT NO.
ENW.WENW03020-01

Figure 3

W:\Projects\VAN\69650\WENW03020-01\GIS\Maps\WENW03020-01_Figure03_Sewer.mxd modified 10/11/2017 by stephanie.leusink

W:\Projects\VAN\69650\WENW03020-01\GIS\Maps\WENW03020-01_Figure04_StormWater.mxd modified 10/6/2017 by morgan.zondervan

LEGEND

- ⊕ Water Supply Well
- ● Catch Basin
- ● Manhole
- — Underground Pipe
- ▬ YG Highways Stormwater Drain (approximate)
- → River Flow Direction

NOTES
Base data source: Imagery from mapservices.gov.yk (2003/2014)
Storm Water Network from Mammoth Mapping (2010)

STATUS
ISSUED FOR USE

DAWSON CITY AQUIFER AND WELLHEAD PROTECTION PLAN

Storm Water Systems

PROJECTION	DATUM	CLIENT
UTM Zone 7	NAD83	Yukon Government

Scale: 1:5,000
50 25 0 50
Metres

TETRA TECH

FILE NO.
WENW03020-01_Figure04_StormWater.mxd

OFFICE	DWN	CKD	APVD	REV
Tt-VANC	MEZ	SL	AS	0

DATE
October 6, 2017

PROJECT NO.
ENW.WENW03020-01

Figure 4

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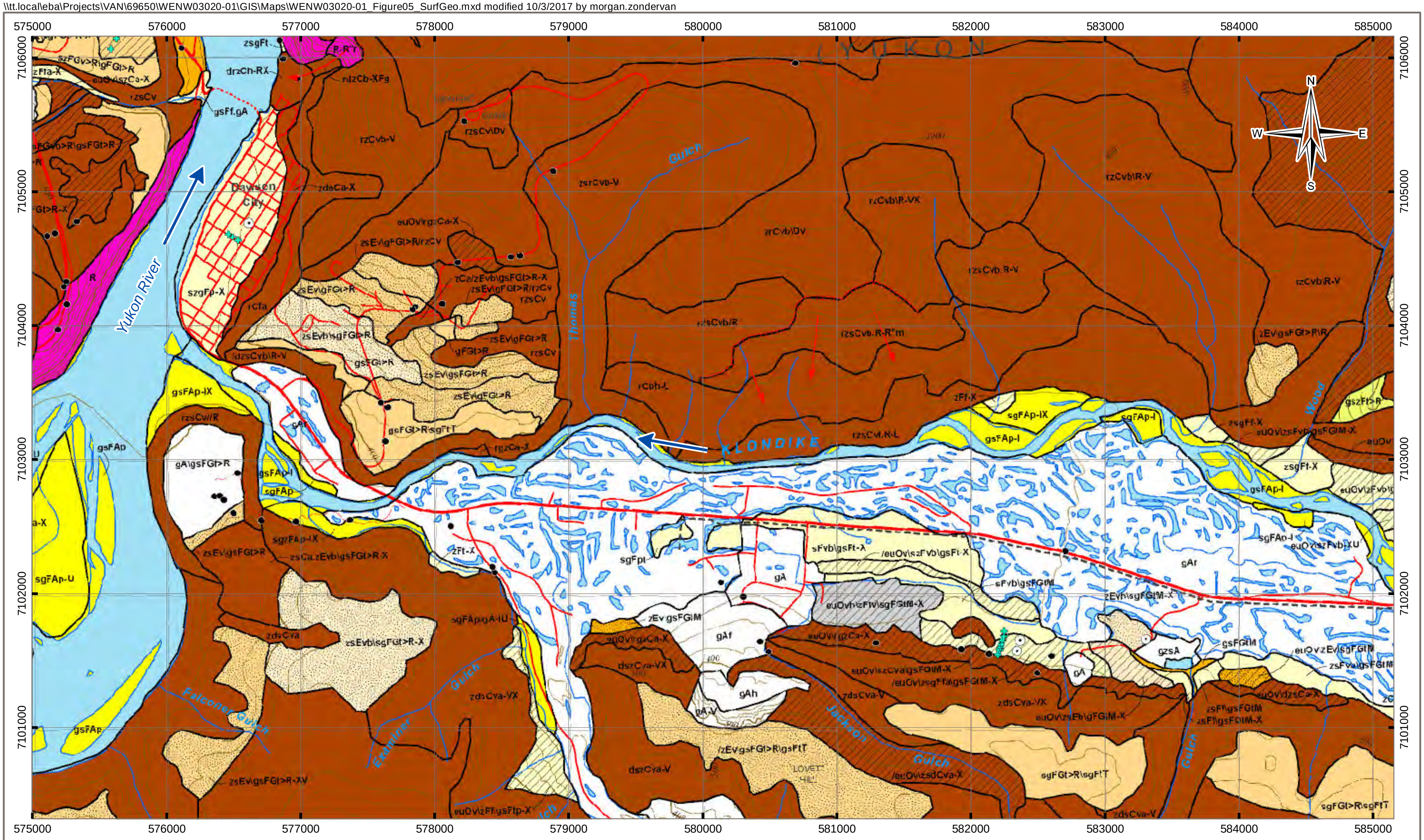

LEGEND

Surficial Geology

☐ Ar -Gravel,

🟫 Ca -Colluvium, Rubble

☐ Fp - Holocene Fluvial Deposits, Sand and Gravel

🟨 FAp - Holocene Deposits, Gravel and Sand, Anthropogenic, Plain

☐ Fvb - Holocene Fluvial Deposits, Sand, Veneer to Blanket/ Holocene Fluvial Deposits, Gravel and Sand Terrace

NOTES
Base data source: Geology map from
YGS Open File 2014-12 (McKenna & Lipovsky)

STATUS
ISSUED FOR USE

Scale: 1:40,000
500 250 0 500
Metres

PROJECTION	**DATUM**
UTM Zone 7	NAD83

FILE NO.
WENW03020-01_Figure05_SurfGeo.mxd

CLIENT

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DAWSON CITY AQUIFER AND WELLHEAD PROTECTION PLAN

Surficial Geology

OFFICE	**DWN**	**CKD**	**APVD**	**REV**
Tt-VANC	MEZ	SL	AS	0

DATE	**PROJECT NO.**
October 3, 2017	ENW.WENW03020-01

Figure 5

W:\Projects\VAN\69650\WENW03020-01\GIS\Maps\WENW03020-01_Figure06_Permafrost.mxd modified 10/6/2017 by morgan.zondervan

LEGEND

- — Inferred Permafrost Boundary
- 🟦 Inferred Permafrost Transition Zone
- ▨ Inferred Former Slough Extent
- → River Flow Direction

NOTES
Base data source: Imagery from mapservices.gov.yk (2003/2014)
Permafrost (EBA, 2017)
Slough extent (EBA, 1977)

STATUS
ISSUED FOR USE

Scale: 1:10,000
200 100 0 200
Metres

PROJECTION	**DATUM**
UTM Zone 7	NAD83

FILE NO.
WENW03020-01_Figure06_Permafrost.mxd

CLIENT
Yukon Government

TETRA TECH

DAWSON CITY AQUIFER AND WELLHEAD PROTECTION PLAN

Permafrost and Slough Extent

OFFICE	**DWN**	**CKD**	**APVD**	**REV**
Tt-VANC	MEZ	SL	AS	0

DATE	**PROJECT NO.**
October 6, 2017	ENW.WENW03020-01

Figure 6

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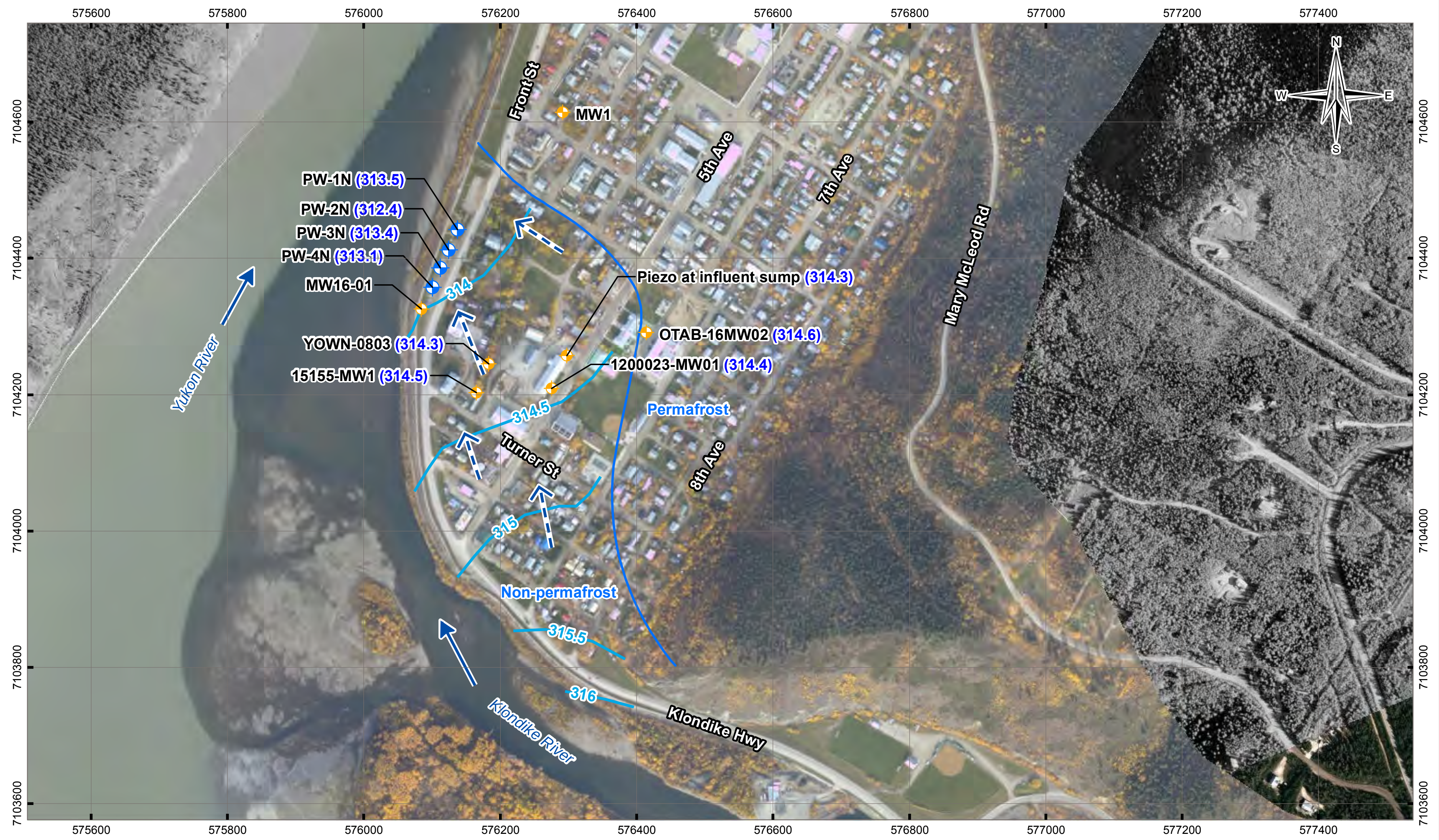


LEGEND

- ● Monitoring Well
- ● Water Supply Well
- — Inferred Permafrost Boundary
- ～ Groundwater Contour (0.5 masl)
- - - → Inferred Groundwater Flow Direction
- (XXX.X) Groundwater Elevation – February 2017 (masl)
- → River Flow Direction

NOTES
Base data source: Imagery from mapservices.gov.yk (2003/2014)
Permafrost (EBA, 2017)

STATUS
ISSUED FOR USE

Scale: 1:8,000
100 50 0 100
Metres

PROJECTION	DATUM
UTM Zone 7	NAD83

FILE NO.
WENW03020-01_Figure07_GWFlow.mxd

CLIENT
Yukon Government

TETRA TECH

DAWSON CITY AQUIFER AND WELLHEAD PROTECTION PLAN

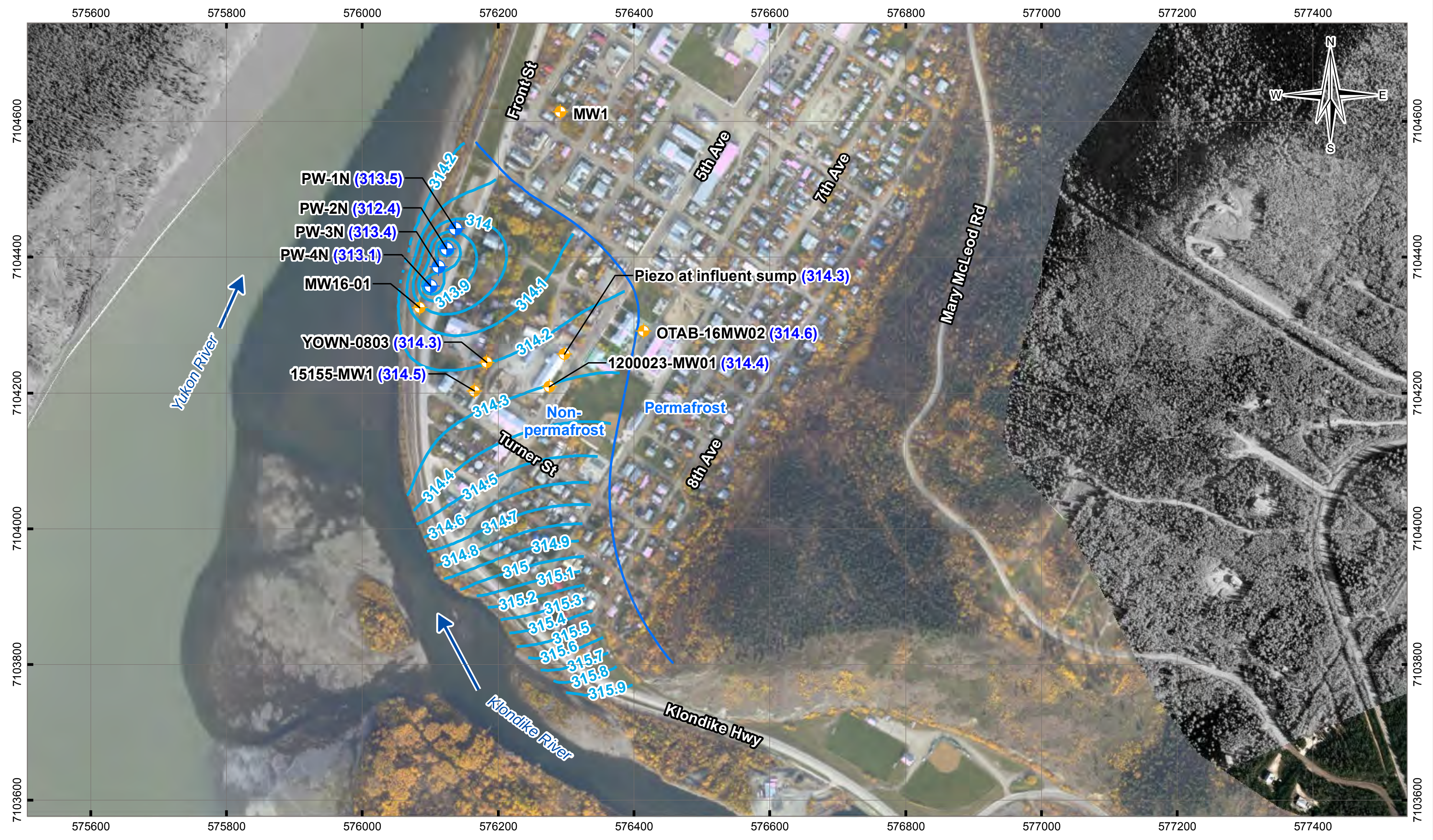
Inferred Groundwater Flow Direction – Non Pumping Conditions

OFFICE	DWN	CKD	APVD	REV
Tt-VANC	MEZ	SL	AS	0

DATE	PROJECT NO.
October 3, 2017	ENW.WENW03020-01

Figure 7

\\tt.local\eba\Projects\VAN\69650\WENW03020-01\GIS\Maps\WENW03020-01_Figure08_GWPump.mxd modified 10/3/2017 by morgan.zondervan



LEGEND

⊕ Monitoring Well

⊕ Water Supply Well

— Inferred Permafrost Boundary

~ Simulated Water Level Elevation Contour (0.1 masl)

(XXX.X) Groundwater Elevation – February 2017 (masl)

→ River Flow Direction

NOTES
Base data source: Imagery from mapservices.gov.yk (2003/2014)
Permafrost (EBA, 2017)

STATUS
ISSUED FOR USE

Scale: 1:8,000
100 50 0 100
Metres

PROJECTION UTM Zone 7

DATUM NAD83

FILE NO. WENW03020-01_Figure08_GWPump.mxd

CLIENT Yukon Government

TETRA TECH

DAWSON CITY AQUIFER AND WELLHEAD PROTECTION PLAN

Inferred Groundwater Flow Direction – Pumping Conditions

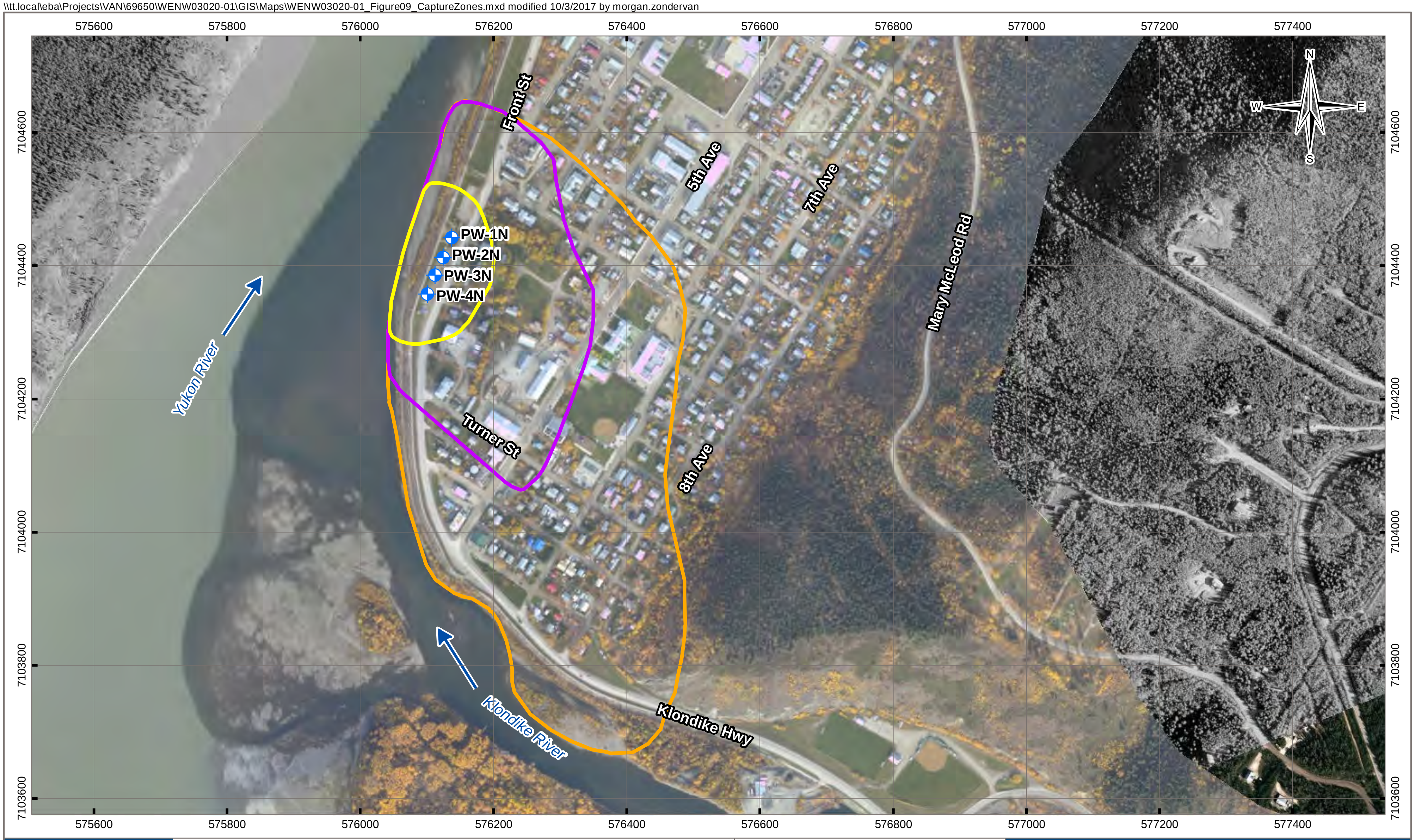
OFFICE	DWN	CKD	APVD	REV
Tt-VANC	MEZ	SL	AS	0

