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

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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 uppermost 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

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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.

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

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

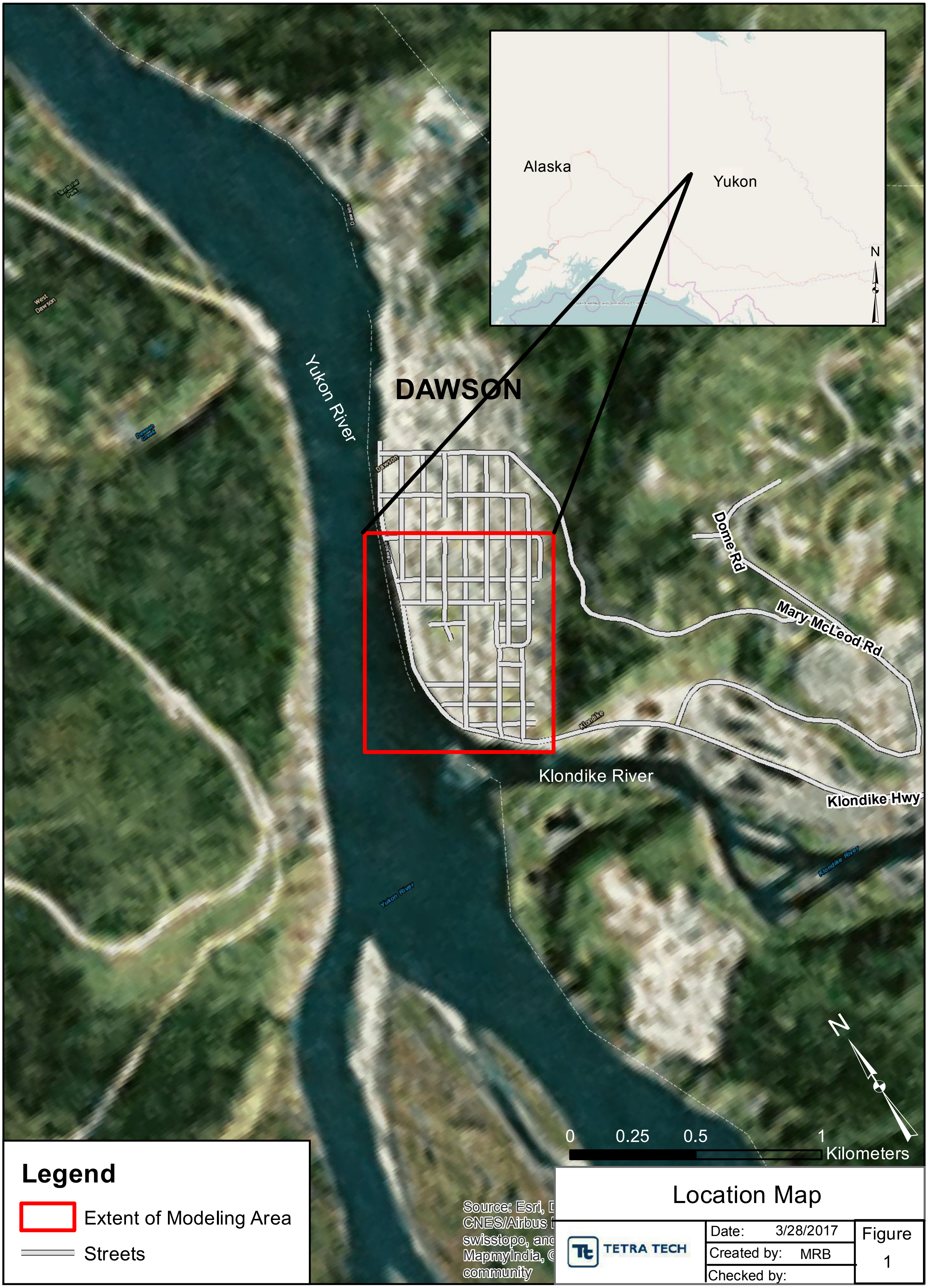
In certain instances, the discovery of hazardous substances or conditions and materials may require that regulatory agencies and other persons be informed and the client agrees that notification to such bodies or persons as required may be done by TETRA TECH in its reasonably exercised discretion.

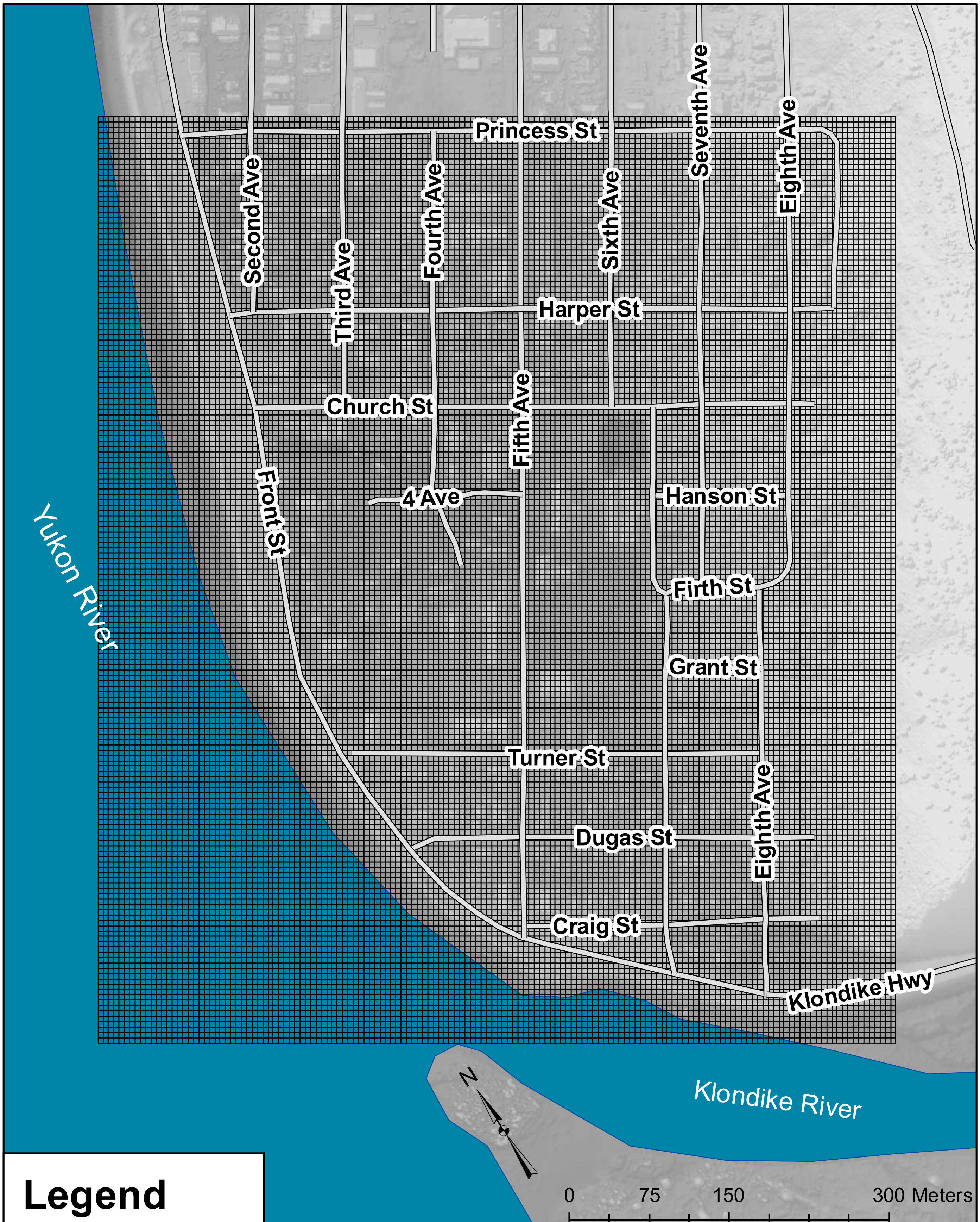
1.4 INFORMATION PROVIDED TO TETRA TECH BY OTHERS

