Appendix G Carmacks Conceptual Flood Mitigation Design Options

The contents of this appendix are subject to the project objectives, methods, assumptions, and limitations outlined in the main body of the Yukon Territory Flood Mitigation Conceptual Design Options report and in Appendix T.

G.1 Existing Conditions

The existing conditions presented in this section provide a brief summary of characteristics of the Study Area that are pertinent to the development of mitigation options and their evaluation. The contents of this section are not a comprehensive review of all existing conditions for the Carmacks area.

G.1.1 POPULATION

Carmacks has a population of 588 with 302 private dwellings according to 2021 census data (Statistics Canada 2023c). The population has increased by approximately 19% from 2016 when the population was 493 (Statistics Canada 2023c).

G.1.2 STUDY AREA

The Study Area in Figure G2 outlines the areas that are considered in this Project at Carmacks. The boundaries of the Study Area are based on Stantec's understanding that the flood mitigations are to be designed for communities, and that individual properties outside of the main community consolidation are not included.

G.1.3 FIRST NATIONS

The Carmacks area is within the Traditional Territory of the Little Salmon / Carmacks First Nation (LS/CFN). The LS/CFN have parcels of Category B Settlement Lands and Fee Simple Lands near Carmacks along the Yukon River. The land claim selection is C-1B/D, C-18 FS, C-2B, C-46B, C-5B, and C-40B. This means that LS/CFN has surface ownership of this parcel of land (Government of Yukon 2022). Figure G2 illustrates the LS/CFN settlement lands within the Study Area.

G.1.4 BATHYMETRY AND TOPOGRAPHY

Bathymetry data for the Yukon River and Nordenskiold River were not provided to Stantec.

The following topographic data sources were provided to or obtained by Stantec:

- 2019 LiDAR derivative 1m horizontal resolution Digital Elevation Model (DEM), UTM Zone 8 CSRS NAD1983, CGVD1928 (GeoYukon 2023)

All elevations are reported in CGVD2013. The LiDAR accuracy is assumed to be sufficient for the preliminary flood inundation analysis and conceptual design presented in this Report. There is insufficient metadata to determine whether the LiDAR meets the base requirement in terms of accuracy or precision for flood mapping per NRCan (2022b).

G.1.5 GEOLOGY

Based on the surficial geology mapping (Yukon Geological Survey 2020), the Study Area consists of alluvial deposits of flood plain sediments including gravel to silt size sediments deposited by streams. As per the geology mapping, the floodplain sediments are described as follows: gravel, cobble to pebble size; massive to thick bedded capped by sand and silt; flat lying; includes lacustrine and organic deposits in abandoned channels and backswamp areas subject to periodic inundation and reworking by floods; thickness ranging from 1 to 5 m.

Based on borehole and testpit data provided in the Yukon Permafrost Database (Government of Yukon, 2022b), the soil conditions in the flooding areas within the Carmacks area consist of intermixed layers of silt, sand and gravel to depths exceeding 15 m. Based on the borehole and testpit data reviewed from the Yukon Permafrost Database (Government of Yukon, 2022b) permafrost was not encountered; however, permafrost may be present in the Carmacks area based on the Permafrost Probability Model (Yukon Geological Survey, 2020) and the Canada Permafrost Map (The National Atlas of Canada, 1995). The Permafrost Probability Model suggests the Study Area is located within a region of extensive discontinuous permafrost (40-50% of land underlain by permafrost). The Canada Permafrost Map also indicates that the Study Area is in a region of extensive discontinuous permafrost (50%-90% of land underlain by permafrost) with a low to medium (<10%-20% by volume of visible ice) ground ice content in the upper 10-20 m of the ground. If permafrost is present within the limits of the flood mitigation options, differential settlements of the proposed flood mitigation options may occur and should be further investigated and evaluated in preliminary and detailed designs.

G.1.6 HYDROGEOLOGY

The gravels, sands, and silt encountered within the Study Area are likely to result in relatively fast rates of groundwater flow. The alluvial deposits along the Yukon River encompassing most of the shoreline are likely to result in a groundwater table that would be highly dependant on the Yukon River levels. During flooding, the high river levels would result in high groundwater levels and after flood waters recede, it is likely that the groundwater levels would recede relatively quickly based on the hydraulic conductivity of the soil conditions in the area.