DATE October 3, 2017

PROJECT NO. ENW.WENW03020-01

Figure 8

\\tt.local\eba\Projects\VAN\69650\WENW03020-01\GIS\Maps\WENW03020-01_Figure09_CaptureZones.mxd modified 10/3/2017 by morgan.zondervan



LEGEND

- ⊕ Water Supply Well
- ○ 90 Day Capture Zone
- ○ 1 Year Capture Zone
- ○ 2 Year Capture Zone
- → River Flow Direction

NOTES
Base data source: Imagery from mapservices.gov.yk (2003/2014)
Permafrost (EBA, 2017)

STATUS
ISSUED FOR USE

Scale: 1:8,000
100 50 0 100
Metres

PROJECTION	**DATUM**
UTM Zone 7	NAD83

FILE NO.
WENW03020-01_Figure09_CaptureZones.mxd

CLIENT
Yukon Government

TETRA TECH

DAWSON CITY AQUIFER AND WELLHEAD PROTECTION PLAN

Well Capture Zones

OFFICE	**DWN**	**CKD**	**APVD**	**REV**
Tt-VANC	MEZ	SL	AS	0

DATE
October 3, 2017

PROJECT NO.
ENW.WENW03020-01

Figure 9

W:\Projects\VAN\69650\WENW03020-01\GIS\Maps\WENW03020-01_Figure10_RiskDC.mxd modified 10/12/2017 by morgan.zondervan

LEGEND

- ⊕ Water Supply Well
- ▨ Inferred Former Slough Extent
- ○ 90 Day Capture Zone
- ○ 1 Year Capture Zone
- ○ 2 Year Capture Zone
- → River Flow Direction

Sources of Potential Contamination

Risk Rank

- ▲ Low
- ● Medium
- ■ High
- ♦ Very High

NOTES

Base data source: Imagery from mapservices.gov.yk (2003/2014)

STATUS

ISSUED FOR USE

DAWSON CITY AQUIFER AND WELLHEAD PROTECTION PLAN

SPC Locations and Risk Map – Dawson City

PROJECTION
UTM Zone 7

DATUM
NAD83

CLIENT
Yukon
Government

Scale: 1:3,000
50 25 0 50
Metres

TETRA TECH

FILE NO.
WENW03020-01_Figure10_RiskDC.mxd

OFFICE	DWN	CKD	APVD	REV
Tt-VANC	MEZ	SL	AS	0

DATE
October 12, 2017

PROJECT NO.
ENW.WENW03020-01

Figure 10

W:\Projects\VAN\69650\WENW03020-01\GIS\Maps\WENW03020-01_Figure10a_Tanks.mxd modified 10/12/2017 by morgan.zondervan

LEGEND

- ⯐ Water Supply Well
- ▨ Inferred Former Slough Extent
- ◯ 90 Day Capture Zone
- ◯ 1 Year Capture Zone
- ◯ 2 Year Capture Zone
- → River Flow Direction

AST Location

Risk Rank

● Medium

NOTES
Base data source: Imagery from mapservices.gov.yk (2003/2014)

STATUS
ISSUED FOR USE

DAWSON CITY AQUIFER AND WELLHEAD PROTECTION PLAN

AST Locations and Risk Map – Dawson City

PROJECTION
UTM Zone 7

DATUM
NAD83

CLIENT
Yukon Government

Scale: 1:3,000
50 25 0 50
Metres

FILE NO.
WENW03020-01_Figure10a_Tanks.mxd

TETRA TECH

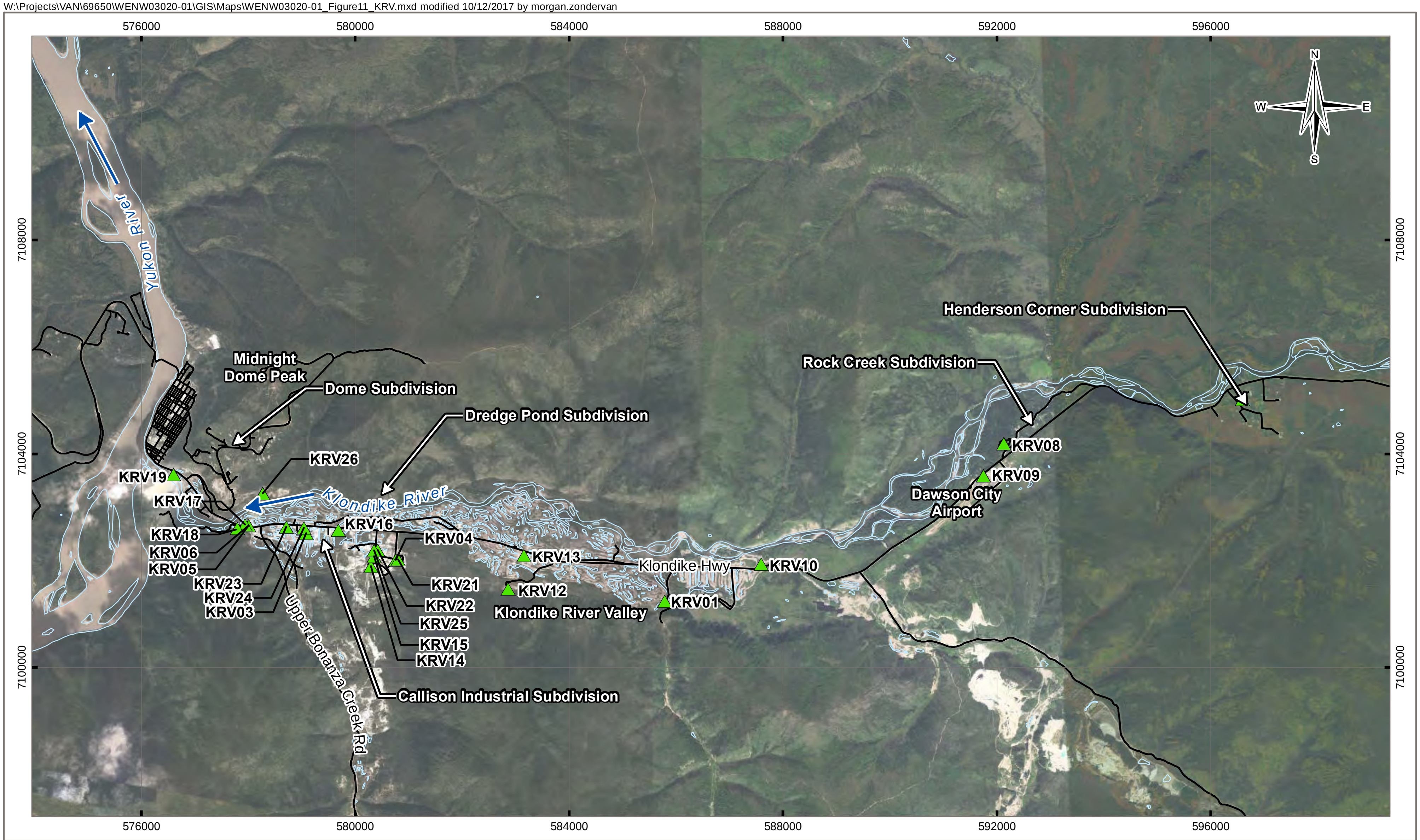
OFFICE	DWN	CKD	APVD	REV
Tt-VANC	MEZ	SL	AS	0

DATE
October 12, 2017

PROJECT NO.
ENW.WENW03020-01

Figure 10a

W:\Projects\VAN\69650\WENW03020-01\GIS\Maps\WENW03020-01_Figure11_KRV.mxd modified 10/12/2017 by morgan.zondervan



LEGEND

— Road

Waterbody

River Flow Direction

Sources of Potential Contamination

Risk Rank

▲ Low

NOTES

Base data source: Imagery from Google (2016)
CanVec 1:50,000 (2016)

STATUS
ISSUED FOR USE

Scale: 1:100,000
2 1 0 2
Kilometres

PROJECTION UTM Zone 7	**DATUM** NAD83
FILE NO. WENW03020-01_Figure11_KRV.mxd	
CLIENT Yukon Government	TETRA TECH

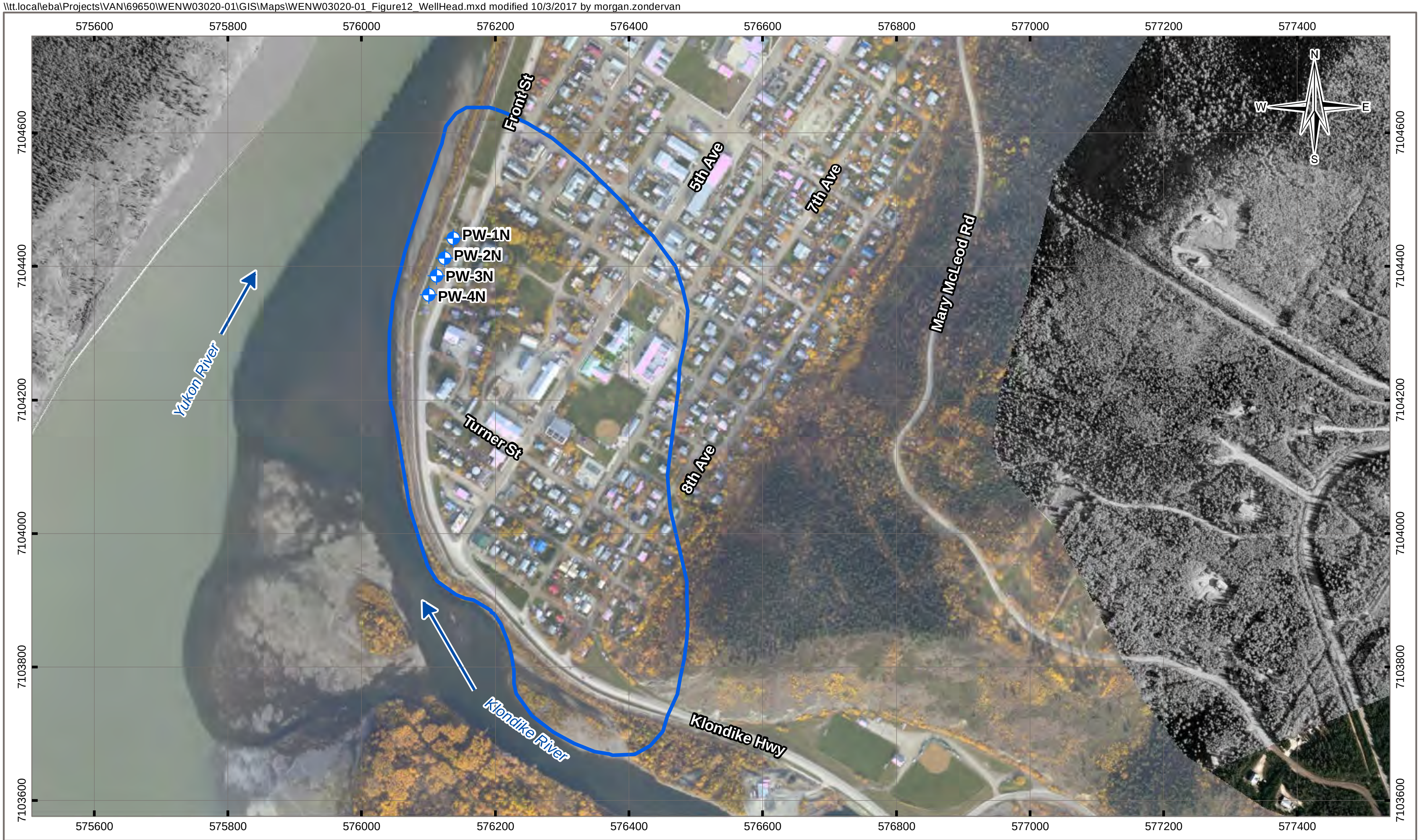
DAWSON CITY AQUIFER AND WELLHEAD PROTECTION PLAN

SPC Locations – Klondike River Valley

OFFICE	**DWN**	**CKD**	**APVD**	**REV**
Tt-VANC	MEZ	SL	AS	0
DATE	**PROJECT NO.**			
October 3, 2017	ENW.WENW03020-01			

Figure 11

\\tt.local\eba\Projects\VAN\69650\WENW03020-01\GIS\Maps\WENW03020-01_Figure12_WellHead.mxd modified 10/3/2017 by morgan.zondervan



LEGEND

⊕ Water Supply Well

◯ Dawson City Wellhead Protection Area (DC-WPA)

→ River Flow Direction

NOTES
Base data source: Imagery from mapservices.gov.yk (2003/2014)
Permafrost (EBA, 2017)

STATUS
ISSUED FOR USE

Scale: 1:8,000
100 50 0 100
Metres

PROJECTION
UTM Zone 7

DATUM
NAD83

FILE NO.
WENW03020-01_Figure12_WellHead.mxd

CLIENT
Yukon Government

TETRA TECH

DAWSON CITY AQUIFER AND WELLHEAD PROTECTION PLAN

Dawson City Wellhead Protection Area

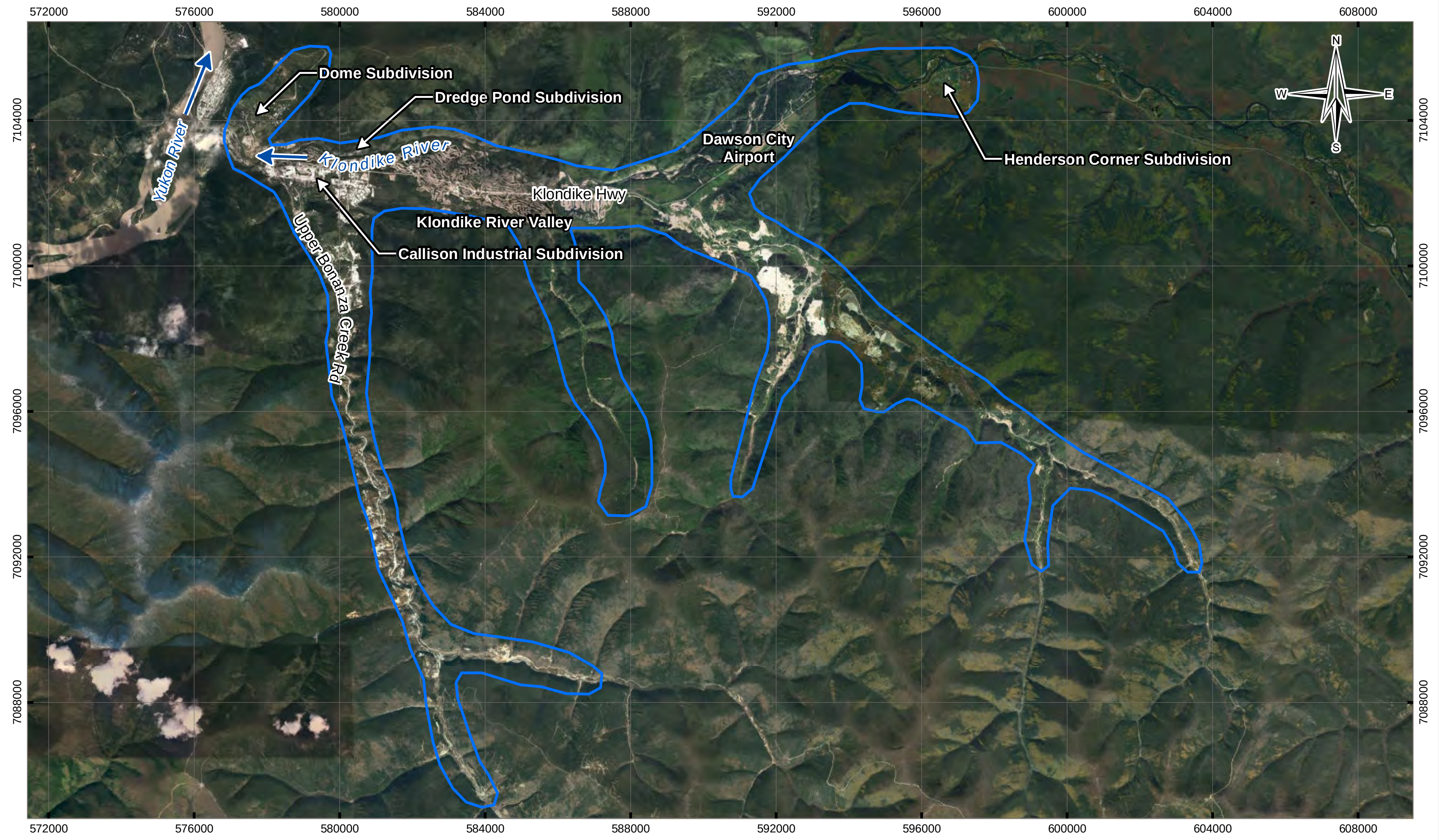
OFFICE	DWN	CKD	APVD	REV
Tt-VANC	MEZ	SL	AS	0

DATE
October 3, 2017

PROJECT NO.
ENW.WENW03020-01

Figure 12

\\tt.local\eba\Projects\VAN\69650\WENW03020-01\GIS\Maps\WENW03020-01_Figure13_KRWPA.mxd modified 10/3/2017 by morgan.zondervan



LEGEND

- Klondike River Valley Watershed Protection Area
- River Flow Direction

NOTES
Base data source: Imagery from Google (2016)
CanVec 1:50,000 (2016)

STATUS
ISSUED FOR USE

Scale: 1:150,000
2 1 0 2
Kilometres

PROJECTION	**DATUM**
UTM Zone 7	NAD83

FILE NO.
WENW03020-01_Figure13_KRWPA.mxd

CLIENT

TETRA TECH

DAWSON CITY AQUIFER AND WELLHEAD PROTECTION PLAN

Klondike River Valley Watershed Protection Area

OFFICE	**DWN**	**CKD**	**APVD**	**REV**
Tt-VANC	MEZ	SL	AS	0

DATE	**PROJECT NO.**
October 3, 2017	ENW.WENW03020-01

Figure 13

APPENDIX A

TETRA TECH'S LIMITATIONS ON THE USE OF THIS DOCUMENT

LIMITATIONS ON USE OF THIS DOCUMENT

GEOENVIRONMENTAL

1.1 USE OF DOCUMENT AND OWNERSHIP

This document pertains to a specific site, a specific development, and a specific scope of work. The document may include plans, drawings, profiles and other supporting documents that collectively constitute the document (the “Professional Document”).

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The Professional Document is subject to copyright and shall not be reproduced either wholly or in part without the prior, written permission of TETRA TECH. Additional copies of the Document, if required, may be obtained upon request.

1.2 ALTERNATIVE DOCUMENT FORMAT

Where TETRA TECH submits electronic file and/or hard copy versions of the Professional Document or any drawings or 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. The original signed and/or sealed electronic file and/or hard copy version archived by TETRA TECH shall be deemed to be the original. TETRA TECH will archive a protected digital copy of the original signed and/or sealed version for a period of 10 years.

Both electronic file and/or hard copy versions of TETRA TECH’s Instruments of Professional Service shall not, under any circumstances, be altered by any party except TETRA TECH. 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.

1.3 STANDARD OF CARE

Services performed by TETRA TECH for the Professional Document have been conducted in accordance with the Contract, in a manner consistent with the level of skill ordinarily exercised by members of the profession currently practicing under similar conditions in the jurisdiction in which the services are provided. Professional judgment has been applied in developing the conclusions and/or recommendations provided in this Professional Document. No warranty or guarantee, express or implied, is made concerning the test results, comments, recommendations, or any other portion of the Professional Document.

If any error or omission is detected by the Client or an Authorized Party, the error or omission must be immediately brought to the attention of TETRA TECH.

1.4 DISCLOSURE OF INFORMATION BY CLIENT

The Client acknowledges that it has fully cooperated with TETRA TECH with respect to the provision of all available information on the past, present, and proposed conditions on the site, including historical information respecting the use of the site. The Client further acknowledges that in order for TETRA TECH to properly provide the services contracted for in the Contract, TETRA TECH has relied upon the Client with respect to both the full disclosure and accuracy of any such information.

1.5 INFORMATION PROVIDED TO TETRA TECH BY OTHERS

During the performance of the work and the preparation of this Professional Document, TETRA TECH may have relied on information provided by persons other than the Client.