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


Alaska
Yukon
N
DAWSON
Yukon River
Dome Rd
Mary McLeod Rd
Klondike River
Klondike Hwy
N
0
0.25
0.5
1
Kilometers
Legend
Extent of Modeling Area
Streets
Location Map
TETRA TECH
Date: 3/28/2017
Created by: MRB
Checked by:
Figure
1



Legend

Model Grid

Streets

Model Grid

TETRA TECH

Date: 3/28/2017

Created by: MRB

Checked by: GR

Figure 2


Princess St
Harper St
Church St
4 Ave
Hanson St
Firth St
Grant St
Turner St
Dugas St
Craig St
Klondike Hwy
Front St
Second Ave
Third Ave
Fourth Ave
Fifth Ave
Sixth Ave
Seventh Ave
Eighth Ave
Mary McLeod Rd
Yukon River
Klondike River
Permafrost Boundary
N
0 50 100 200 300 Meters
Legend
Permafrost Boundary
Streets
Model Extent
Permafrost Boundary
TETRA TECH
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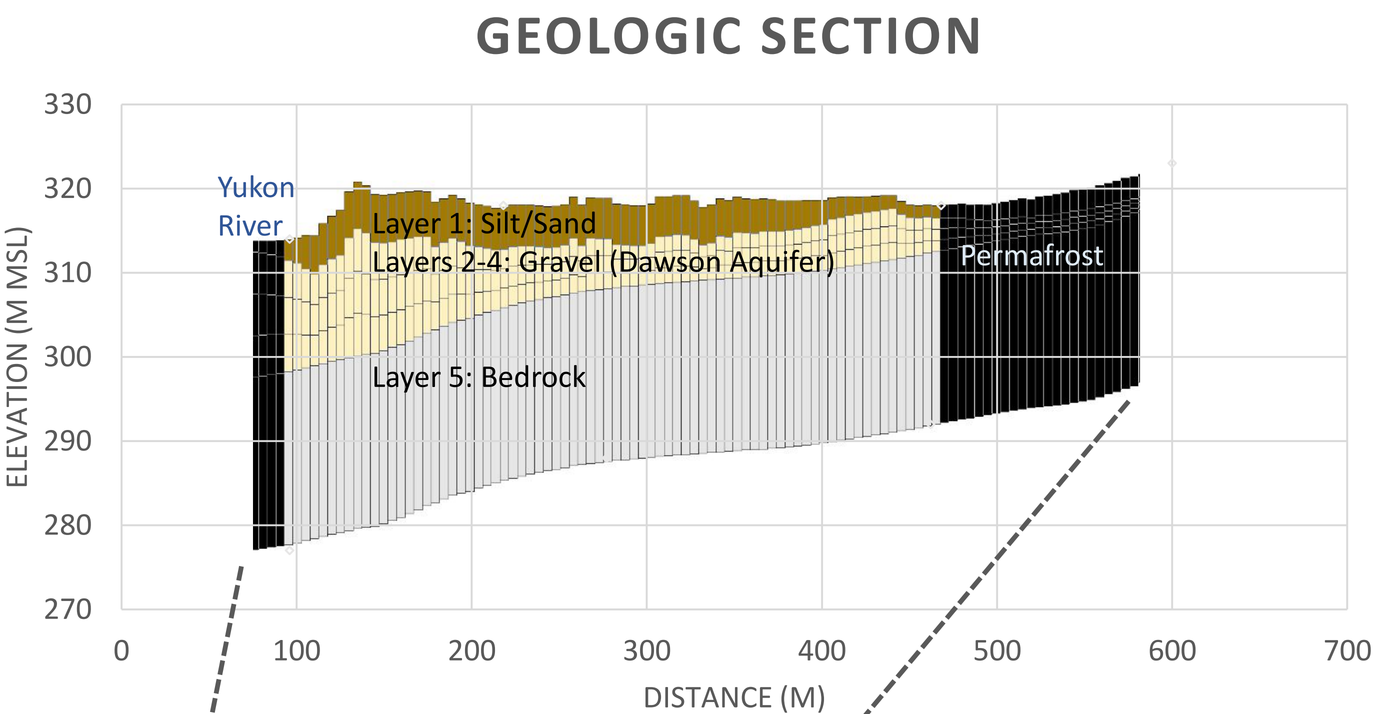
Figure
3