Based on the anticipated soils in the Study Area, the need for seepage control measures (i.e. seepage cut-off below flood mitigation option, toe drains, sump pits and pumping, sewer system inflow and infiltration reduction strategies, etc.) may be required for the proposed flood mitigation options and should be further evaluated in preliminary and detailed designs.

G.1.7 PAST FLOODING EVENTS AND RESPONSE

A summary of documented flood events is provided below. The flood events summarized below do not represent a comprehensive review of flooding history in the Study Area; rather, they are a summary of the flooding documentation provided to Stantec at the time of writing.

2000 Flood Event

Localized flooding occurred in late-November 2000 during freeze-up on the Nordenskiold River (YG, 2000). Ice along the river was noted to have caused the deflection of flow toward low-lying

properties. In response, the local emergency coordination group constructed a 1 m high by 300 m long sandbag berm along the Nordenskiold River and pumping of groundwater from the cellar of one property in the industrial area (YG, 2000). A local state of emergency was not declared, and the Yukon Emergency Coordination Group was not required. Flows were diverted away from the berm and properties a few days later, and no damage to infrastructure was noted.

2008 Flood Event

Localized flash flooding was noted in the Carmacks area in late-August 2008 when more than 40 mm of precipitation fell during a two-day period (YG 2008). Flooding caused blocked culverts and water to flow across the North Klondike Highway south of Carmacks. The highway was intermittently closed to allow for the installation of two culverts to convey water under the highway. No infrastructure damage was noted in the community.

2021 & 2022 Flood Events

Severe flooding occurred in the Carmacks area in late spring of 2021 and 2022. The severe flooding was largely attributed to high snowpack accumulation in south/central Yukon over the winter of 2020–2021 and 2021-2022, combined with a cool and wet spring that delayed snowmelt. For 2021 in particular, warm temperatures in late-June resulted in rapid melting of the snowpack and record inflows to the local water systems. Flood defense construction was ongoing from late June through mid-July, and included temporary superbag and sandbag dikes on River Road. WSC Station 09AH001 (Yukon River at Carmacks) indicates that the daily WSE during the 2021 and 2022 flood events at Carmacks peaked at 521.93 m (June 28, 2021) and 522.35 m (July 1, 2022), respectively, at the WSC station, (GoC 2023).

While not related directly to overland flooding, one of the major challenges experienced by Carmacks was infiltration into its wastewater pipe network from elevated groundwater. The elevated groundwater is likely correlated with elevated WSEs in the Yukon River. The additional flows entering the wastewater pipe network resulted in wastewater inflows that far exceeded the plant capacity. Adaptive management during the high groundwater conditions were able to keep the plant operational in both 2021 and 2022, however the issue has not been resolved and is likely to re-occur if elevated groundwater conditions are encountered again in the future.

G.1.8 EXISTING FLOOD MITIGATION INFRASTRUCTURE

Carmacks currently has no existing permanent flood mitigation infrastructure documented within the Study Area.

G.1.9 WIND, WAVES, AND EROSION

While floodplain mapping and associated hydraulic modelling of the DFSL has not been completed for Carmacks to date, it is likely that flow velocities in the Yukon River during flood conditions would require some flood mitigations to include erosion mitigation on the river side. In addition, bank erosion and river migration should be studied and considered in preliminary and detailed design phases of flood mitigations.

Wind and wave effects are not anticipated to occur at a scale which would require additional flood mitigation design at Carmacks.

G.1.10 HYDROLOGY

There are two rivers in the Carmacks Study Area: the Yukon River and the Nordenskiold River (Figure G2).

Yukon River

The Yukon River is the larger of the two rivers in Carmacks. The Yukon River conveys snowmelt, rainfall induced runoff, and glacier melt from southern Yukon and northern British Columbia northwards into Alaska and eventually the Bering Sea.