While TETRA TECH endeavours to verify the accuracy of such information, TETRA TECH accepts no responsibility for the accuracy or the reliability of such information even where inaccurate or unreliable information impacts any recommendations, design or other deliverables and causes the Client or an Authorized Party loss or damage.

1.6 GENERAL LIMITATIONS OF DOCUMENT

This Professional Document is based solely on the conditions presented and the data available to TETRA TECH at the time the data were collected in the field or gathered from available databases.

The Client, and any Authorized Party, acknowledges that the Professional Document is based on limited data and that the conclusions, opinions, and recommendations contained in the Professional Document are the result of the application of professional judgment to such limited data.

The Professional Document 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 conditions present, or variation in assumed conditions which might form the basis of design or recommendations as outlined in this report, at or on the development proposed as of the date of the Professional Document requires a supplementary investigation and assessment.

TETRA TECH is neither qualified to, nor is it making, any recommendations with respect to the purchase, sale, investment or development of the property, the decisions on which are the sole responsibility of the Client.

1.7 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.

APPENDIX B

WELL LOGS

PROJECT: City of Dawson Production Wells
CLIENT: City of Dawson
HOLE NO: **PW-1N**
LOCATION: Dawson City UTM N 576,134.8 E 7,104,441.4
PROJECT NO.: 5140579
CONTRACTOR: MSD
METHOD: Air Rotary
GROUND ELEVATION (m): 320.45

BACKFILL TYPE ■ BENTONITE ⁚ GRAVEL ▥ SLOUGH ⁖ GROUT ▨ CUTTINGS ⁚ SAND

SOIL DESCRIPTION

Top Soil, sandy loam with rootlets.

FILL, coarse sand and gravel with some silt. Light brown, dry.

Fine GRAVELLY SAND, with trace silt. Dark brown, moist. Gravel sub-rounded, sand is medium to fine, well sorted.

Fine SANDY SILT, dark grey to black with woody/organic pieces, cohesive and moist. Similar to "Black Muck".

Coarse SAND and GRAVEL with trace silt, occasional cobbles, light brown, saturated.

BEDROCK, greenstone and shist rock chips observed.
end of hole

COMMENTS

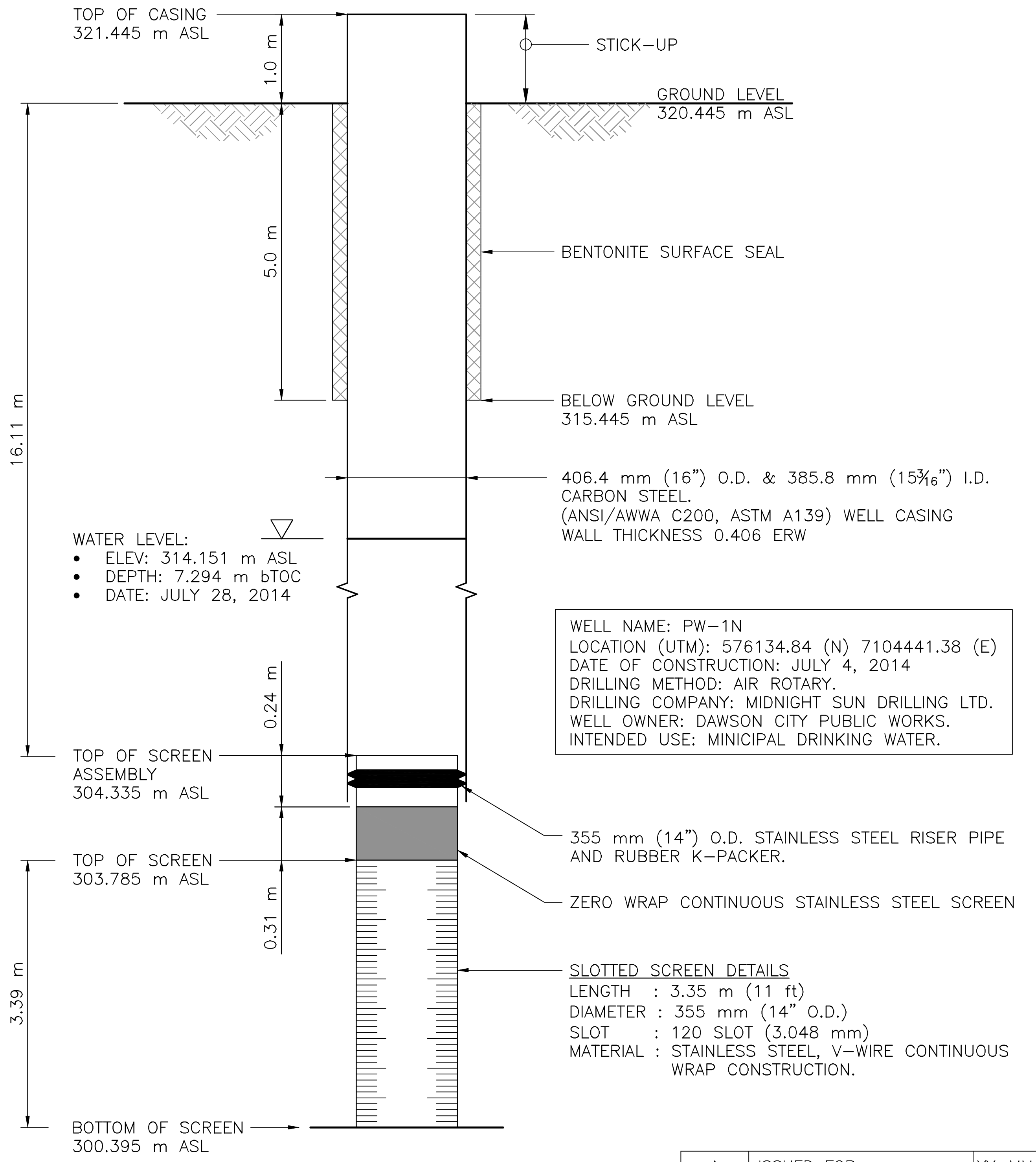
Rapid casing advancement observed through fine, sandy material.

Very slow casing push noted by driller, likely coarse gravel or cobbles present.

Well Screen Completion Details:
Lenght: 3.35 m (11 ft)
Diameter: 355 mm (14") OD
Slot: 120-slot (3.048 mm) open area
Material: Stainless Steel, v-wire continuous wrap construction
See as-builts for additional details.

MORRISON HERSHFIELD

LOGGED BY: Caleb Light
REVIEWED BY: Jonathan Kerr
PROJECT ENGINEER: Jonathan Kerr
COMPLETION DEPTH: 20.05 m
COMPLETION DATE: 11/07/14



WELL NAME: PW–1N
LOCATION (UTM): 576134.84 (N) 7104441.38 (E)
DATE OF CONSTRUCTION: JULY 4, 2014
DRILLING METHOD: AIR ROTARY.
DRILLING COMPANY: MIDNIGHT SUN DRILLING LTD.
WELL OWNER: DAWSON CITY PUBLIC WORKS.
INTENDED USE: MINICIPAL DRINKING WATER.

<u>SLOTTED SCREEN DETAILS</u>

LENGTH : 3.35 m (11 ft)
DIAMETER : 355 mm (14” O.D.)
SLOT : 120 SLOT (3.048 mm)
MATERIAL : STAINLESS STEEL, V–WIRE CONTINUOUS WRAP CONSTRUCTION.

A	ISSUED FOR _____	YY–MM–DD
ISSUE	DESCRIPTION	DATE

Notes:

ID – INNER DIAMETER
BTOC – BELOW TOP OF CASING
ASL – ABOVE SEA LEVEL
OD – OUTER DIAMETER

Client:

INCORPORATED JAN. 9, 1902

DAWSON CITY GROUNDWATER WELL CONSTRUCTION

PW-1N

Project No.: 5140579.00
Drawing. No. 101

Design	Drawn:	Reviewed:	Scale:	Date:
–	–	–	NTS	14–08–08

MORRISON HERSHFIELD

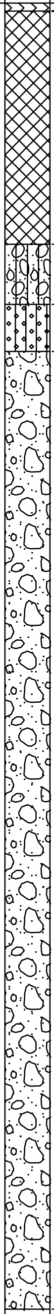
Suite 310, 4321 Still Creek Dr,
Burnaby, BC V5C 6S7
www.morrisonhershfield.com
Tel: 604 454 0402 Fax: 604 454 0403

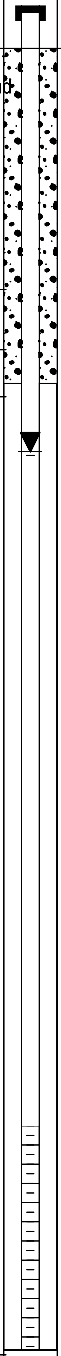
M:\PROJ\5140579\Drawing\Well–Construction–8.5X11.dwg 1/9/2012 11:49 AM

PROJECT: City of Dawson Production Wells	CLIENT: City of Dawson	HOLE NO: **PW-2N**
LOCATION: Dawson City UTM N 576,123.4 E 7,104,413.7		PROJECT NO.: 5140579
CONTRACTOR: MSD	METHOD: Air Rotary	GROUND ELEVATION (m): 320.29

BACKFILL TYPE ■ BENTONITE ▨ GRAVEL ▥ SLOUGH ▨ GROUT ▨ CUTTINGS ▨ SAND

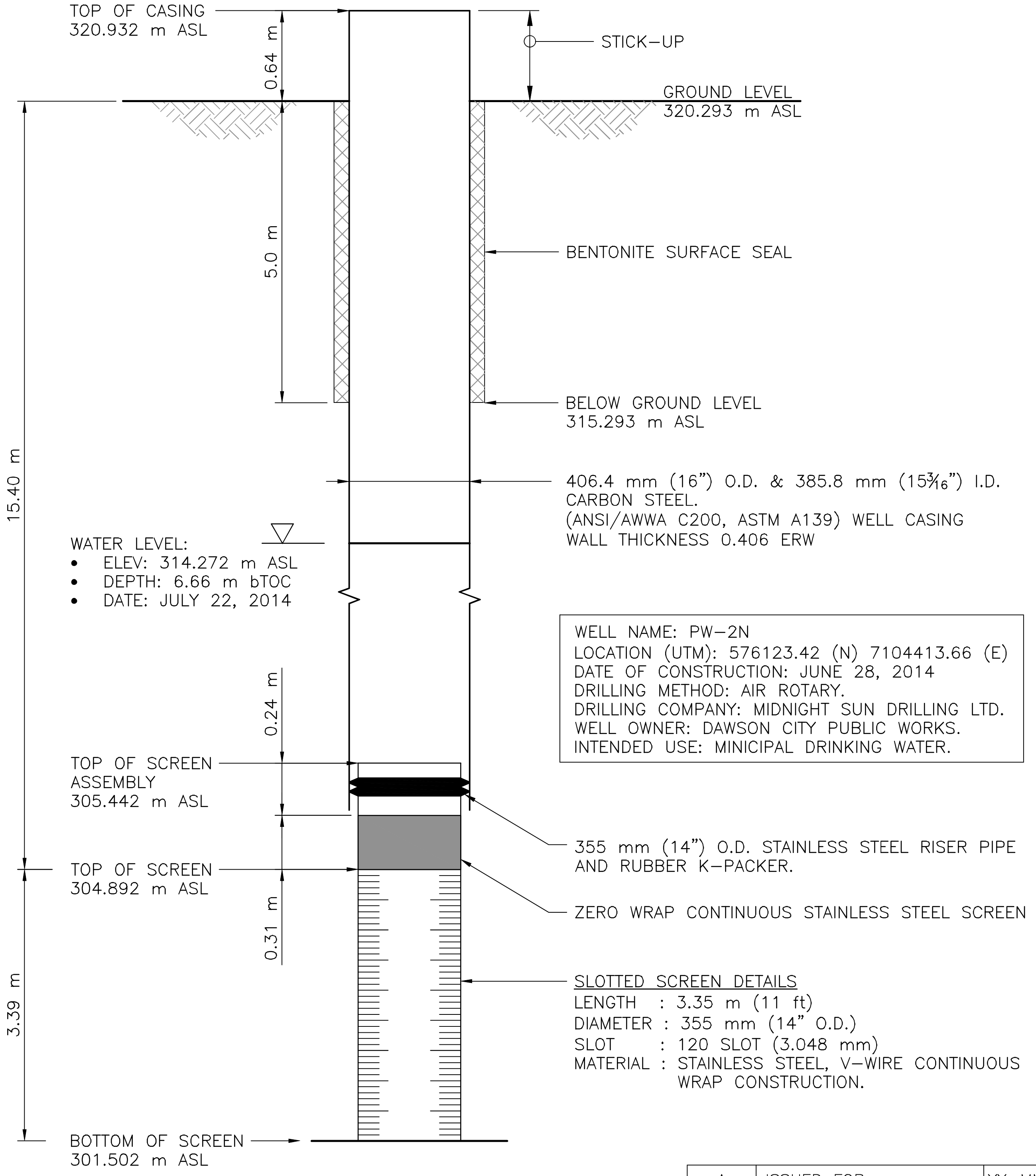
DEPTH (m)	SOIL SYMBOL	SOIL DESCRIPTION	WELL INSTALLATION	COMMENTS	ELEVATION (m)
0		Top soil, sandy loam with rootlets.			320
		FILL, SILTY GRAVEL with some sand. Fill material consists of silty gravel with some sand and is not native material.			
1					319
2					318
3					317
4		Silty GRAVEL, dark brown, dry.			316
		SILT, black, moist, homogenous with trace wood framents.			
5		Coarse sandy GRAVEL with trace silt, wet, dark brown.			315
6 ▼		Boulder and cobble sized material present, chips observed.	▼		▼ 314
7					313
8					312
9					311
10					310
11					309
12					308
13					307
14				Drilling stopped on June 28, 2014. Resumed on June 29, 2014.	306
15					305
16				**Well Screen Completion Details:** Lenght: 3.35 m (11 ft) Diameter: 355 mm (14") OD Slot: 120-slot (3.048 mm) open area Material: Stainless Steel, v-wire continuous wrap construction See as-builts for additional details.	304
17					303
18					302
19					301
20		BEDROCK, greenstone and schist rock chips observed. end of hole			300
21					
22					299





MORRISON HERSHFIELD

LOGGED BY: Caleb Light	COMPLETION DEPTH: 18.79 m
REVIEWED BY: Jonathan Kerr	COMPLETION DATE: 13/07/14
PROJECT ENGINEER: Jonathan Kerr	Page 1 of 1



WELL NAME: PW–2N
LOCATION (UTM): 576123.42 (N) 7104413.66 (E)
DATE OF CONSTRUCTION: JUNE 28, 2014
DRILLING METHOD: AIR ROTARY.
DRILLING COMPANY: MIDNIGHT SUN DRILLING LTD.
WELL OWNER: DAWSON CITY PUBLIC WORKS.
INTENDED USE: MINICIPAL DRINKING WATER.

SLOTTED SCREEN DETAILS

LENGTH	: 3.35 m (11 ft)
DIAMETER	: 355 mm (14" O.D.)
SLOT	: 120 SLOT (3.048 mm)
MATERIAL	: STAINLESS STEEL, V–WIRE CONTINUOUS WRAP CONSTRUCTION.

A	ISSUED FOR _____	YY–MM–DD
ISSUE	DESCRIPTION	DATE

Notes:

ID – INNER DIAMETER
BTOC – BELOW TOP OF CASING
ASL – ABOVE SEA LEVEL
OD – OUTER DIAMETER

Client:

DAWSON CITY GROUNDWATER WELL CONSTRUCTION

PW-2N

Project No.:	Drawing. No.
5140579.00	102

MORRISON HERSHFIELD

Suite 310, 4321 Still Creek Dr,
Burnaby, BC V5C 6S7
www.morrisonhershfield.com
Tel: 604 454 0402 Fax: 604 454 0403

Design	Drawn:	Reviewed:	Scale:	Date:
–	–	–	NTS	14–08–08

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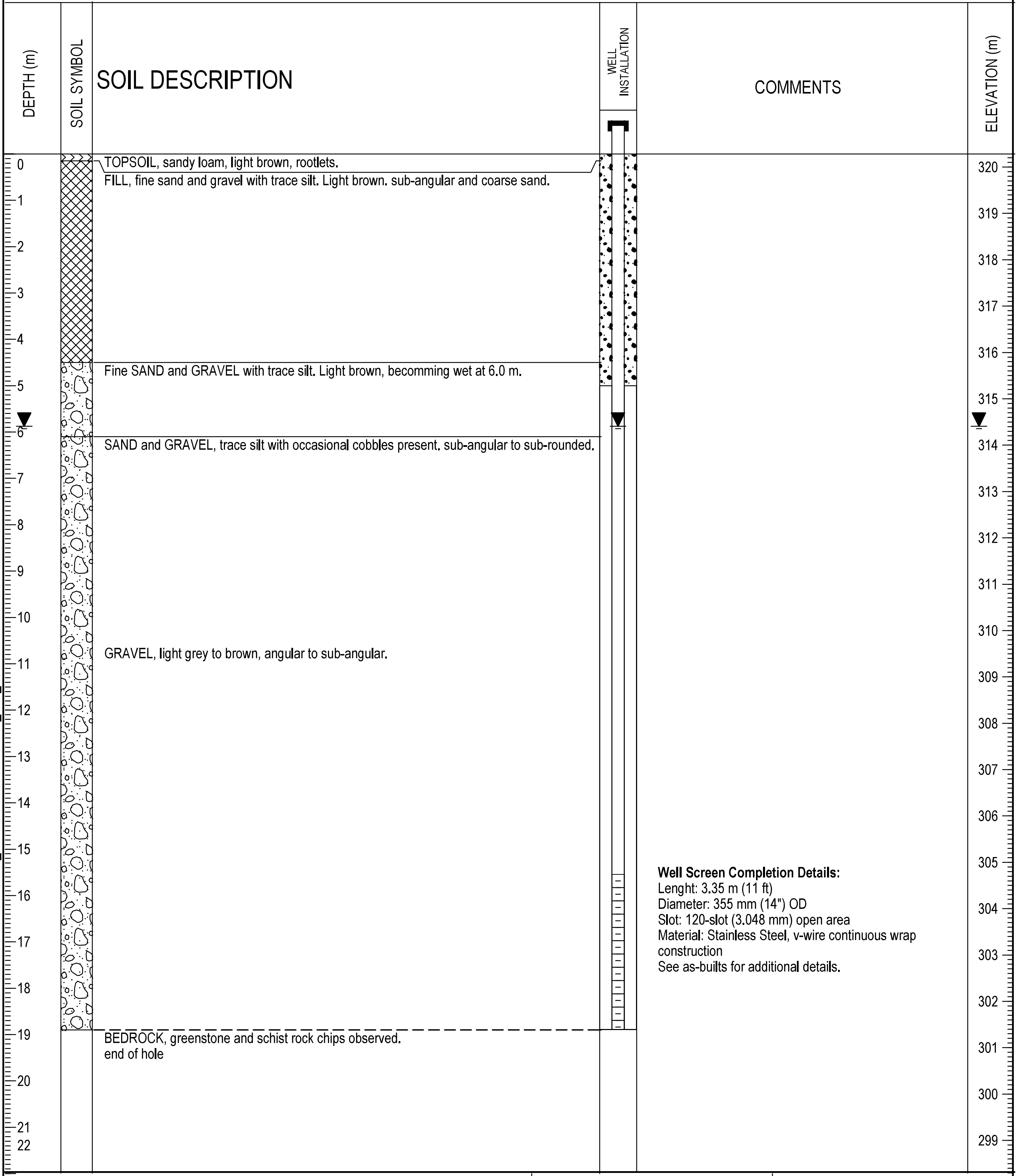
PROJECT: City of Dawson Production Wells	CLIENT: City of Dawson	HOLE NO: **PW-3N**
LOCATION: Dawson City UTM N 576,111.4 E 7,104,386.2		PROJECT NO.: 5140579
CONTRACTOR: MSD	METHOD: Air Rotary	GROUND ELEVATION (m): 320.28

BACKFILL TYPE ■ BENTONITE ⁚ GRAVEL ▥ SLOUGH ▨ GROUT ▧ CUTTINGS ⁚ SAND



TOPSOIL, sandy loam, light brown, rootlets.

FILL, fine sand and gravel with trace silt. Light brown. sub-angular and coarse sand.

Fine SAND and GRAVEL with trace silt. Light brown, becomming wet at 6.0 m.