Model Cross-Section at Row 85

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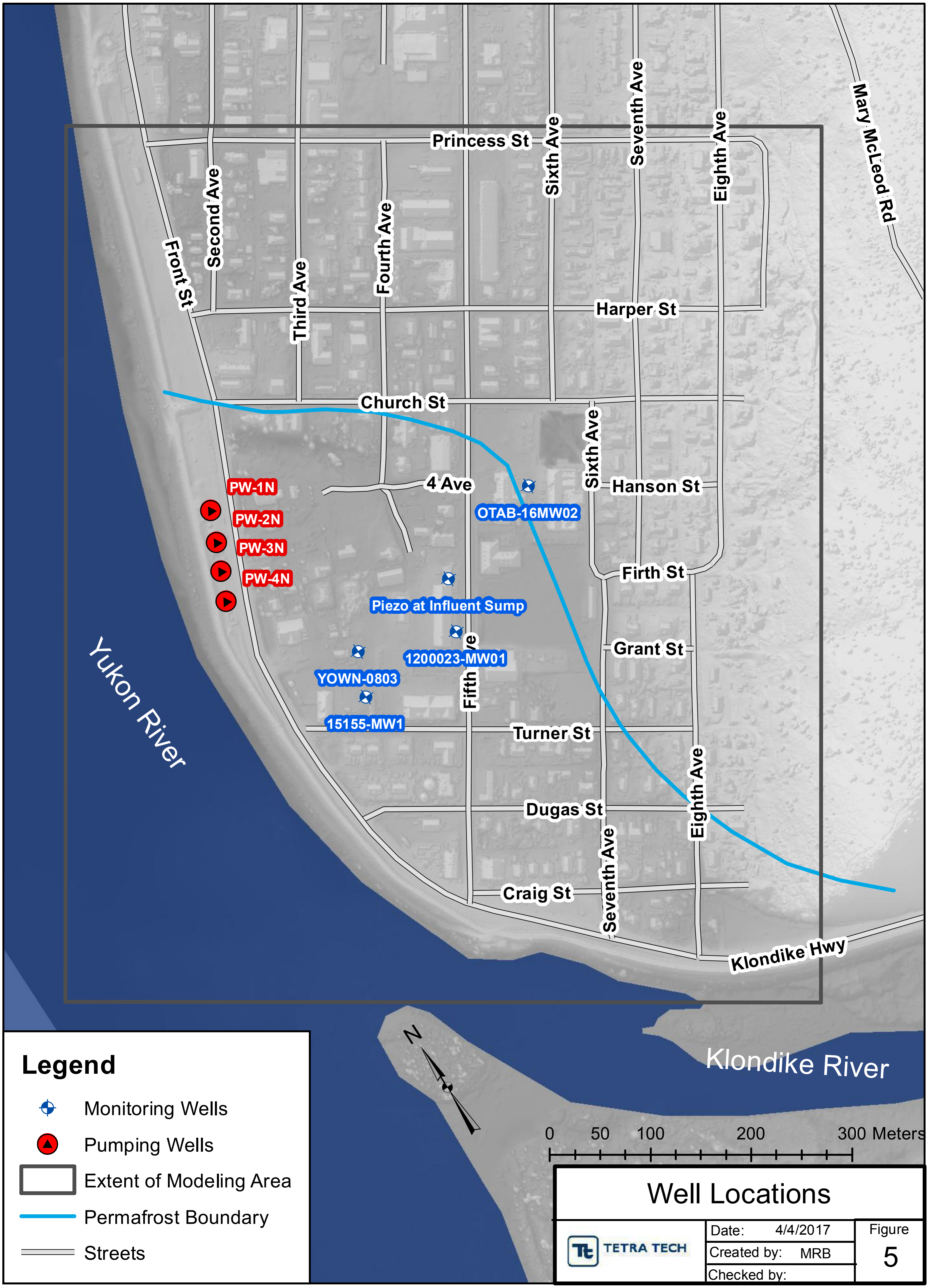
Figure 4



Well Locations

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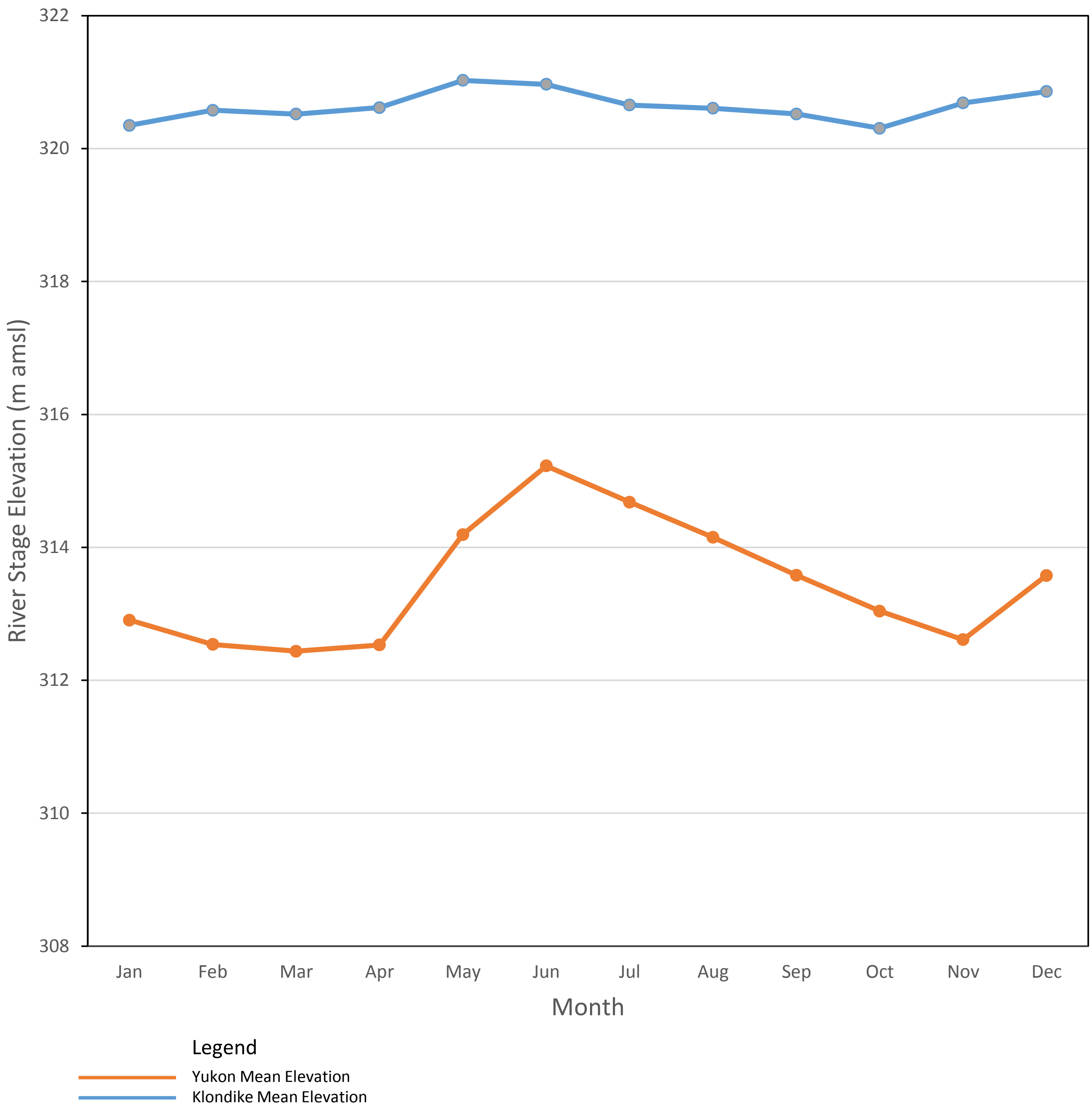