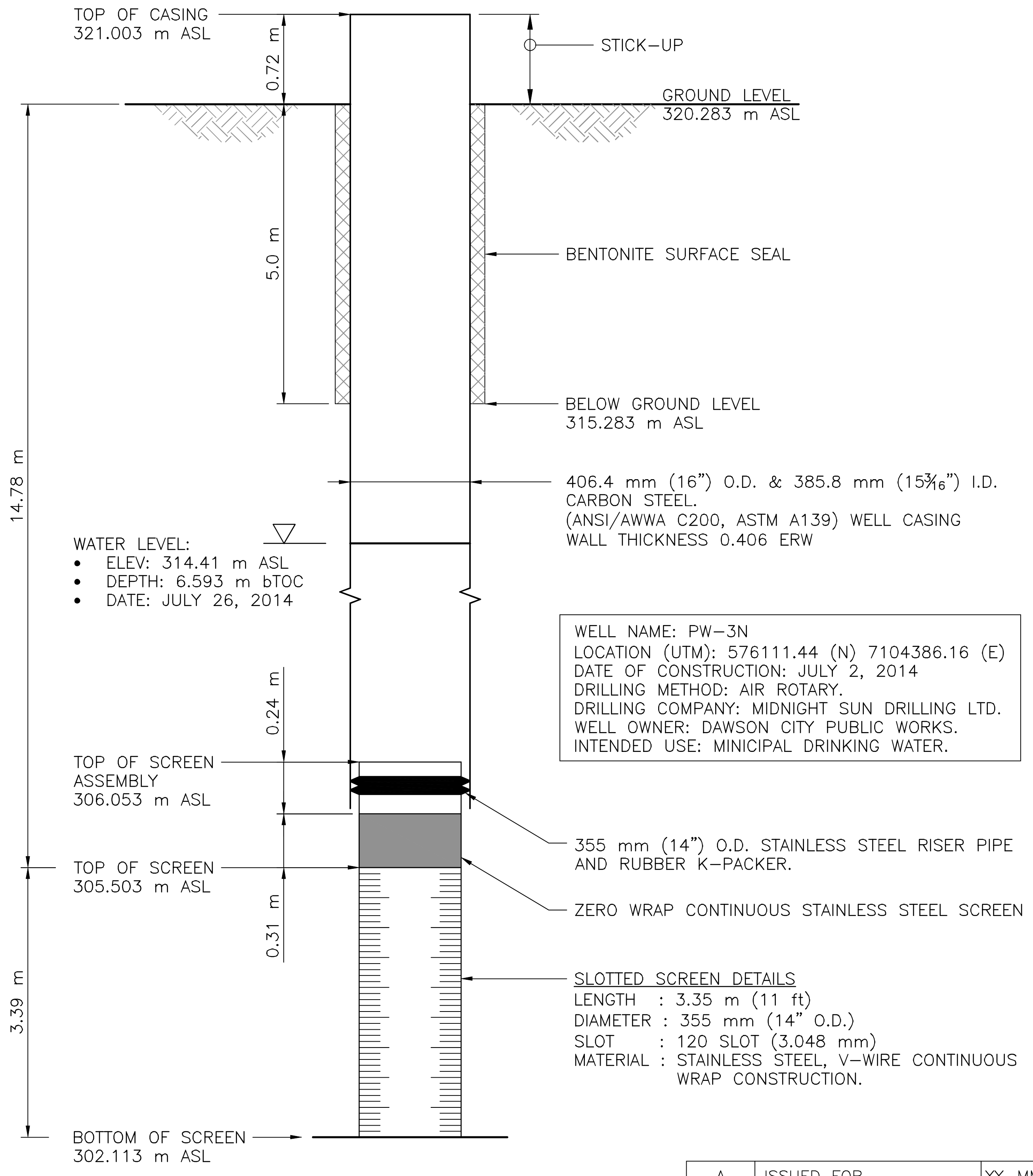
SAND and GRAVEL, trace silt with occasional cobbles present. sub-angular to sub-rounded.

GRAVEL, light grey to brown, angular to sub-angular.

BEDROCK, greenstone and schist rock chips observed.
end of hole

Well Screen Completion Details:
Lenght: 3.35 m (11 ft)
Diameter: 355 mm (14") OD
Slot: 120-slot (3.048 mm) open area
Material: Stainless Steel, v-wire continuous wrap construction
See as-builts for additional details.

MORRISON HERSHFIELD	LOGGED BY: Caleb Light	COMPLETION DEPTH: 18.17 m
	REVIEWED BY: Jonathan Kerr	COMPLETION DATE: 14/07/14
	PROJECT ENGINEER: Jonathan Kerr	Page 1 of 1



WELL NAME: PW–3N
LOCATION (UTM): 576111.44 (N) 7104386.16 (E)
DATE OF CONSTRUCTION: JULY 2, 2014
DRILLING METHOD: AIR ROTARY.
DRILLING COMPANY: MIDNIGHT SUN DRILLING LTD.
WELL OWNER: DAWSON CITY PUBLIC WORKS.
INTENDED USE: MINICIPAL DRINKING WATER.

SLOTTED SCREEN DETAILS
LENGTH : 3.35 m (11 ft)
DIAMETER : 355 mm (14" O.D.)
SLOT : 120 SLOT (3.048 mm)
MATERIAL : STAINLESS STEEL, V–WIRE CONTINUOUS WRAP CONSTRUCTION.

A	ISSUED FOR _____	YY–MM–DD
ISSUE	DESCRIPTION	DATE

Notes:

ID – INNER DIAMETER
BTOC – BELOW TOP OF CASING
ASL – ABOVE SEA LEVEL
OD – OUTER DIAMETER

Client:

DAWSON CITY GROUNDWATER WELL CONSTRUCTION

PW-3N

Project No.: 5140579.00

Drawing. No. 103

MORRISON HERSHFIELD

Suite 310, 4321 Still Creek Dr,
Burnaby, BC V5C 6S7
www.morrisonhershfield.com
Tel: 604 454 0402 Fax: 604 454 0403

Design	Drawn:	Reviewed:	Scale:	Date:
–	–	–	NTS	14–08–08

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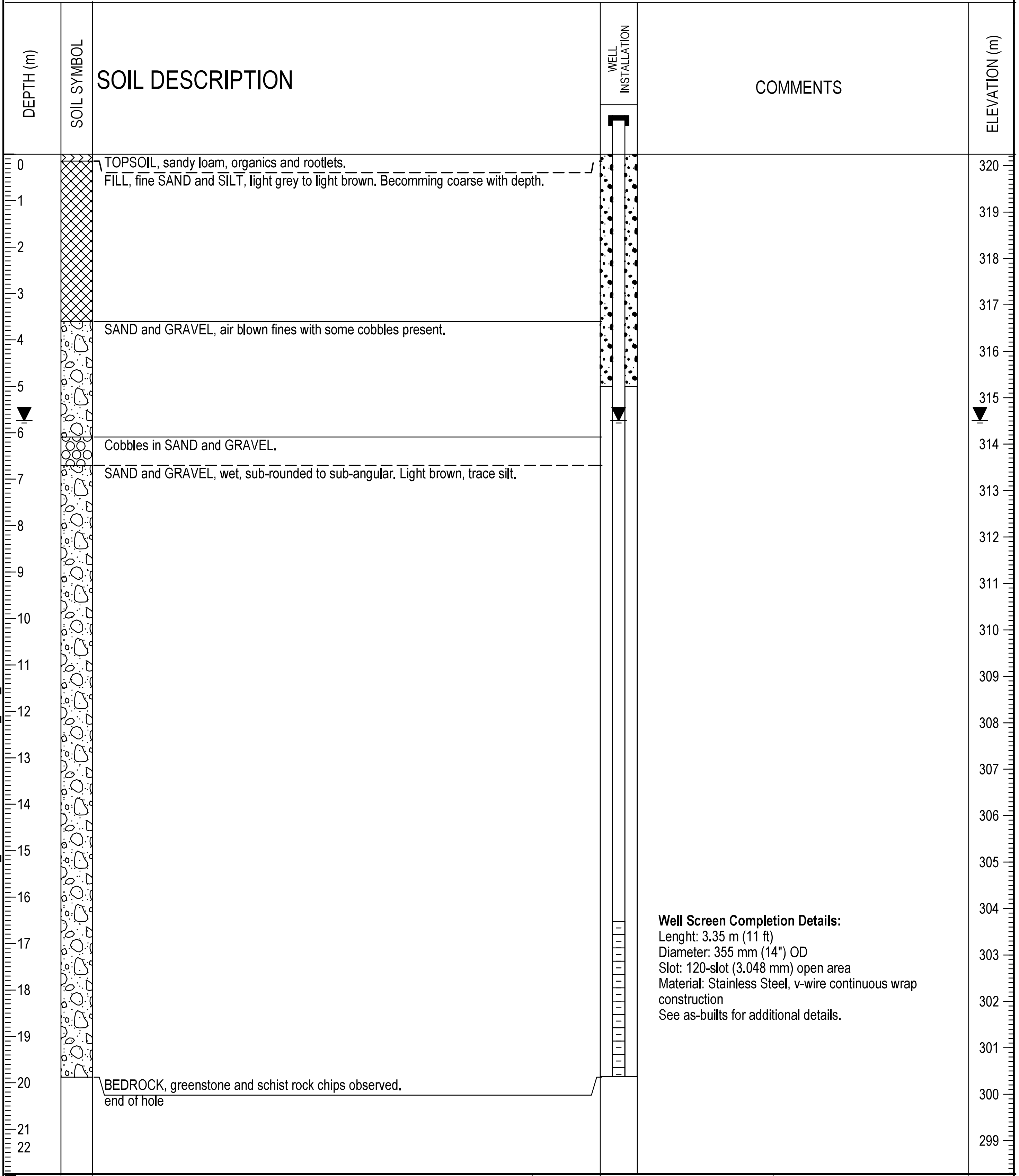
PROJECT: City of Dawson Production Wells	CLIENT: City of Dawson	HOLE NO: **PW-4N**
LOCATION: Dawson City UTM N 576,099.5 E 7,104,358.7		PROJECT NO.: 5140579
CONTRACTOR: MDS	METHOD: Air Rotary	GROUND ELEVATION (m): 320.25

BACKFILL TYPE ■ BENTONITE ⁚ GRAVEL ▥ SLOUGH ⁖ GROUT ▨ CUTTINGS ⁚ SAND



TOPSOIL, sandy loam, organics and rootlets.

FILL, fine SAND and SILT, light grey to light brown. Becomming coarse with depth.

SAND and GRAVEL, air blown fines with some cobbles present.

Cobbles in SAND and GRAVEL.

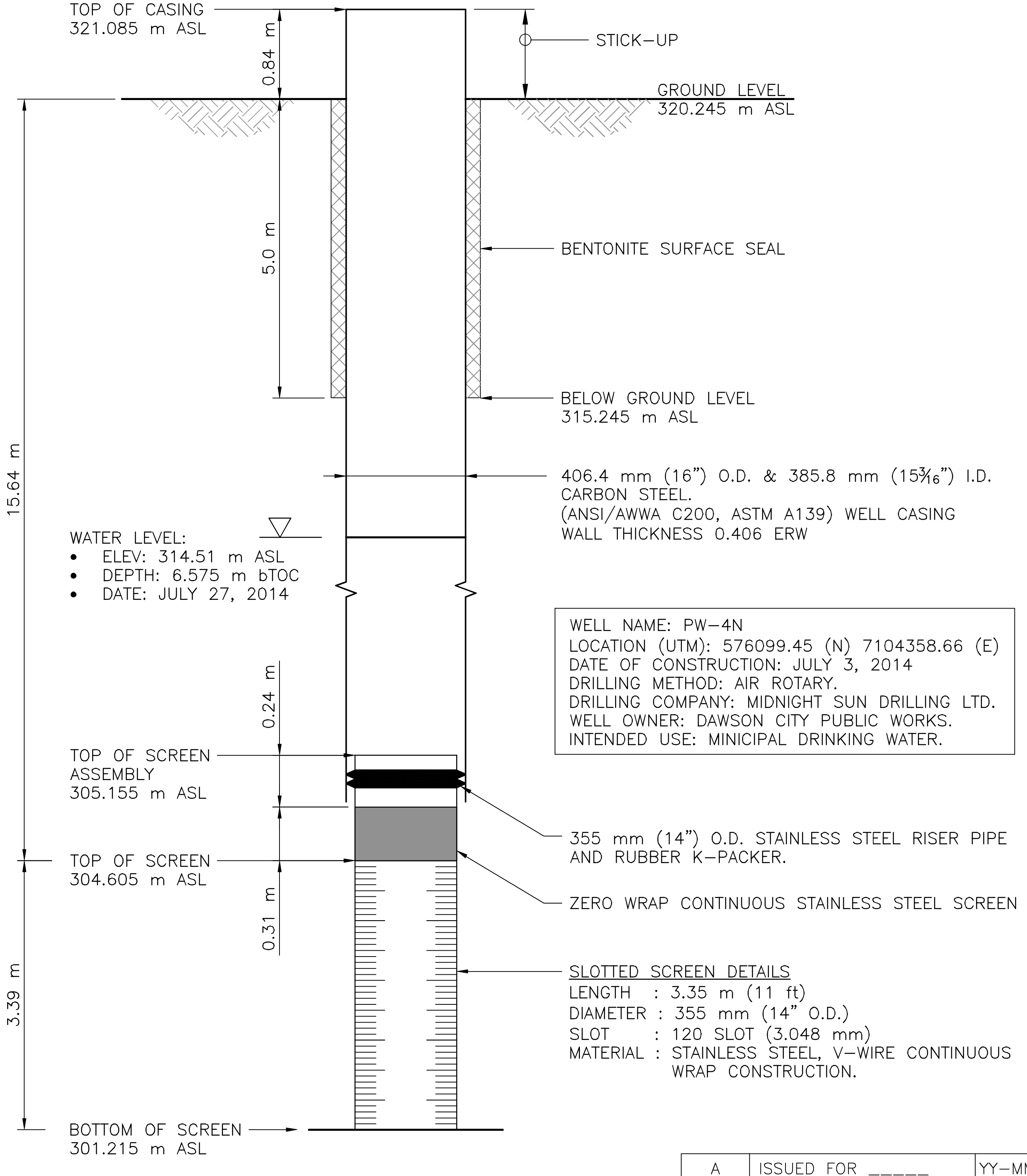
SAND and GRAVEL, wet, sub-rounded to sub-angular. Light brown, trace silt.

BEDROCK, greenstone and schist rock chips observed.
end of hole

Well Screen Completion Details:
Lenght: 3.35 m (11 ft)
Diameter: 355 mm (14") OD
Slot: 120-slot (3.048 mm) open area
Material: Stainless Steel, v-wire continuous wrap construction
See as-builts for additional details.

MORRISON HERSHFIELD

LOGGED BY: Caleb Light	COMPLETION DEPTH: 19.00 m
REVIEWED BY: Jonathan Kerr	COMPLETION DATE: 15/07/14
PROJECT ENGINEER: Jonathan Kerr	



WELL NAME: PW-4N
LOCATION (UTM): 576099.45 (N) 7104358.66 (E)
DATE OF CONSTRUCTION: JULY 3, 2014
DRILLING METHOD: AIR ROTARY.
DRILLING COMPANY: MIDNIGHT SUN DRILLING LTD.
WELL OWNER: DAWSON CITY PUBLIC WORKS.
INTENDED USE: MINICIPAL DRINKING WATER.

SLOTTED SCREEN DETAILS
LENGTH : 3.35 m (11 ft)
DIAMETER : 355 mm (14" O.D.)
SLOT : 120 SLOT (3.048 mm)
MATERIAL : STAINLESS STEEL, V-WIRE CONTINUOUS
WRAP CONSTRUCTION.

A	ISSUED FOR _____	YY-MM-DD
ISSUE	DESCRIPTION	DATE

Notes:

ID - INNER DIAMETER
BTOC - BELOW TOP OF CASING
ASL - ABOVE SEA LEVEL
OD - OUTER DIAMETER

Client:

INCORPORATED JAN. 9, 1902

DAWSON CITY GROUNDWATER WELL CONSTRUCTION

PW-4N

Project No.:	Drawing. No.
5140579.00	104

Design	Drawn:	Reviewed:	Scale:	Date:
-	-	-	NTS	14-08-08

MORRISON HERSHFIELD

Suite 310, 4321 Still Creek Dr,
Burnaby, BC V5C 6S7
www.morrisonhershfield.com
Tel: 604 454 0402 Fax: 604 454 0403

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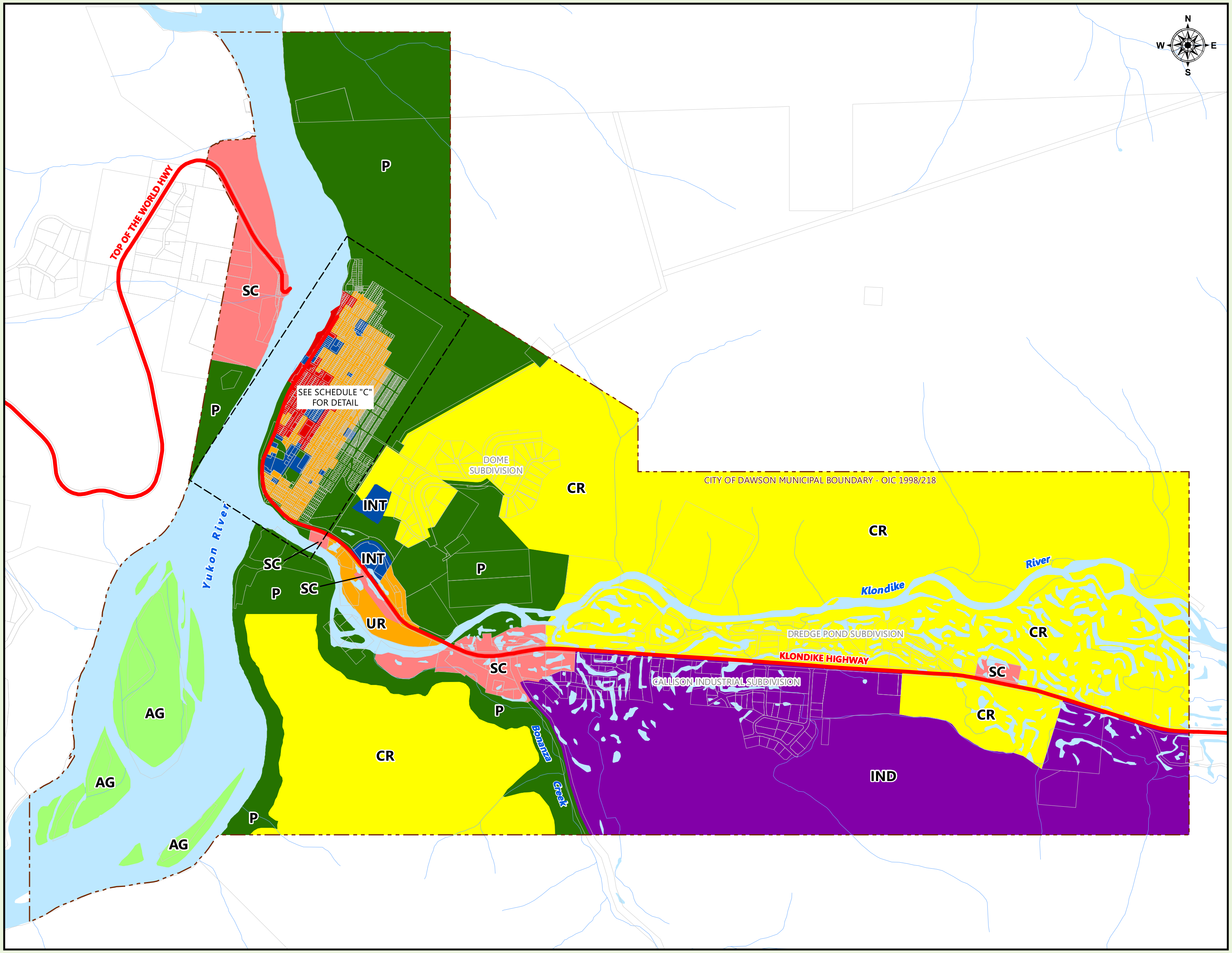
APPENDIX C

LAND USE ZONING



The Town of the City of Dawson
Official Community Plan
Bylaw No. 12-23
Land Use Map (Valley, Confluence and Bowl)
Schedule B

0 0.5 1 km

OCP Land Use Designations

- 🟨 CR - Country Residential
- 🟧 UR - Urban Residential
- 🟥 DC - Downtown Core
- 🟥 SC - Service Commercial
- 🟦 INT - Institutional
- 🟪 IND - Industrial
- 🟩 AG - Agriculture
- 🟩 P - Parks & Natural Space

Schedule B, Bylaw No. 12-23

As adopted ________________________

ORIGINAL SIGNED BY:

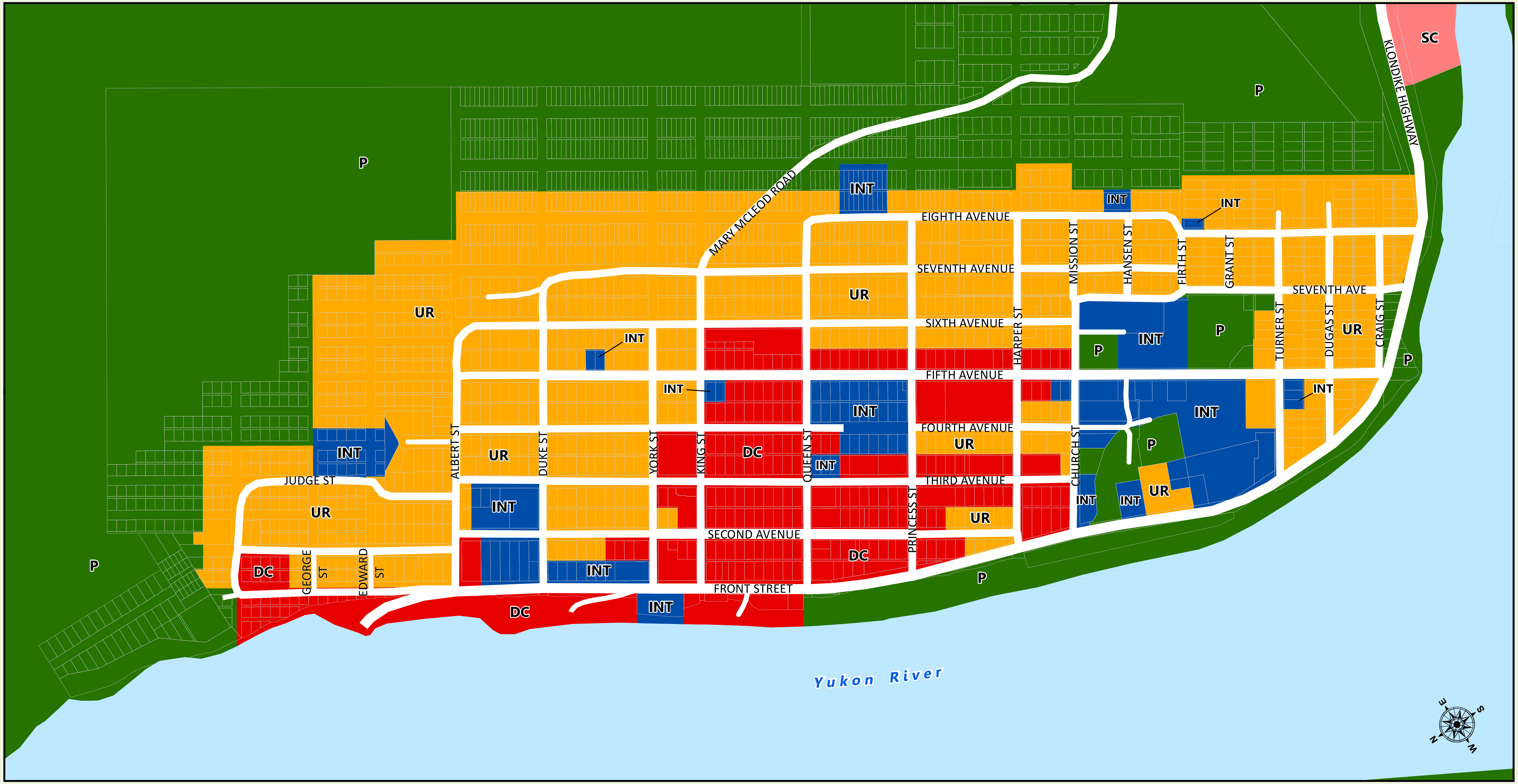
PETER JENKINS, MAYOR

JEFF RENAUD, CAO

Bylaw No.	Amendments	Date

Data sources:
OCP-City of Dawson;
Lot boundaries-NRCan
28 Jul 2012

03-OCP-VCB_B



The Town of the City of Dawson
Official Community Plan

Bylaw No. 12-23
Land Use Map (Historic Townsite)
Schedule C

OCP Land Use Designations

- 🟨 CR - Country Residential
- 🟧 UR - Urban Residential
- 🟥 DC - Downtown Core
- 🟥 SC - Service Commercial
- 🟦 INT - Institutional
- 🟪 IND - Industrial
- 🟩 AG - Agriculture
- 🟩 P - Parks & Natural Space

0 50 100 150 200 250 m

Schedule C, Bylaw No.12-23

As adopted ____________________

ORIGINAL SIGNED BY:

PETER JENKINS, MAYOR

JEFF RENAUD, CAO

Bylaw No.	Amendments	Date

INCORPORATED JAN. 9,1902

Data sources:
OCP-City of Dawson
Lot boundaries-NRCan
13 Sep 2012

03-OCP-HT_C

APPENDIX D

NUMERICAL MODEL REPORT

TETRA TECH

TECHNICAL MEMO

ISSUED FOR USE

To:	Ryan Martin, Tetra Tech	**Date:**	April 7, 2017
cc:	Adam Seeley, Tetra Tech	**Memo No.:**	1
From:	Christopher Gutmann, Tetra Tech	**File:**	ENW.WENW03020-01
Subject:	Groundwater Model Simulations for City of Dawson Water-Supply Well Capture Zone Analysis		

1.0 INTRODUCTION

Tetra Tech Canada Inc. (Tetra Tech) was retained by the Government of Yukon, Community Services Infrastructure Development Branch (YG-IDB) to prepare an Aquifer and Wellhead Protection Plan (AWHPP) for the City of Dawson (CoD) community water system. One of the first steps in developing such a plan is to determine the well capture zones, and define well protection areas. The City of Dawson uses four municipal water supply wells (PW-1N, PW-2N, PW-3N and PW 4N) that were brought into service in 2015. Tetra Tech developed a groundwater flow model and utilized it to conduct an analysis of the map extent of the groundwater capture zones for these four water supply wells.

The unique groundwater environment underlying the City of Dawson includes the alluvial gravel and cobble deposits of the Klondike and Yukon rivers, and is constrained on the east and north by the presence of permafrost. These features influence the patterns of groundwater flow and result in the capture zones for these wells curving east and south to the Klondike River.

2.0 METHODOLOGY AND SIMULATION RESULTS

A groundwater model was developed to predict the area within which groundwater would be captured in association with water-supply pumping for the aquifer underlying a portion of the City of Dawson. The extent of the area simulated by this model is shown in Figure 1. The model grid was constructed using 5-meter model cell spacing of 174 rows by 150 columns and 5 numerical layers, for a total of 130,500 model cells, a subset of which were used in the active model domain. The model grid is rotated by 33 degrees in a clockwise direction to align with the anticipated direction of groundwater flow to the water supply wells. The model grid is shown in Figure 2. Due to the complexity of the area which included the need to simulate the influence of permafrost, an aquifer which thins to the east, the presence of the Yukon River to the west and the Klondike River to the south, and seasonally varying precipitation influences and pumping rates, the model was constructed using the United States Geological Survey finite-difference modeling code MODFLOW 2000 (Harbaugh et al., 2000) for simulation purposes. The model was developed using geologic and hydrogeologic data presented in previous investigations.

The model was constructed using the Yukon and Klondike Rivers as the western and southern boundary conditions, respectively. Previous investigation efforts undertaken by Tetra Tech between 1977 and 2017 have documented the presence of permafrost under Dawson from north of approximately Church St, extending southeast from its intersection with Fifth Avenue to Dugas St and Eighth Ave (Figure 3). The zone south and west of this line represents the “thaw bulb” formed by the subsurface flow of Klondike River water through the gravel layers. The flowing river water represents a consistent thermal influence on the groundwater preventing the formation of permafrost. This line represents the northern and eastern boundaries of the active portion of the groundwater flow model. Four vertical model layers were used to represent the two primary higher-permeability lithologic types overlying the metamorphic bedrock and one layer to represent the upper 20 meters of the bedrock itself. The upper-most model layer (one) was used to represent the surficial silts and sands present at land surface. Model layers 2 to 4 were used to represent the underlying gravels and cobbles encountered from approximately 4 meters below ground surface to the top of the metamorphic bedrock. The combined thickness of clastics including silts, sands, gravels and cobbles ranges approximately from 0.5 to 20 meters thick. A cross section of the model geologic framework is shown in Figure 4.

Observations of groundwater level elevations are very important to the development of a groundwater flow model, which accurately represents the conditions it is designed to simulate. Water level observation data were available from a limited set of monitoring wells and from the water-supply wells themselves. Depth-to-water data was collected from each of the wells in February 2017 by Tetra Tech. A subsequent wellhead survey was performed in March 2017, permitting the observations of water level elevations to be calculated. These well locations are shown in Figure 5.

The primary influence on groundwater flow within the model is anticipated to be groundwater-surface water interactions with the Klondike and Yukon Rivers. The steeper hydraulic gradient of the Klondike River results in hydraulic heads approximately 5-6 meters higher at the Klondike River Bridge than that observed in the Yukon River at the northern end of Dawson. River stages in the Yukon and Klondike Rivers vary seasonally. During the winter months from October to April, river stages are low and the rivers freeze. Ice break occurs typically during late-April. As the snowpack melts, river levels increase, periodically made significantly higher due to blockage. Yukon River levels generally fluctuate over a 2 to 3 meter range, although under extreme high conditions (due to ice jam), elevations can be in the order of 6 meters above average. Since the goal of the model was to simulate groundwater flow conditions, average river stages for each month are presented in Figure 6.

A digital elevation model, or map of land and water surface elevations derived from an aircraft overflight, provides information about where the river elevations change (Figure 7). Boundary conditions used to represent the rivers in the model use this distribution of hydraulic heads to simulate groundwater flow accurately. Klondike River water flows into the gravel beneath Dawson at its southern end where river elevations are higher than water level elevations observed in monitoring wells beneath Dawson creating a hydraulic gradient (Figure 5). Groundwater then follows a path parallel to the permafrost boundary until finally discharging into the Yukon River or at the water-supply wells.

The top of the metamorphic bedrock surface was generated based on lithologic picks from borings and wells in Dawson. These top of bedrock points were contoured to create the top of Model layer 5 (see Figure 8). The top of bedrock varies from approximately 350 m above mean sea level (amsl) east of Dawson where the bedrock outcrops to approximately 300 m amsl at the Yukon River.

Seasonal influences on the model in the form of spring snowmelt and summer precipitation events were integrated into the model assuming that 10% of the average accumulated April snowpack (24 cm), and 10% of the average monthly summer precipitation infiltrated and became part of the groundwater flow. The spring snowmelt contribution was estimated by calculating the area upgradient of the permafrost line, multiplying by the snowpack thickness, then distributing 10% of the resulting water along the eastern edge of the permafrost boundary (Figure 9). The remaining 90% of the precipitation from the water budget was assumed to either run off as surface water, or evaporate during summer months, and not contribute to the groundwater budget. Over a 1-year period, recharge was estimated to represent approximately 4 – 5 % of the total volume of water pumped from the water-supply wells.

Calibration Evaluation

Due to the limited water-level data with which to compare the model, a typical calibration process characteristic of most groundwater flow models was not performed as part of the development of the model. Instead, the water-level data collected during February 2017 was compared to the simulated results of the model for similar conditions using the aquifer parameters as determined by available testing results. The calibration of the groundwater flow model was evaluated using a combination of observed data from river stages and groundwater wells in Dawson, as well as the results from a set of aquifer tests performed in the coarse-grained gravel layer from which water-supply pumping occurs. Aquifer testing was performed at various times in Dawson wells. Results from tests in monitoring wells 91-1, and "Test Well" were considered in addition to testing results from the former water supply wells PW-1, PW-2 and PW-3, and the recently installed water-supply wells PW-1N, PW-2N, PW-3N and PW-4N. Packer testing performed in WWTP-01-09 at the wastewater treatment plant in the deeper bedrock unit was additionally used in model development (EBA, 2009). A summary of the aquifer parameters reviewed and the selected values used in the model are presented in Table 1. The sources of the data evaluated and summarized in Table 1 are listed in the References Section 5.0 of this report. The only aquifer testing data available for the surficial silt was a slug test performed at the Old Territorial Administration Building in OTAB-16MW01, which resulted in an interpreted value of 0.08 meters per day (m/d) for horizontal hydraulic conductivity. Tetra Tech assumed an anisotropy of 10:1 horizontal to vertical hydraulic conductivity in model layers 1-4. The range of observed hydraulic conductivity values from the gravel-layer testing was 27.8 to 678.9 m/d. An averaging of a subset of the results judged to be representative of typical conditions yielded an average hydraulic conductivity value of 121 m/d, and the packer-testing results indicated an average hydraulic conductivity value for the bedrock of 0.22 m/d, both of which were used in the model simulations. Specific storage values of $1.0\text{x}10^{-6}$ 1/m were assumed for all lithologic zones. Specific yield values of 30% and 1% were used for model layers 1-4 and model layer 5 (bedrock), respectively. Effective porosity values of 30% were assumed for model layers 1-4 and 1% for the bedrock model layer. Given the month-long stress periods used in the model, the storage values are not expected to have a significant impact on modeling results, however.

Observed water level elevation data from the wells described earlier was used to determine whether the combination of river-stage elevation data, and aquifer testing results was sufficient to reproduce the observed groundwater conditions beneath Dawson. The observed water-level elevations used are shown in Figure 10. For comparison, contours for simulated water level observations based on the resulting model are also provided in Figure 11. For the purposes of evaluating the calibration, the target residual values (Simulated Head – Observed Head) are presented on Figure 11. It is interpreted that the high simulated heads in the pumping wells is in part a product of the pumping conditions in the well where the simulated heads are representative of hydraulic head in the surrounding aquifer.

Simulation Results

The model constructed as described in the section above simulates groundwater flow following a path originating along the southern boundary of Dawson at the Klondike River and passing beneath Dawson to discharge into the Yukon River or the water supply wells. Generally flow paths originating at the eastern-most end of the model follow the permafrost line discharging farthest downstream. Although water is introduced through recharge, the impacts are limited to the one-month snowmelt period. The result is a temporary change in flow direction, which quickly dissipates during the following month due to the permeable nature of the gravels.

Following calibration of the model, an assessment of the hydraulic impacts of pumping from the four water-supply wells was performed. Although in daily use, distribution of pumping is alternated between the wells used in pairs (PW-1N and PW-3N, alternating with PW-2N and PW-4N), since the model was constructed for simulation on a monthly basis, the pumping demand was distributed evenly between all four wells over each season. Water demands were based on projected estimated daily demands for 2036, which assume a 1.3% annual growth rate between 2017 and 2036 demands. During the period from May to September, the total pumping was assumed to be 24.6 Liters per second (L/s). During the winter period from October to April, the water demand was increased to 44 L/s due to increased demand from bleeding. The simulated drawdown resulting from each of these two pumping regimes is presented in Figure 12.

Capture zones were evaluated for the four water-supply wells by using particle tracking run in a reverse direction to groundwater flow using the USGS code MODPATH (Pollock, 1994). The paths traveled during each of the 90-day, 1-yr, 2-yr, 5-yr and 10-yr scenarios were evaluated using particles released in the Dawson Aquifer model layers, and a zone of capture drawn to encompass the area from which the particles originated to reach the wells. The results are presented in Figures 13a, 13b, 13c, 13d and 13e. The minimum simulated travel time necessary for water to travel from the Klondike River to the wells was 596 days, and 37 days from the Yukon River.

Simulated travel paths for water being pumped by the water-supply wells indicate that the majority of the water source for the wells is the adjacent Yukon River, although a component includes water that originates in the Klondike River prior to its confluence with the Yukon River, and which travels through the gravels before being captured. Based on a combination of the fraction of particles originating at each river, and the water balance of the model, over the duration of a 1-year period of simulation, an estimated 5% of the water pumped by the wells originates as infiltration, 90% originates from the Yukon River, and the remaining 5% originates from the Klondike River via the Dawson Aquifer. During the spring snowmelt, the fraction of water originating as precipitation is likely higher, perhaps 15% of pumping, however this period is limited in duration each year and is balanced by the essentially zero recharge contribution that occurs during the winter months when most of the groundwater pumping is expected to take place.

3.0 SOURCES OF UNCERTAINTY

Due to the variable nature of the upper-most 3 to 5 meters of the zone delineated as permafrost, which is expected to at least partially melt during the summer, this depth interval and area of Dawson was not possible to model as part of the longer-term simulations. Since it is recognized that water originating to the east of the active model area will eventually discharge to the Yukon River through a combination of overland flow and infiltration, this area should not be ignored as a possible area to consider as part of the capture zone of the water-supply wells. Although the surface water flow component of the area cannot be simulated using the groundwater flow model, the portion of Dawson into which infiltration occurs and is transported via groundwater flow in the surficial silt layer can be evaluated.

Essentially all of the water which infiltrates would have to flow through the surficial silts and would therefore represent a much lower addition to the flow component in the model. A reasonable estimate for travel distance can be calculated using the hydraulic conductivity (K) for the silt (0.08 m/d), the assumption that the hydraulic gradient (i) was similar to land surface since much of the surface silts are likely to be saturated as the ground thaws, and an assumed porosity (n=30%). The average linear pore velocity can be calculated as Ki / n, resulting in a groundwater velocity of approximately 0.016 m/d. In 2 years, assuming the ground is frozen for at least half the year, groundwater can be expected to travel approximately 6 meters. In 5 years, again assuming the ground is frozen at least half the year, the travel distance would be approximately 15 meters. Although much of the permafrost area uphill from the non-permafrost zone may represent potential capture area in terms of where groundwater will eventually flow, the travel rates are very slow, and the fluxes at the permafrost boundary are likely to be negligible compared to the total flow moving through the gravel unit below.

In addition to the nearby seasonal infiltration, past studies have suggested the possibility of infiltration occurring upgradient of the permafrost-impacted portion of the Dawson Aquifer. This water would seasonally infiltrate into gravels along the hillside and travel beneath the permafrost layer through locally thawed gravels. The presence of this travel mechanism has neither been documented in the vicinity of the model domain, and has not be included in the model structure. If subsequent investigation were to reveal a laterally continuous zone of unfrozen Dawson Aquifer beneath the permafrost, inclusion of the zone in the model would likely result in the expansion of the capture zone for the wells to include an area along the hillslope east of Eighth Avenue.

4.0 LIMITATIONS OF REPORT

This report and its contents are intended for the sole use of the Yukon Government and their agents. Tetra Tech Canada Inc. (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 the Yukon Government or for any Project other than the proposed development at the subject site. Any such unauthorized use of this report is at the sole risk of the user. Use of this report is subject to the terms and conditions stated in Tetra Tech Canada Inc.'s Services Agreement. Tetra Tech's General Conditions are attached to this memo.

5.0 REFERENCES

Shiltec 1992. 1992 Water Supply Project Exploration Phase. Prepared for The City of Dawson. January 1992.

Stanley, 1992. Water Supply Well Installation Dawson City Yukon Territory. Prepares for Shiltec Consultants Ltd. August 1992.

Morrison Hershfield, 2014. City of Dawson: 2014 Drinking Water Well Construction and Testing Report. Prepared for City of Dawson. October 2014.

Tetra Tech EBA, 2009. Hydraulic Test Results, Test Well WWTP-01-09, Dawson City, Yukon. Technical Memorandum prepared for Corix Water Systems during drilling of test hole WWTP-01-09 at proposed WWTP. September 2009.

Tetra Tech, 2017. Phase II Environmental Site Assessment Old Territorial Administration Building Dawson City, YT. Prepared for Government of Yukon – Site Assessment and Remediation Unit. February 2017.

6.0 CLOSURE

We trust this technical memo 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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Attachments:

- Tetra Techs General Conditions
- Table 1. Summary of Aquifer Properties
- Figures 1 – 13E

GENERAL CONDITIONS

GEOENVIRONMENTAL REPORT – GOVERNMENT OF YUKON

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.

1.2 ALTERNATE REPORT FORMAT

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.

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.