Note:
Yukon River Station (YT09EB001)
approximately 1.6 km downstream of PW-4N.

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

Average Monthly River Stages

TETRA TECH

Date: 03/23/17

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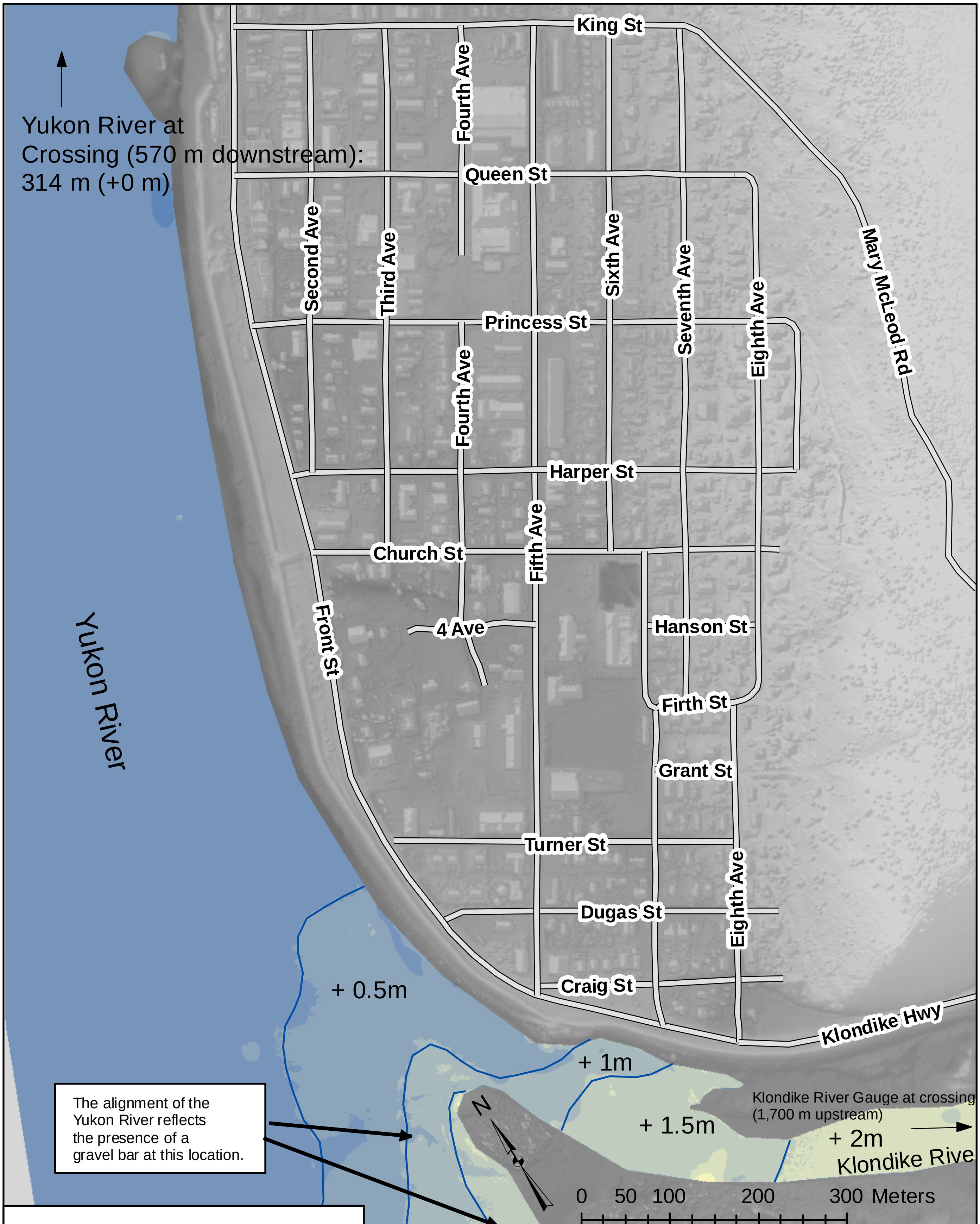
Figure
6



Surface Water Gradient

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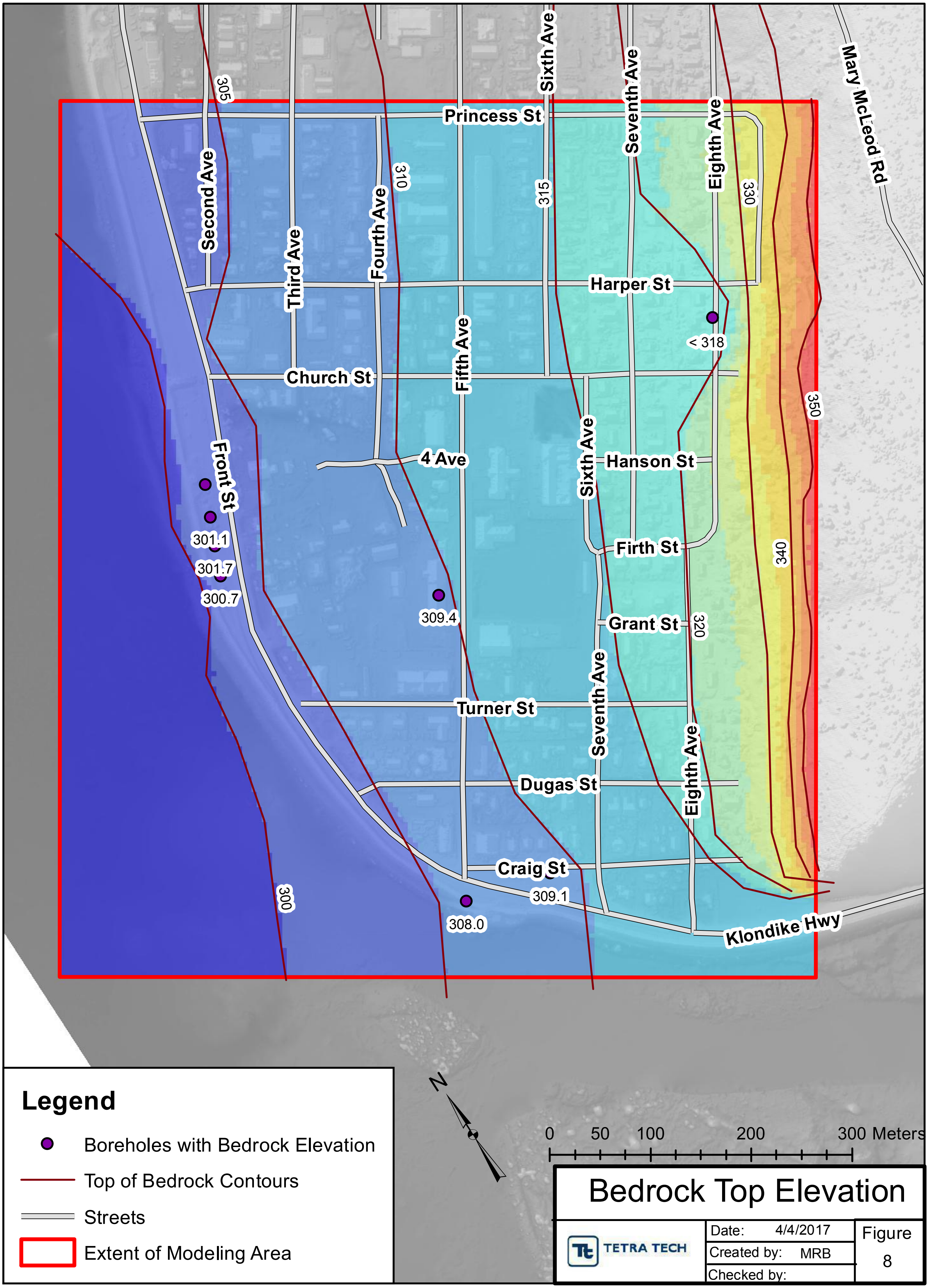

Bedrock Top Elevation

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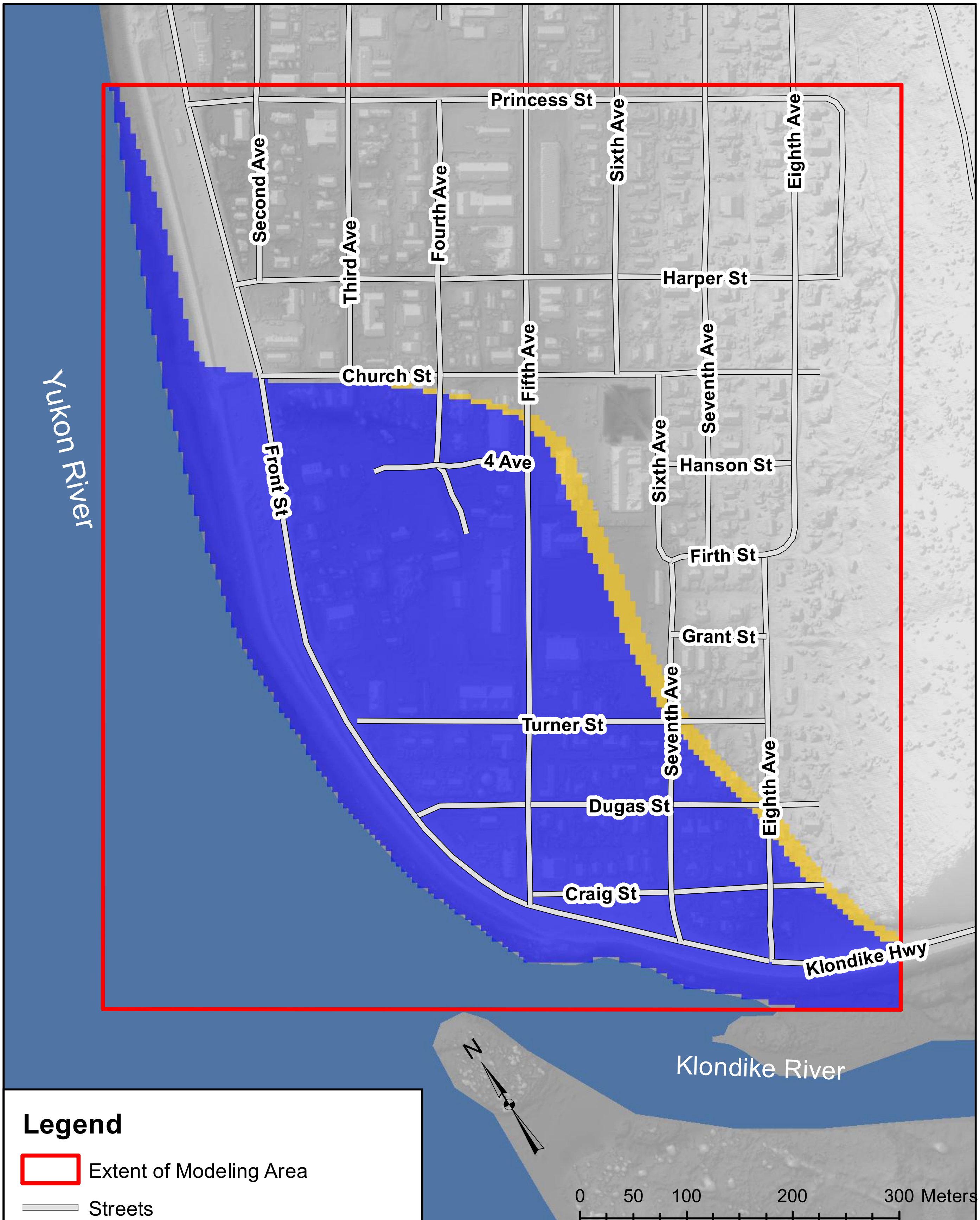
Figure 8