1.3 NOTIFICATION OF AUTHORITIES

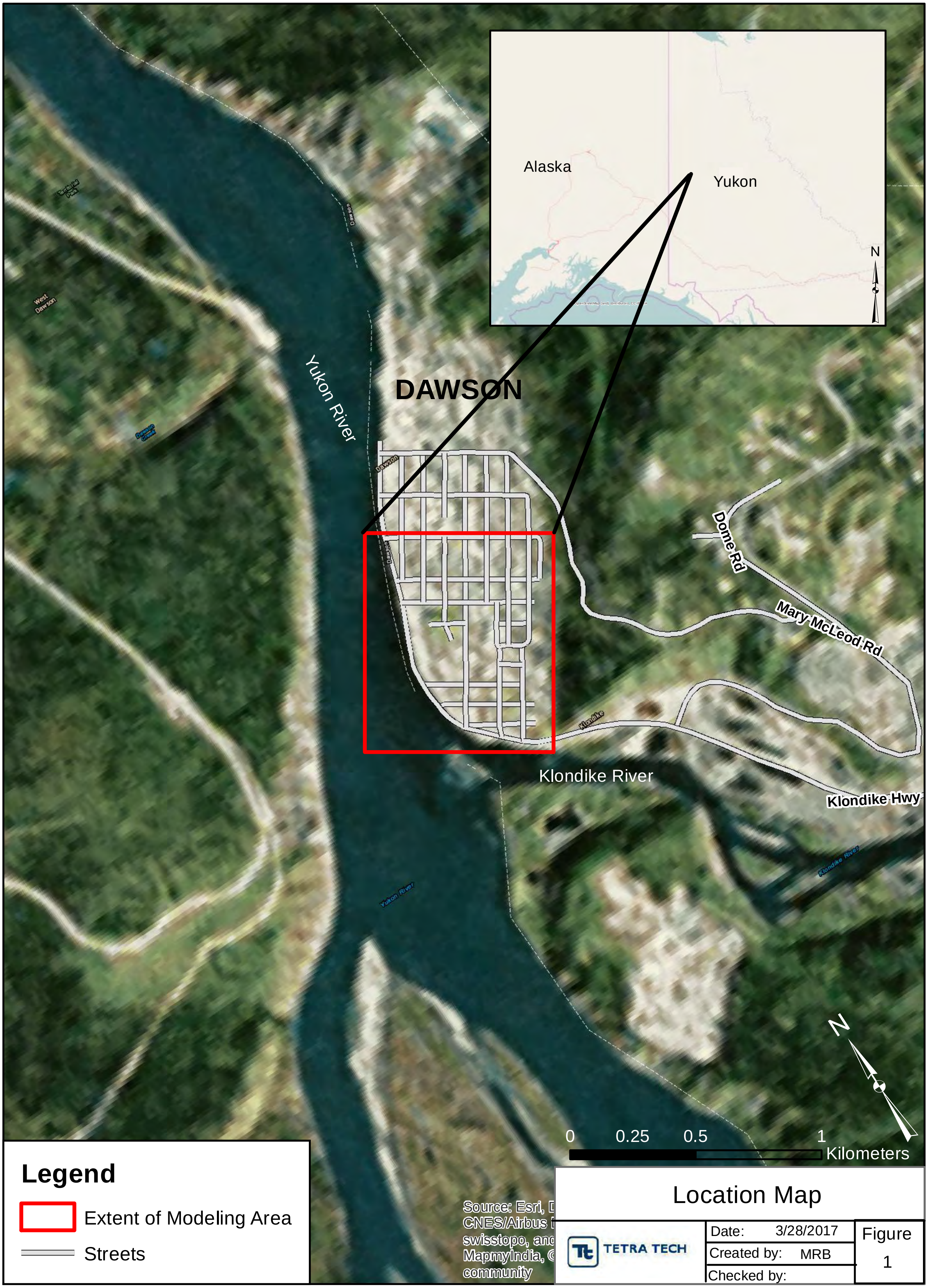
In certain instances, the discovery of hazardous substances or conditions and materials may require that regulatory agencies and other persons be informed and the client agrees that notification to such bodies or persons as required may be done by TETRA TECH in its reasonably exercised discretion.

1.4 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.

Table 1. Summary of Aquifer Parameters

	Model Layer	Hydraulic Conductivity (m/d) Horizontal / Vertical	Specific Storage	Specific Yield	Porosity
Silt/Sand	1				
Observed Range		0.08 (horizontal)	-	-	-
Model Value		0.08 / 0.008	1.0×10^{-6}	0.3	0.3
Gravel	2 - 4				
Observed Range		27.8 - 678.9 (horizontal)	-	-	-
Model Value		121 / 12.1	1.0×10^{-6}	0.3	0.3
Bedrock	5				
Observed Range		0.17 - 0.26 (horizontal)	-	-	-
Model Value		0.22 / 0.22	1.0×10^{-6}	0.01	0.01



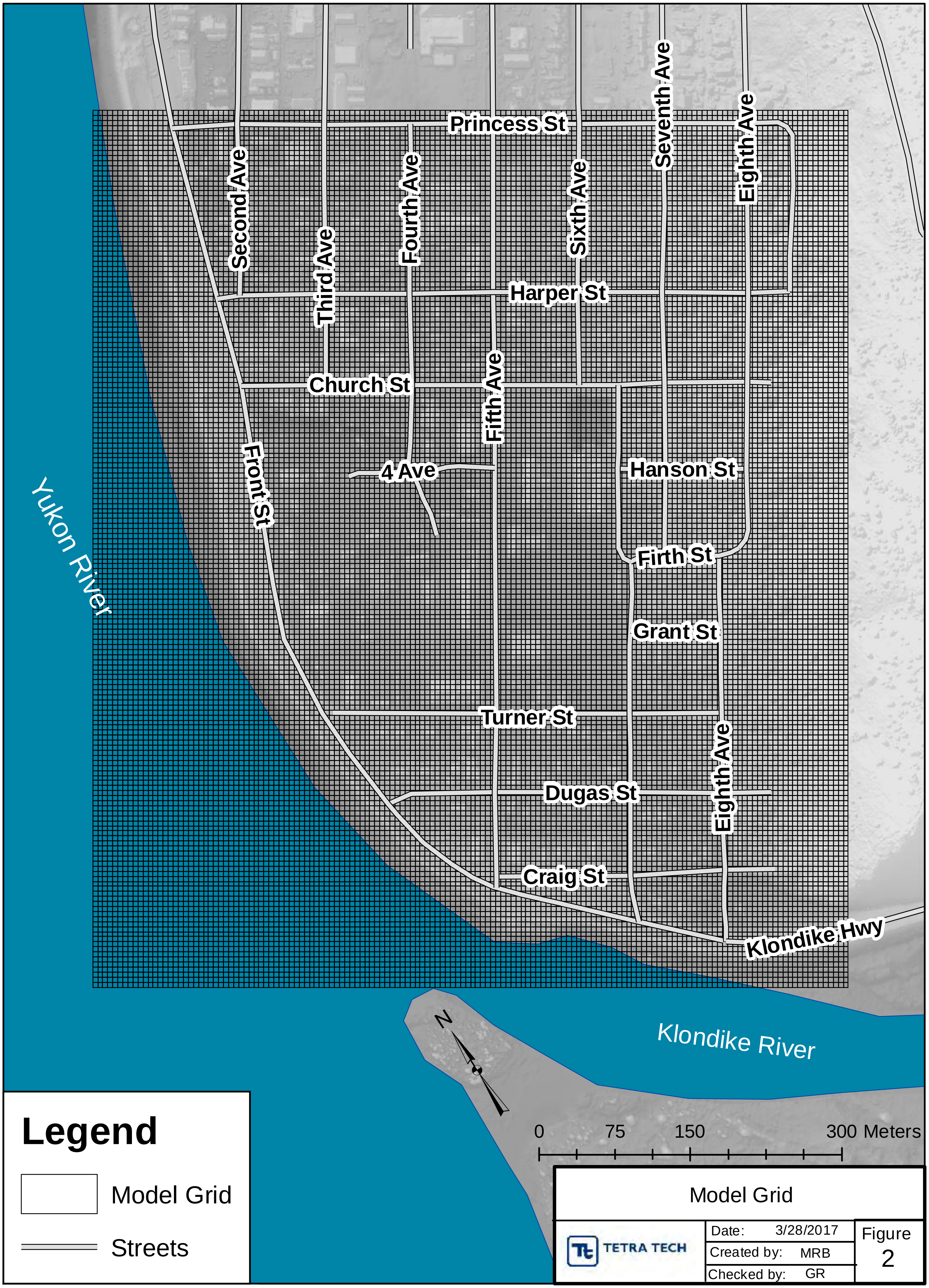
Source: Esri, D
CNES/Airbus
swisstopo, and
MapmyIndia, ©
community

Location Map

TETRA TECH

Date:	3/28/2017
Created by:	MRB
Checked by:	

Figure
1



Legend

▭	Model Grid
═	Streets

Model Grid

TETRA TECH

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Checked by: GR

Figure 2

Permafrost Boundary

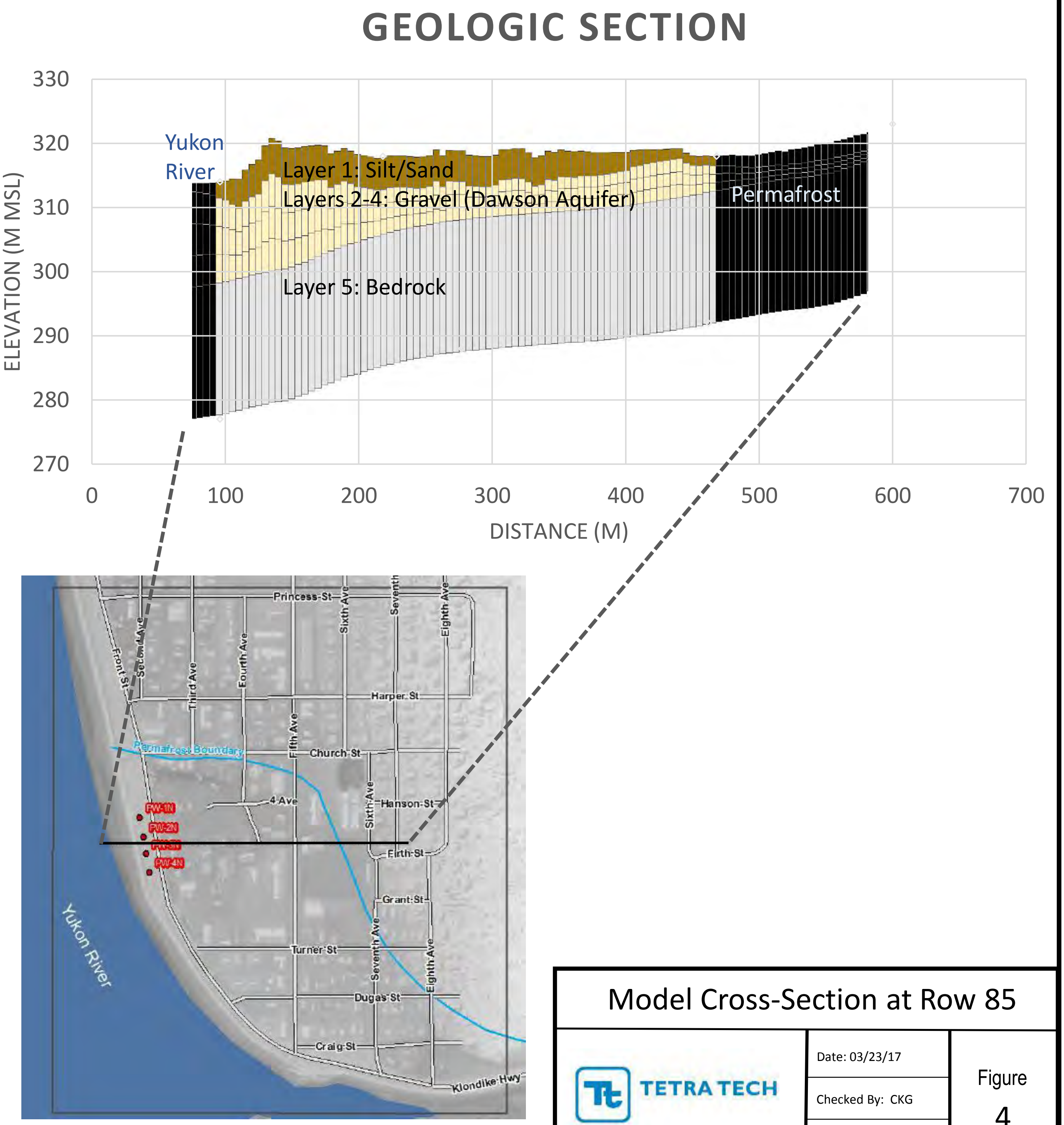
TETRA TECH

Date: 3/24/2017

Created by: MRB

Checked by:

Figure 3



Model Cross-Section at Row 85

TETRA TECH

Date: 03/23/17

Checked By: CKG

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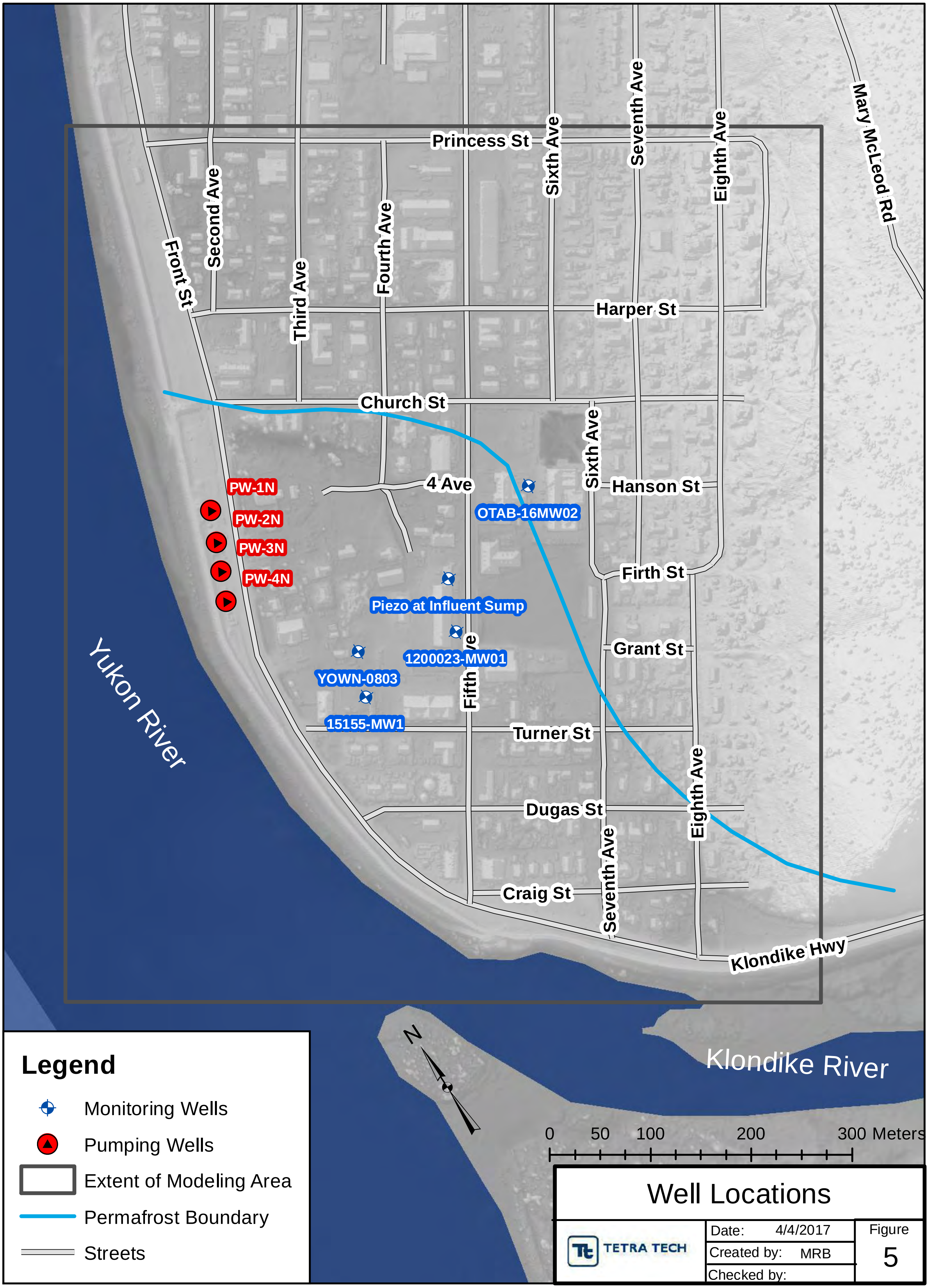
Figure

4



Well Locations

TETRA TECH

Date: 4/4/2017

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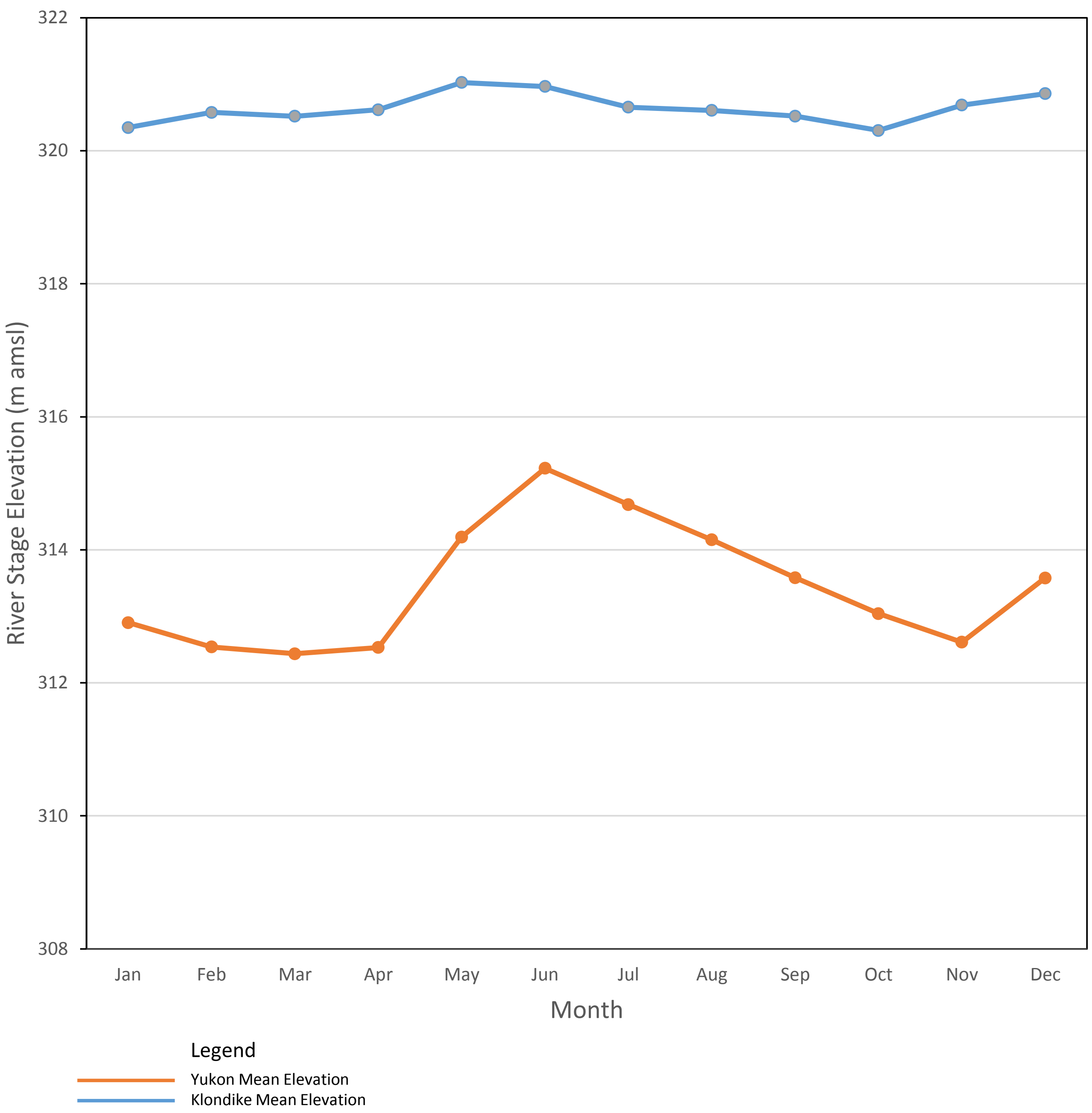
Figure 5



Note:
Yukon River Station (YT09EB001)
approximately 1.6 km downstream of PW-4N.