Legend

Extent of Modeling Area

Streets

Recharge Zones

Surface runoff-enhanced recharge

Recharge from precipitation only

Recharge Distribution

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Date: 4/4/2017	Figure 9
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Observed Water Table

Figure 10

Legend

- Residual at Observation Well
- Simulated Water Level Elevation
- Extent of Modeling Area
- Streets
- Permafrost Boundary

Simulated Water Table		
TETRA TECH	Date: 4/5/2017 Created by: MRB Checked by:	Figure 11

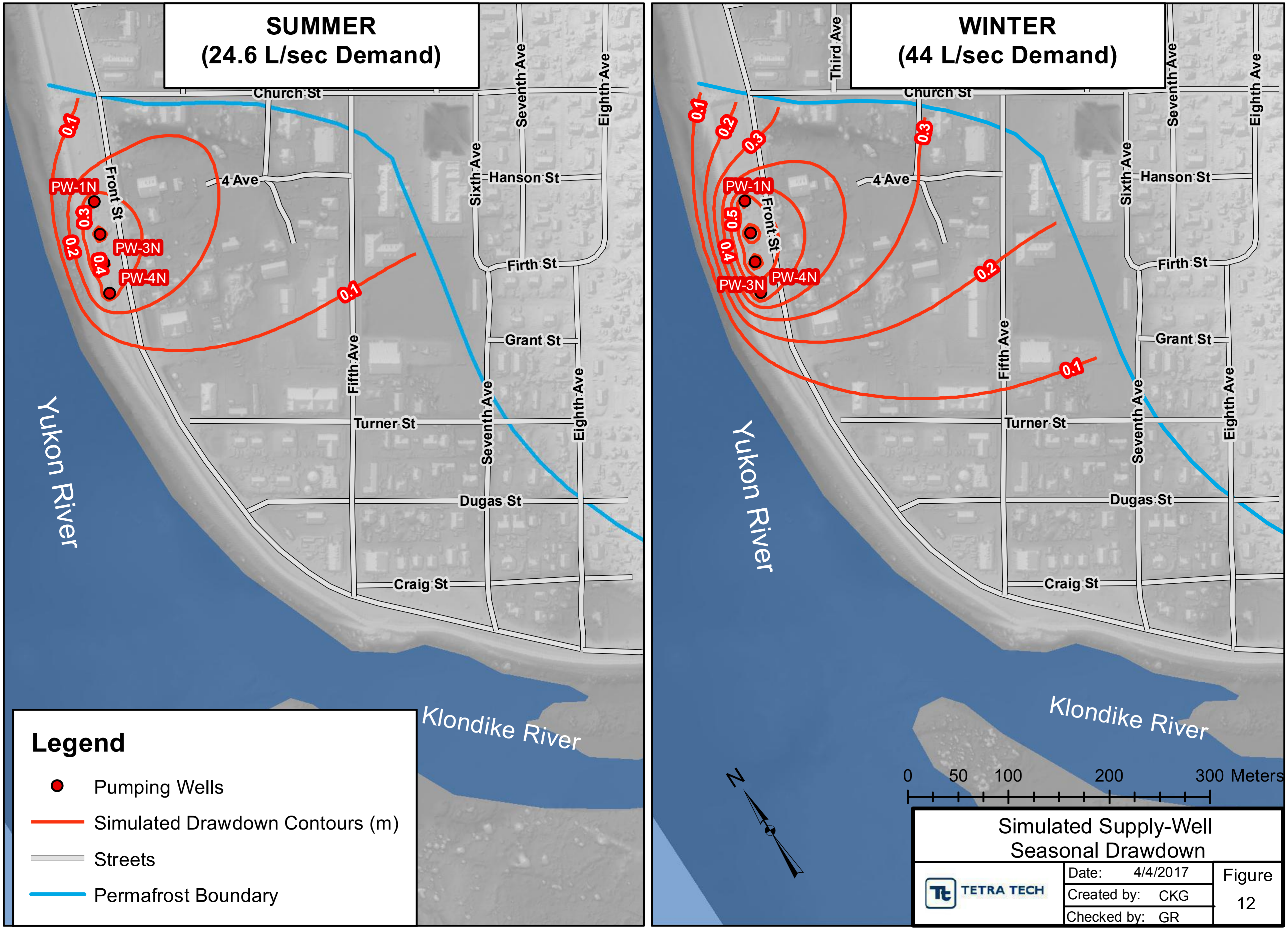
SUMMER
(24.6 L/sec Demand)
WINTER
(44 L/sec Demand)
Church St
Front St
Third Ave
4 Ave
Fifth Ave
Sixth Ave
Seventh Ave
Eighth Ave
Hanson St
Firth St
Grant St
Turner St
Dugas St
Craig St
Yukon River
Klondike River
PW-1N
PW-3N
PW-4N
0.1
0.2
0.3
0.4
0.5
Legend
Pumping Wells
Simulated Drawdown Contours (m)
Streets
Permafrost Boundary
N
0
50
100
200
300 Meters
Simulated Supply-Well
Seasonal Drawdown
TETRA TECH
Date: 4/4/2017
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Figure
12

Princess St
Harper St
Church St
Hanson St
Firth St
Grant St
Turner St
Dugas St
Craig St
Klondike Hwy
Front St
Second Ave
Third Ave
Fourth Ave
Fifth Ave
Sixth Ave
Seventh Ave
Eighth Ave
Mary McLeod Rd
4 Ave
Permafrost Boundary
PW-1N
PW-2N
PW-3N
PW-4N
Yukon River
Klondike River
N
0 50 100 200 300 Meters
Legend
90-day Capture Zone
Pumping Wells
Streets
Extent of Modeling Area
Well Capture (90 days)
TETRA TECH
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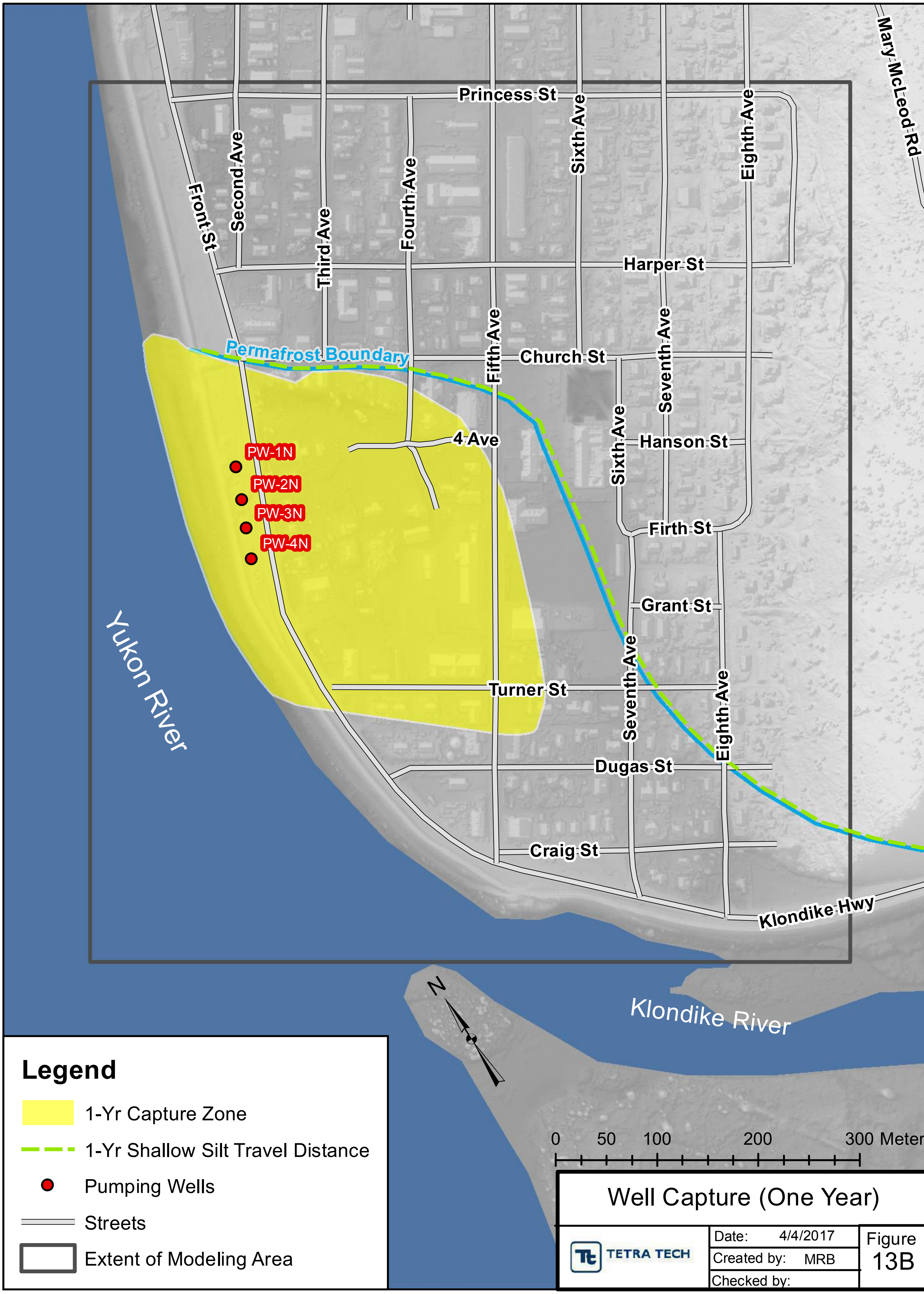
Figure 13A



Princess St
Sixth Ave
Eighth Ave
Mary McLeod Rd
Front St
Second Ave
Third Ave
Fourth Ave
Harper St
Fifth Ave
Seventh Ave
Permafrost Boundary
Church St
4 Ave
Hanson St
Sixth Ave
PW-1N
PW-2N
PW-3N
PW-4N
Firth St
Grant St
Yukon River
Turner St
Seventh Ave
Eighth Ave
Dugas St
Craig St
Klondike Hwy
N
Klondike River
Legend
1-Yr Capture Zone
1-Yr Shallow Silt Travel Distance
Pumping Wells
Streets
Extent of Modeling Area
0 50 100 200 300 Meters
Well Capture (One Year)
TETRA TECH
Date: 4/4/2017
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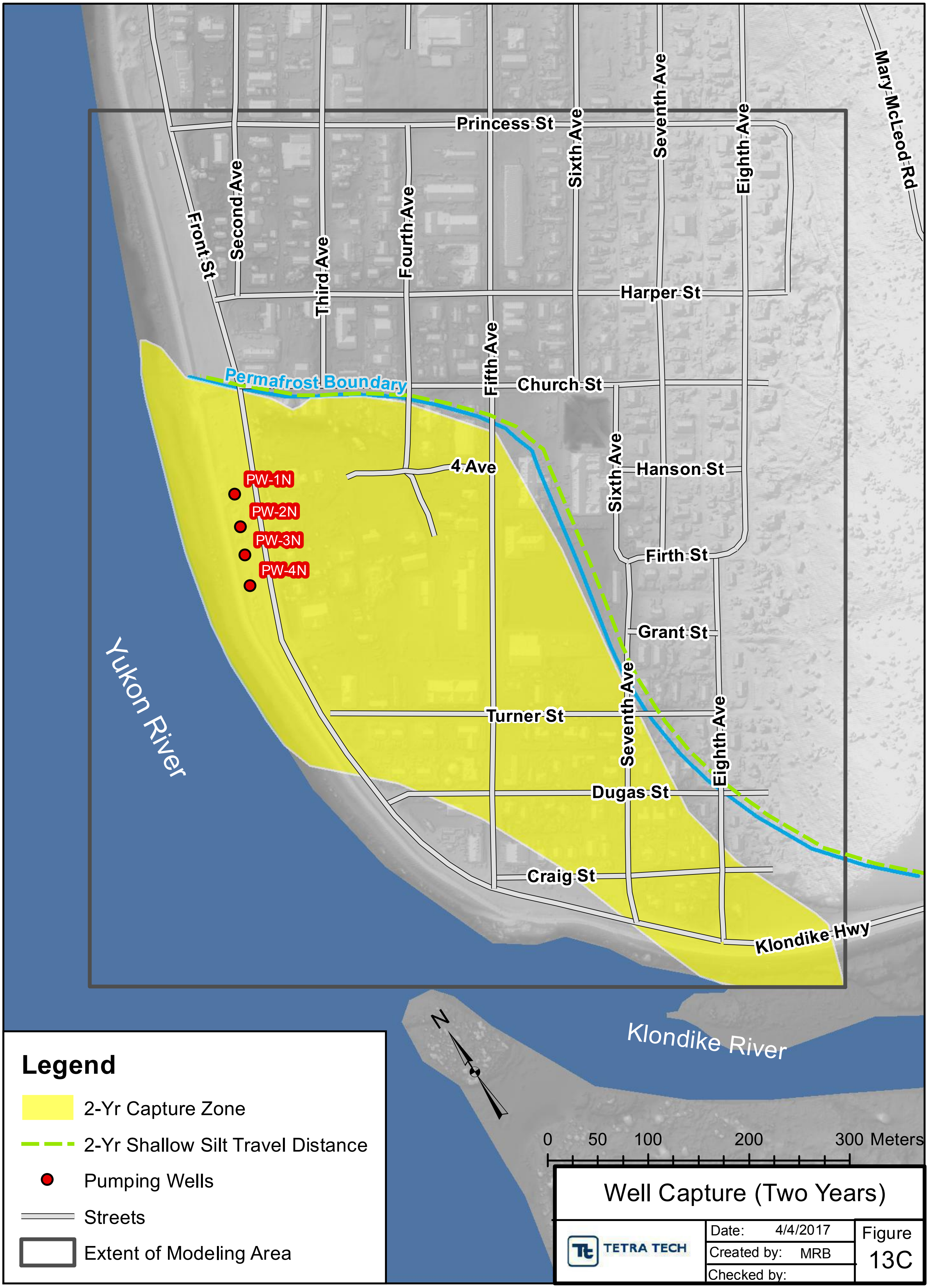
Figure 13B