Klondike River Station (YT09EA001)
approximately 2.7 km upstream of PW-4N.

Average Monthly River Stages

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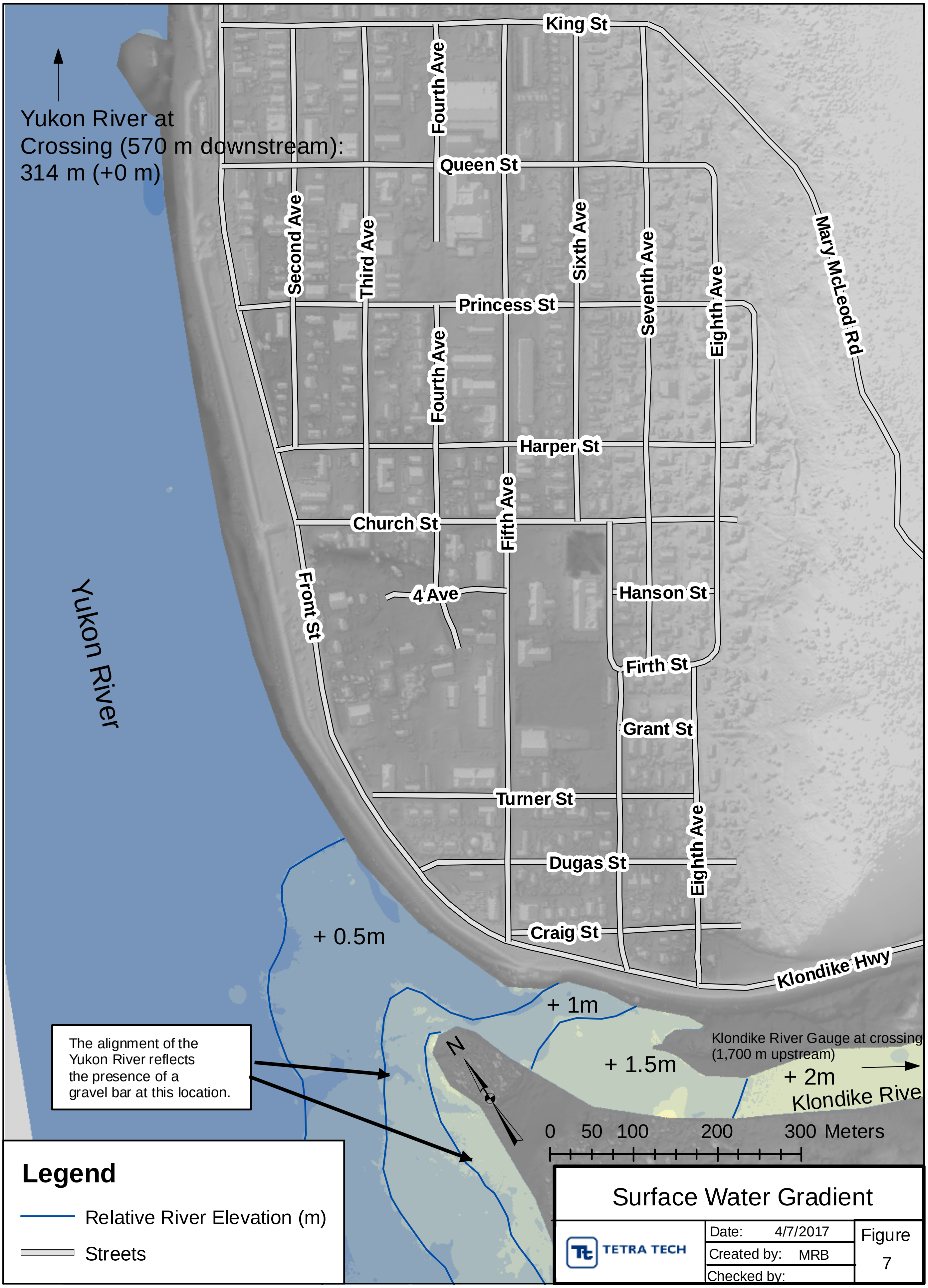
Figure
6



The alignment of the
Yukon River reflects
the presence of a
gravel bar at this location.

Surface Water Gradient

TETRA TECH

Date: 4/7/2017
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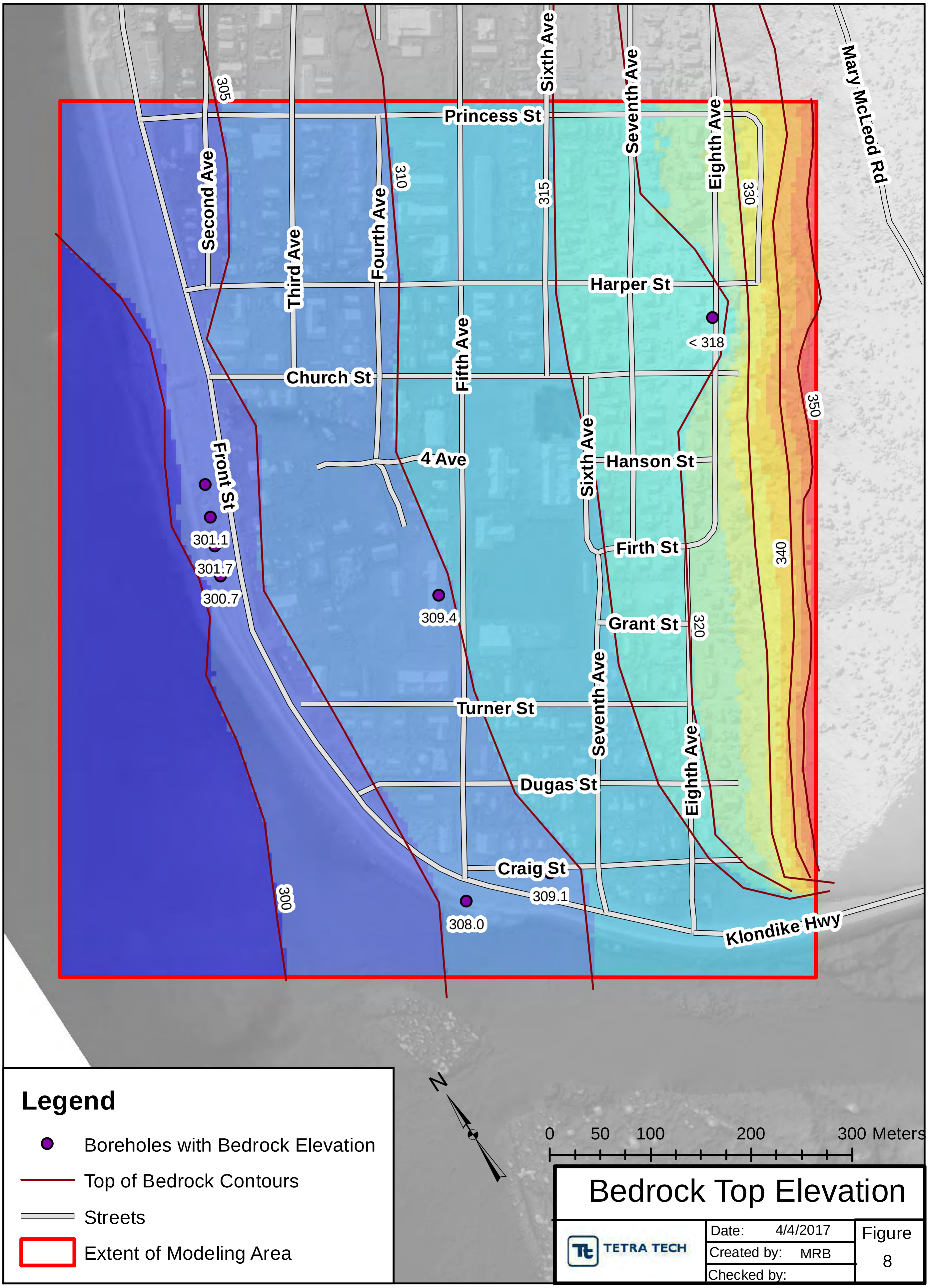
Figure
7



Bedrock Top Elevation

TETRA TECH

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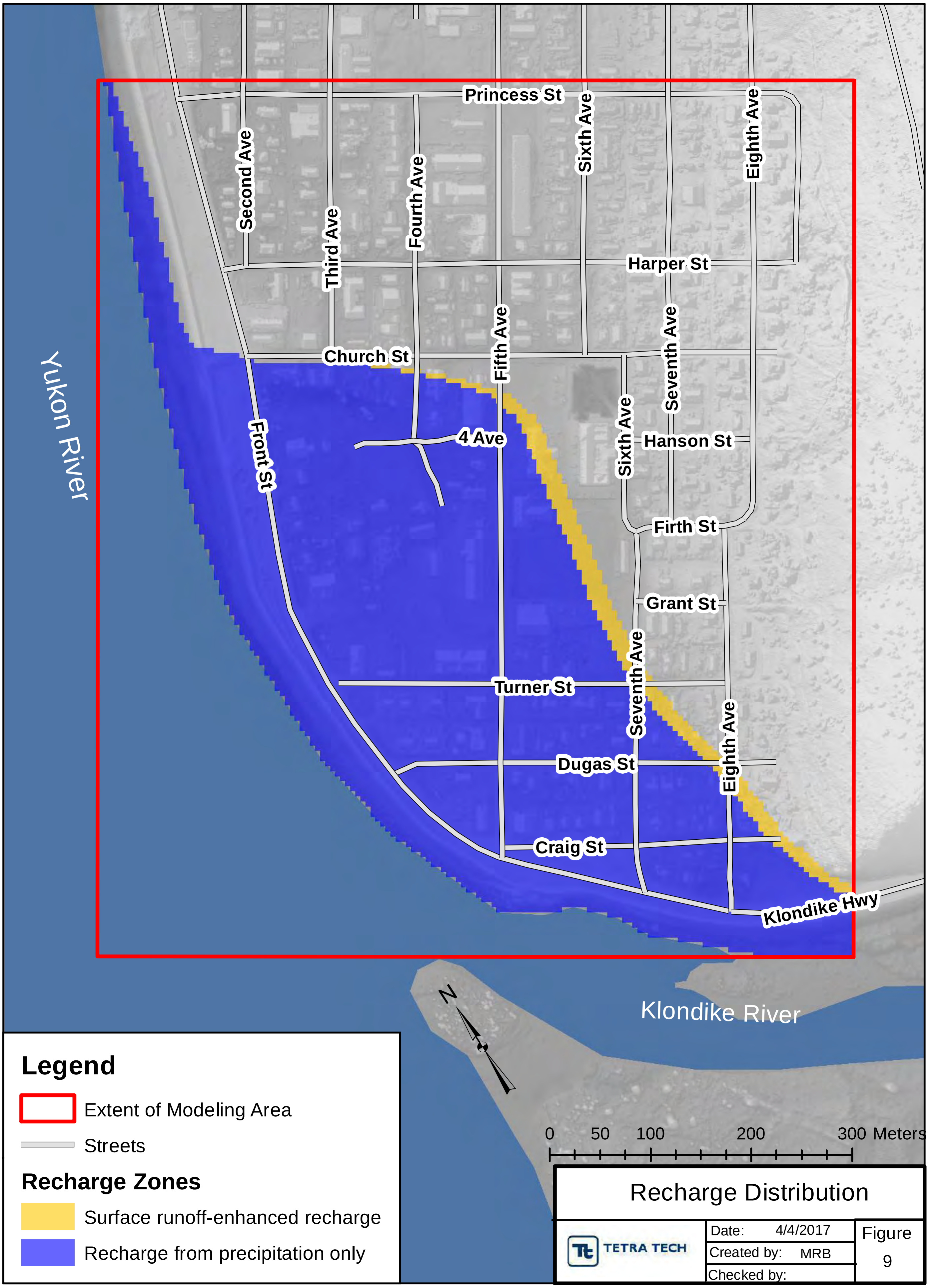
Figure 8



Recharge Distribution

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Figure 9

Observed Water Table

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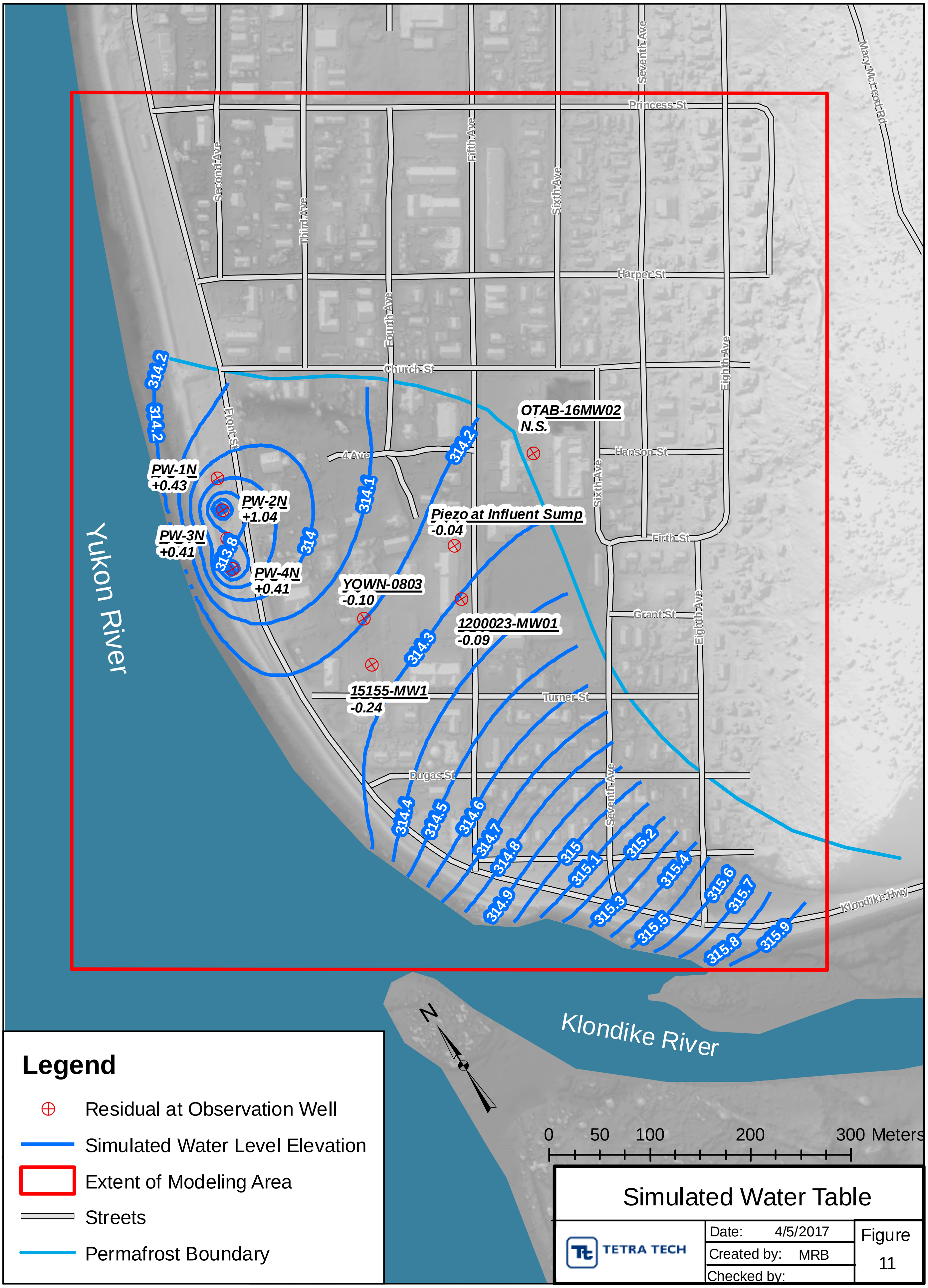
Figure 10



Simulated Water Table

Date: 4/5/2017
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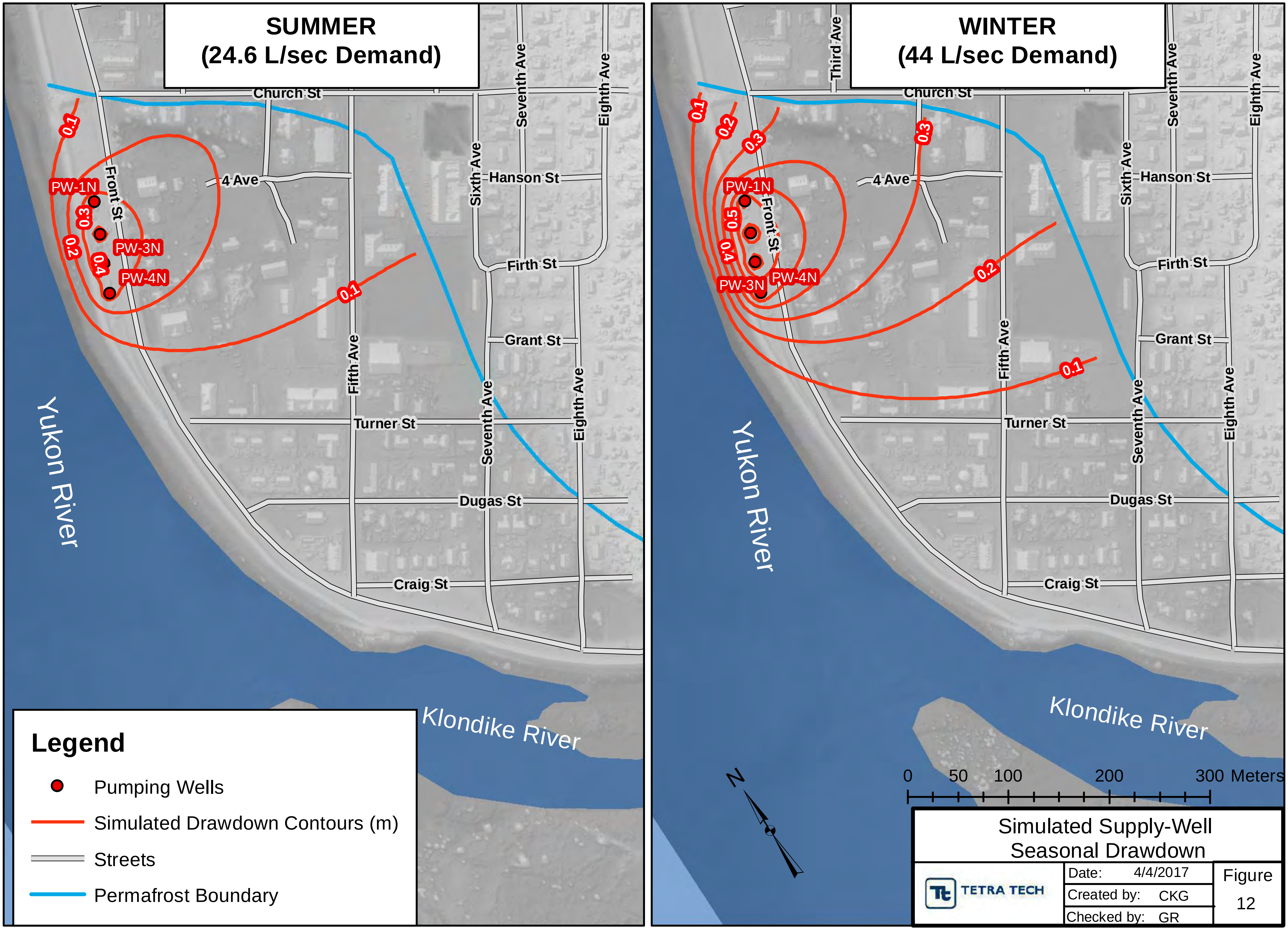
Figure 11



Simulated Supply-Well Seasonal Drawdown

Date:	4/4/2017
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Figure 12

Well Capture (90 days)

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Figure
13A

Well Capture (One Year)