Princess St
Harper St
Church St
Hanson St
Firth St
Grant St
Turner St
Dugas St
Craig St
Klondike Hwy
4 Ave
Front St
Second Ave
Third Ave
Fourth Ave
Fifth Ave
Sixth Ave
Seventh Ave
Eighth Ave
Mary McLeod Rd
Permafrost Boundary
PW-1N
PW-2N
PW-3N
PW-4N
Yukon River
Klondike River
N
0
50
100
200
300 Meters
Legend
2-Yr Capture Zone
2-Yr Shallow Silt Travel Distance
Pumping Wells
Streets
Extent of Modeling Area
Well Capture (Two Years)
TETRA TECH
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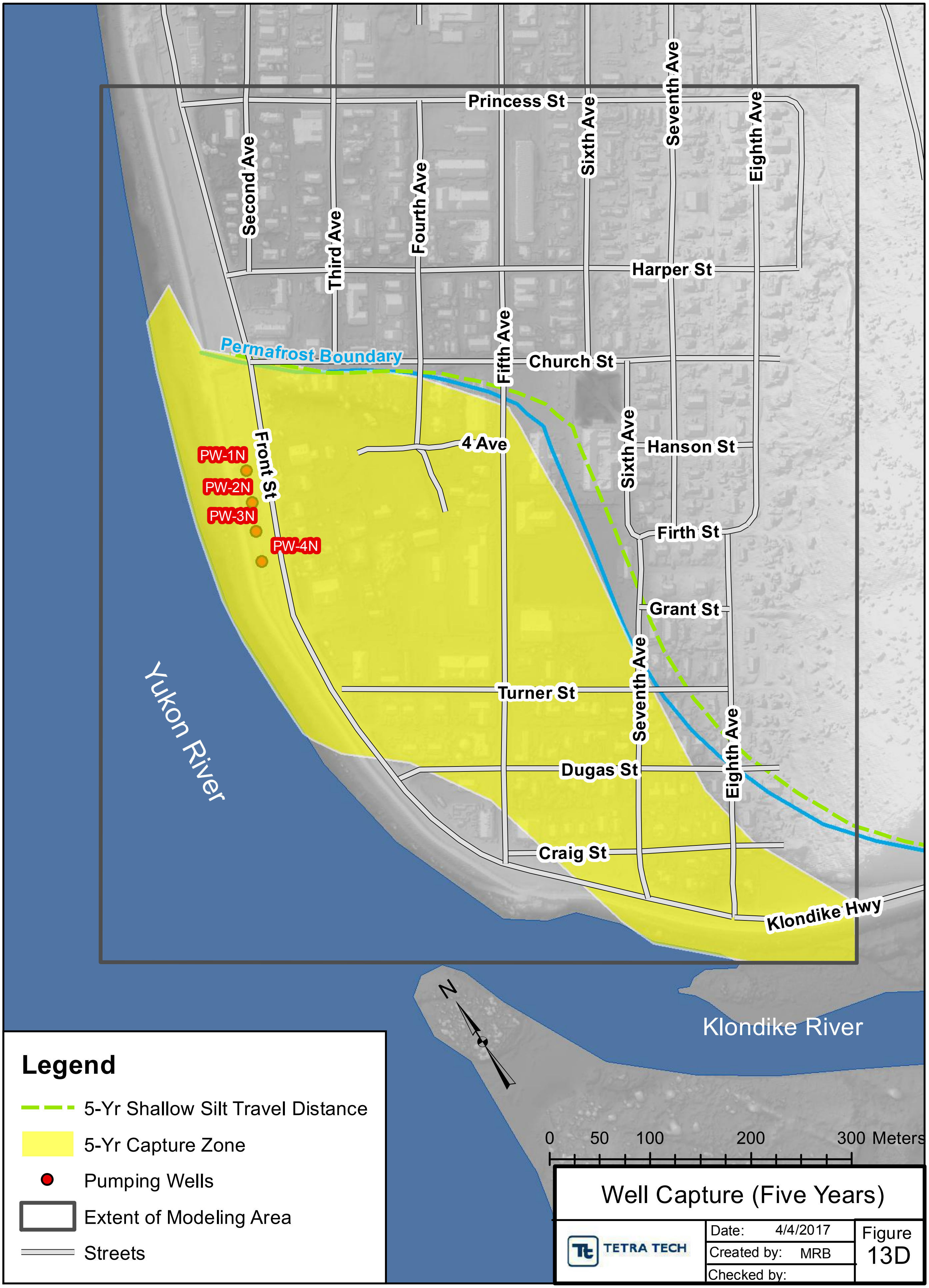
Figure
13C



Well Capture (Five Years)

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Figure 13D

Well Capture (Ten Years)

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Figure 13E