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Date: 4/4/2017

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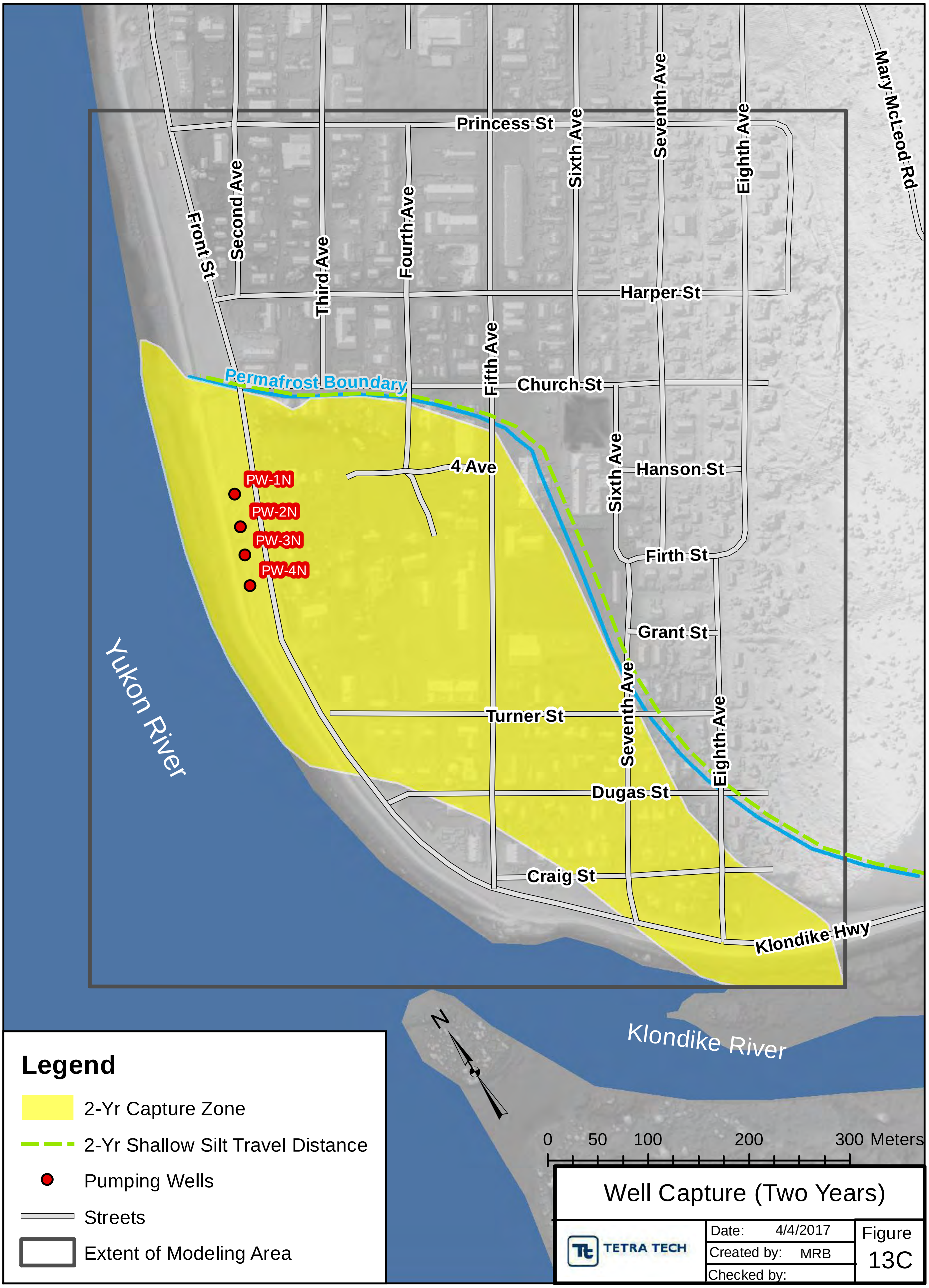
Figure 13B



Well Capture (Two Years)

Date: 4/4/2017
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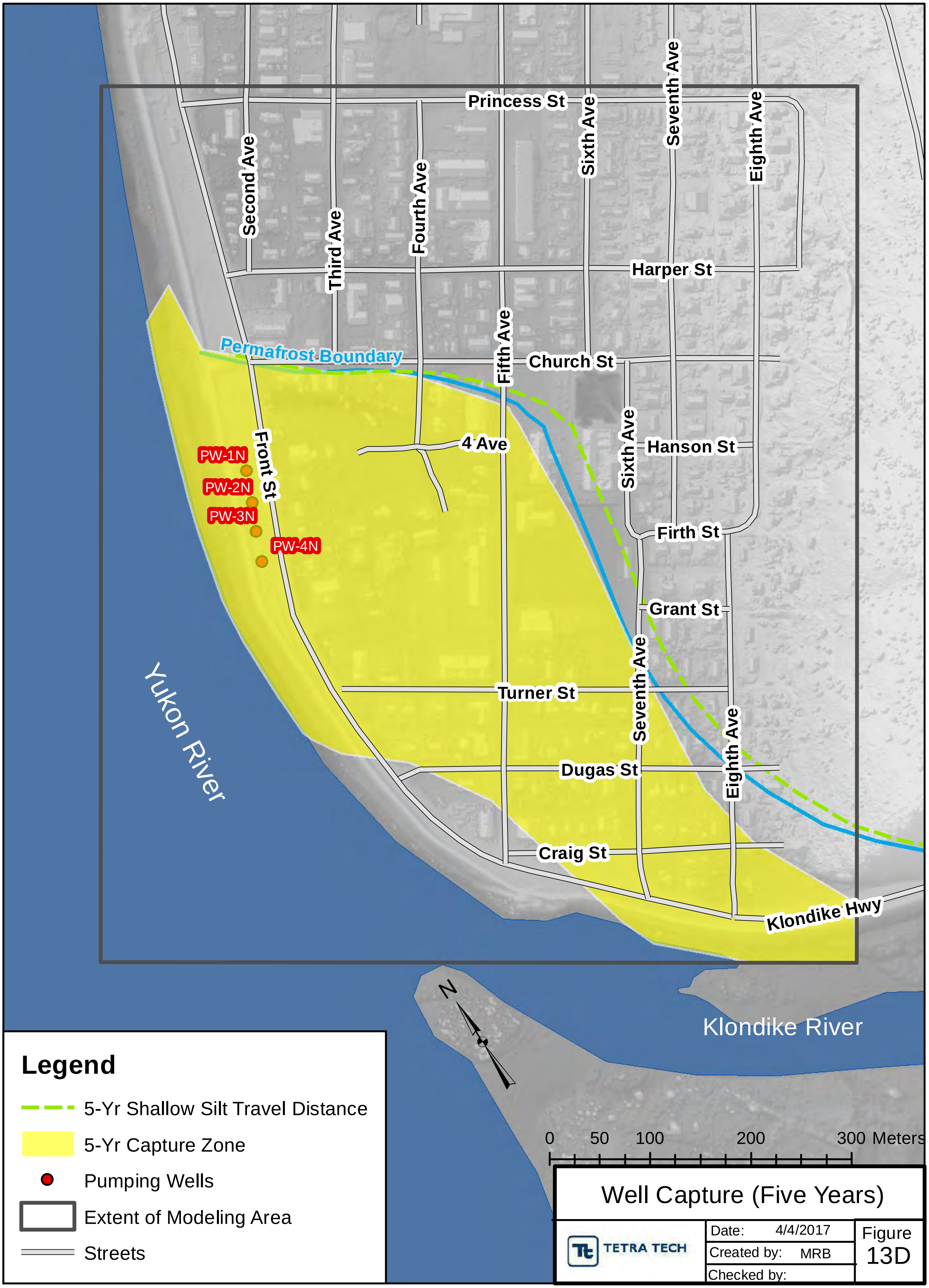
Figure 13C



Well Capture (Five Years)

Date: 4/4/2017
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Figure 13D

Well Capture (Ten Years)

Date: 4/4/2017
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Figure 13E

APPENDIX E

CONTAMINATED SITE AND SPILL SEARCH REPORTS

Yukon
Environment
Box 2703, Whitehorse, Yukon Y1A 2C6

February 9, 2017

Adam Seeley
Tetra Tech

Dear Mr. Seeley:

Re: Contaminated Sites Information Request:

The Environmental Programs Branch has the following listings on properties in and around Dawson City, Yukon:

- Yukon River bank between Duke and York Streets: In 2007, a spill from an overflow vent on a tanker spilled an estimated volume of 600 - 900 L of diesel which was stopped immediately. A relocation permit was issued for 6 m³ of contaminated soil to be relocated to a temporary stockpile next to Mackenzie Petroleums Ltd. LTF in the Callison Subdivision. Ten soil samples were sent in for analysis, nine of these were confirmatory samples from the sidewalls and base of the excavation while the remaining sample was from the contaminated mix relocated to the LTF. Two sidewall sample (Ref # 562079-1, 7) had LEPH of 2430 ug/g and 2940 ug/g (Bodycote Results Aug 3 2007). The contaminated mix sample (Ref # 562079-10), had LEPH of 1410 ug/g. Most of the contamination was found in the western portion of the excavation. MPL confirmed that they removed this west wall where additional contaminants were found, resulting in an additional 2-3 ft by 18 yds of soil, which was relocated to the temporary stockpile described in the RP. However, there is no record of any additional confirmatory samples taken from the new excavation wall so the area cannot be confirmed remediated.

- Old Quigley/Callison Waste Metal Dump: The dump site operated from 1975 through 1986, and was originally to be only a waste metal landfill, however in later years was used for domestic waste purposes (there was some separation of metals from domestic waste). Site was abandoned in 1986 and some work was done to level the ditches and the area was seeded with brome hay. There is little evidence left that the site was a dump save for some metal sticking out of the soil cover. Sampling of a groundwater monitoring well was conducted in 1994 as part of a site assessment. PCBs and organochlorines, except methoxychlor were all below detection (J. Gibson 1994), methoxychlor concentration was 0.58 ug/L. Sampling done in 2004 showed that Mn was present in elevated concentrations (Laberge 2004). No soil samples have been taken at this site, and sampling is recommended. There is likely still contamination present below the soil cap, however site is now used for lumber milling/storage and the ground is not to be disturbed. We have two reports on file for this site that document sampling performed on water taken from points within and near the site; no soil samples appear to have been taken from this property at all. The Gibson 1994 report showed the presence of methoxychlor (pesticide) at a level of 0.58 ug/L (well below the CSR Drinking Water standard of 900 ug/L). The Laberge 2004 report also contained results of water analyses from October 1987, July 1991, and November 1992; nearly all of these samples exceeded the Drinking Water standard for iron and manganese. The 2004 analysis showed no exceedances of the standard for iron, but all samples exceeded the standard for manganese. Minor levels of hydrocarbons were measured in 2 of the 2004 samples, as were phenols in all 3 wells, but these levels were below the Aquatic Life standards. The site is considered contaminated.

- North End Dump (east bank of Yukon River at the north end of Dawson): A contamination assessment of the site was completed in 1994 (EBA 1994). Various debris was located on site, and was partially cleaned up during the contamination assessment. The site assessment predates the YCSR, so results were compared to BC MoE Waste Management Program standards. All samples had TPH concentrations below the applicable standard. PCBs and DDT were also below all applicable standards. It was recommended that in future samples BTEX concentrations were also evaluated. There is no information concerning additional work done on site located in the files.

- YECL Substation, Callison Subdivision: In 2003, between 50 and 100L of hydraulic oil was spilled in the power plant. The spill was contained and it was prevented from reaching the Yukon River via the sewer system.

- Lot 8, Callison Subdivision (North 60 Bulk Plant): In 2003, 4000L of diesel fuel was spilled due to an overflowing tank. Fuel was contained and partially cleaned up. It is unknown if the site is remediated.

- Second Ave and Princess St (Gold Buyer's Building): Mercury testing in the building (1994 Workers Health and Compensation Board) found some areas to have concentrations as high as 0.08 to 0.15 mg/m3 mercury, and safety protective wear requirements were put in place for people entering the building. Mercury contaminated soils were also present on site, these have been removed to Williams' Holdings in Callison. The majority of the soil (14 cubic yards) meets guidelines (average concentration), however a small amount was stored separately in a container. Site 1 had soils with mercury concentrations as high as 76.9 µg/g, and was excavated to a depth of 18". Site 2 had a concentration of 16.4 µg/g, and was excavated to a depth of 6", and site 3 had concentrations of up to 2.4 µg/g, and was excavated to a depth of 6". A remediation objective of 2 ppm was set. Samples taken on site following excavation indicate that the site was remediated.

- Lot 12 Callison Subdivison: On May 5, 2002 a spill of approximately 20,000 L of diesel fuel occurred from a parked tanker in the Callison subdivision. This diesel ran into the ditch and moved through culverts. Approximately 11,350 - 13,600 L of free product was recovered from pools using a vacuum truck. There is a 25' well nearby, but it was indicated to COs that water was not used for drinking. A total of seven large test pits were dug along the path of contamination to delineate contamination. Excavated soil was temporarily relocated to a liner placed in the parking lot near the initial release area and covered with a tarpaulin. The total volume of excavated soils was 610 m3. An LTF was constructed on Mackenzie Petroleum property. It was indicated in the Laberge 2002 report that all contaminated soils were successfully excavated and relocated to the LTF. Confirmatory samples indicated that the site is remediated. The LTF was estimated to require at least one season to fully remediate the soils within.

- Lot 1 Callison Subdivision: Lot 1 is the site of a decommissioned Land Treatment Facility (LTF) under Mackenzie Petroleum's permit 24-007. Decommissioning report by Ridgeline

Environmental Inc. provides analytical results of an exceedance of arsenic at the Lot 1 location. Based on a review of the analytical results of the material previously stockpiled within the Lot 1 LTF, it appears that this exceedance may not be associated with the LTF previously located at the site [Pile A-Base: Arsenic, 20.3 mg/kg]. The site is considered contaminated.

- 983 4th Avenue (NWTel office): In 2012, a spill cause by ice falling off roof of building and shearing the fuel line of a 500 gallon AST. Spill response and remediation is detailed in a Groundtrax report dated June 7, 2012. Characterization samples indicated some of the soil was classified as special waste, thus all material was relocated to Arctic Backhoe Services' facility (45-027). Confirmatory samples all below standard, except for historical contamination found on site (sample "HIST", -1.10mbg; VPH=300ppm, LEPH=1480, HEPH=2200). Follow up work September 2012 included excavation and confirmatory sampling around area of historic contamination (23-456). Site is considered remediated.

- 4th Ave & Church St (Forcemain route): During excavation of the roadbed, exceedances of Cr and Ni were found in two boreholes. The site is considered contaminated.

- 1401 Albert Street: In January 2007, a home heating fuel tank was pulled over by a delivery fuel truck driver. Approximately 10m3 contaminated soil and snow was relocated from the site, but 4/5 confirmatory samples were above CSR-IL. Site is considered contaminated.

- Dawson City Firehall (Lots 11-15 Block 2 North End Subdivision, 96-110 LTO YT): contamination was discovered following the removal of a UST (work was being done prior to the development of the Klondike Centennial Society Seniors Park and Fire Hall Museum). Approximately 20 m3 contaminated material was removed from the site, however the most recent report on file (August 2002) indicates residual contamination remains.

- Former Dawson City Hwy Maintenance Camp (Parcel U Government Reserve, 20364 LTO YT, Parcel U-6 Government Reserve, 92-38 LTO YT): significant amount of assessment work has been completed on this property, but some areas still have potential contamination remaining.

- 301 Front Street (Parcel P Government Reserve, 20364 LTO YT): A leak from a fuel feed line from an AST led to soil contamination in 2001. Characterization samples of the estimated 300 m3 contaminated material excavated were above CSR-CL standards, but the file holds no record of confirmatory samples or final volume contaminated material removed from the site.

- Lot 12 (facing Front Street) Dawson City (assumed to be Lot 12 Block E Ladue Estate, 96-110 LTO YT): An application for the relocation of contaminated soil (estimated 20 m3) discovered during the removal of a UST was submitted to the Branch in July 2002. No confirmatory samples or confirmation of volume relocated is on file, thus site is still considered contaminated.

- 5th Ave and Princess: in 2002, 20L of fuel was spilled at Dominion Shell due to an overfilled tank. The spill was cleaned up and the site is considered remediated.

- 5th Ave & Turner Street (Parcel B, comprising Lots 1 and 2, Block 16 and portion of Parcel U Rem in lot 1, Group 2): A UST was broken during excavation and an unknown quantity of diesel fuel was spilled which was subsequently remediated. On the same site, during the installation of electrical lines on the property, hydrocarbon odours were detected. Subsequently, environmental consultant was hired to assess, excavate and sample the area (future parking lot for apartment complex). Confirmatory sampling indicates residual contamination remains – one sample exceeded CSR-CL for LEPHs.

- 954-6th Avenue (Lots 4-6 Block LD Ladue Estate): October 2010 spill results in significant contamination at the Korbo Apartment building. Delineation and excavation has been ongoing. Summer 2012 resulted in a total of 3077 m3 contaminated material being relocated off site; two confirmatory samples remained above CSR standards, thus the site remains classified as contaminated. (Further delineation/excavation was not possible due to the location of an adjacent building.)

- RCMP Station, 415 Front Street (Lot U-5 Government Reserve): In 2003, contamination was found beneath a modular home that was being removed from the site to facilitate new construction. Excavation and relocation of contaminated material occurred, but confirmatory sampling was not completed in accordance with CSR and minor contamination may remain on site. Also, in 2005, a heating fuel line was cut at the RCMP detachment leading an estimated 250 gallon spill. A fire incinerated most of the fuel and a site assessment confirmed that no contamination remains on site.

- 502B Grant Street: An unknown volume of home heating fuel leaked from an AST next to the south wall of the residence. The leak occurred at the fitting where the fuel line joined the AST. Remedial work was conducted in 2014 and confirmatory sampling indicated that LEPH, xylene and ethylbenzene remained along the west wall of the excavation beneath the building. It could not be excavated without compromising the integrity of the building. Further remediation and investigation was recommended. The site is currently considered contaminated.

- 925 7th Avenue: The site caught fire which caused a fuel line that ran underneath the building to burst, releasing an unknown volume of home heating fuel. Remedial work was conducted in 2014 but confirmatory sampling concluded that chromium contamination remains. Cr concentrations were high in samples with high PHC concentrations and those without, thus it was recommended that further investigations be conducted to determine whether the concentrations of Cr are at natural background levels. The site is currently considered contaminated.

- Lot 1047-2 Quad 116 B/03 (Northern Superior Mechanical): In August 2016 a relocation permit was issued for the relocation of approximately 10m3 of PHC-contaminated soil. A characterization sample indicated levels of lead above the TCLP trigger of 100 ug/g.

Please contact Vanessa Scharf at 667-8848 if you have any further questions, would like to view any of our files or need other information in the future.

Sincerely,

Isobel Ness
Environmental Programs Branch

Yukon
Environment
Box 2703, Whitehorse, Yukon Y1A 2C6

21 September 2017

Adam Seeley
Tetra Tech

Dear Mr. Seeley

Re: Contaminated Sites Information Request for City of Dawson

The following table presents a summary of the spills which have occurred since February 2017 within your study area (the SE proximity of the City of Dawson). This summary includes all the sites and spills which the Environmental Programs Branch has on file. Please note that there may be more contaminated properties or undocumented spills within this radius which the Environmental Programs Branch has no information pertaining to.

Please contact me at 667-8816 if you have any further questions, would like to view any of our files or require other information in the future.

Sincerely,

Kent Bretzlaff
Environmental Programs Branch

Table 1: Summary of Recent Spills and Contaminated Sites Records for the City of Dawson

Approximate Date of Occurrence	Site (Address)	File/Spill Report Notes	Site Status
17-Aug-17	Yukon River near Dawson City	Spill Report: Dawson City RCMP received a phone call indicating a brown colored substance / plume on Yukon River. RCMP and CMI's DYCE investigated. Spill Report states "speculation is that a barge had gone upstream today with a fuel truck on board" but other than the observation that a fuel truck went upstream on barge earlier that day, no evidence that observed plume is from a fuel spill.	Minor or Unlikely Contamination
14-Aug-17	Across the road from the General Store in the City of Dawson	Spill Report: An anonymous person reported a spill to Yukon Environment around 1500hrs via telephone. Person described an oil spill across the road from the General Store in the City of Dawson. No more information given, no call-back number.	Unknown
15-July-17	Boat launch/ Dawson Ferry Landing	Spill Report: Spill reported due to unsecured Gas Cap on a work truck. Reported that absorbent booms have been placed in the river to contain the spill. The land portion has had absorbent pads and material to soak up the spill. Following the 25-July-17 inspection it was concluded that pads had been replaced and no visible sheen was observed. The quantity spilled was approximately 1 -2 litres from the fuel tank that was overfilled and then came out the fill cap once the expansion occurred from sitting in the sun. Satisfied that the spill is terminated and no longer present.	File Closure Recommended