WSC Station 09AH001 (Yukon River at Carmacks) is located on the south side of the Yukon River bridge, at the upstream end of Carmacks developed areas (Figure G2) and has a gross drainage area of 81,800 km^2 (GoC 2023). Hydraulic modelling has not been completed to date for the Study Area and is beyond the scope of this Project. Therefore, hydrology review for the Yukon River considered WSEs but not the discharges at WSC Station 09AH001.

Flood frequency analysis for WSEs was performed by both Morrison Hershfield (2022) and Yukon University (2022) for WSEs at WSC Station 09AH001. Table G1 summarizes the frequency results of these two studies.

Table G1 Flood Frequency Analyses at WSC Station 09AH001 from Morrison Hershfield (2022) and Yukon University (2022)

	Morrison Hershfield (2022)	Yukon University (2022)
Years Included in Analysis	1969–1995;2015–2022	1970–2022 [a]
Number of Years	35	53
Selected Distribution	Lognormal 3	Combination of Log-Pearson Type 3 (Freeze-up Jams data) and Gumbel (Breakup ice jams) and average of the two distributions (open water freshet)
Water Surface Elevation (m) [1]		
1:2-year Event (50% AEP)	520.29	520.90
1:20-year Event (5% AEP)	521.57	521.90
1:100-year Event (1% AEP)	522.26	not provided
1:200-year Event (0.5% AEP)	522.54	522.90

Notes:
[a] Gap between 1996 and 2015 partially filled using Teslin Lake data
[1] Elevations provided in CGVD2013 for WSC Station 09AH001

The Yukon University (2022) flood frequency analysis results were adopted for the Project because the 1:200-year event WSE was higher and would yield more conservative conceptual designs.

Figure G1 illustrates the daily minimum, mean, and maximum WSEs, the WSE during the highest year on record (2022), and the WSEs for the 1:2-year and 1:200-year event at WSC Station 09AH001 from Yukon University (2022). While breakup ice jams are possible in the Yukon River and could cause flooding at Carmacks, high open water flows have shown to be the main process for flooding in the Yukon River at Carmacks (Yukon University 2022). Flows in the Yukon River at Carmacks are heavily influenced by Teslin River contributions, as contributions from the Yukon River upstream of the Teslin River/Yukon River confluence are attenuated by the storage effects of upstream lakes (Lake Laberge, Southern Lakes) and the flow limiting effects of Miles Canyon.

As illustrated in Figure G1, water levels in the Yukon River at Carmacks typically begin to rise in mid-May with the onset of freshet and increase late-June/early-July. Water levels typically decrease through the remainder of July and into August. Based on the available data and the documented flood processes at Carmacks, flood conditions in the Yukon River at Carmacks may generally be expected to persist for 3-4 weeks sometime in late-June/early-July.

Nordenskiold River

The Nordenskiold River is the smaller of the two rivers in Carmacks. The Nordenskiold River conveys snowmelt and rainfall induced runoff from its drainage basin south of Carmacks.

WSC Station 09AH004 (Nordenskiold River Below Rowlinson Creek) is located approximately 8 km upstream (south) of the Nordenskiold River bridge in Carmacks and has a gross drainage area of approximately 6,410 km^2 (GoC 2023). The Nordenskiold River at the WSC station demonstrates seasonally high-water levels associated with spring freshet in May through early June. Flood processes on the Nordenskiold have been documented as being different within the Study Area (breakup ice jam driven) than at the WSC station (open water or freeze-up ice jam driven) (WSP 2018; Turcotte et al. 2021). Therefore, flood frequency data for WSC Station 09AH004 are not directly relevant for this Project without ice jam hydraulic modelling.

Turcotte et al. (2021) provided estimates for 1:200-year WSEs within the Study Area accounting for the breakup ice jam flood processes observed in the Nordenskiold River in the Study Reach. The 1:200-year estimates produced by Turcotte et al. (2021) were 523.7 m (in CGVD2013) at the River Drive and 521.8 (in CGVD2013) at the confluence of the Nordenskiold River and Yukon River (approximately 1080 m apart, straight-line slope of 0.18%). A non-linear relationship was used to model the water surface elevations between these two locations by Turcotte et al. (2021). Turcotte et al. (2021) notes the uncertainty and sensitivity in the completed ice jam assessment.

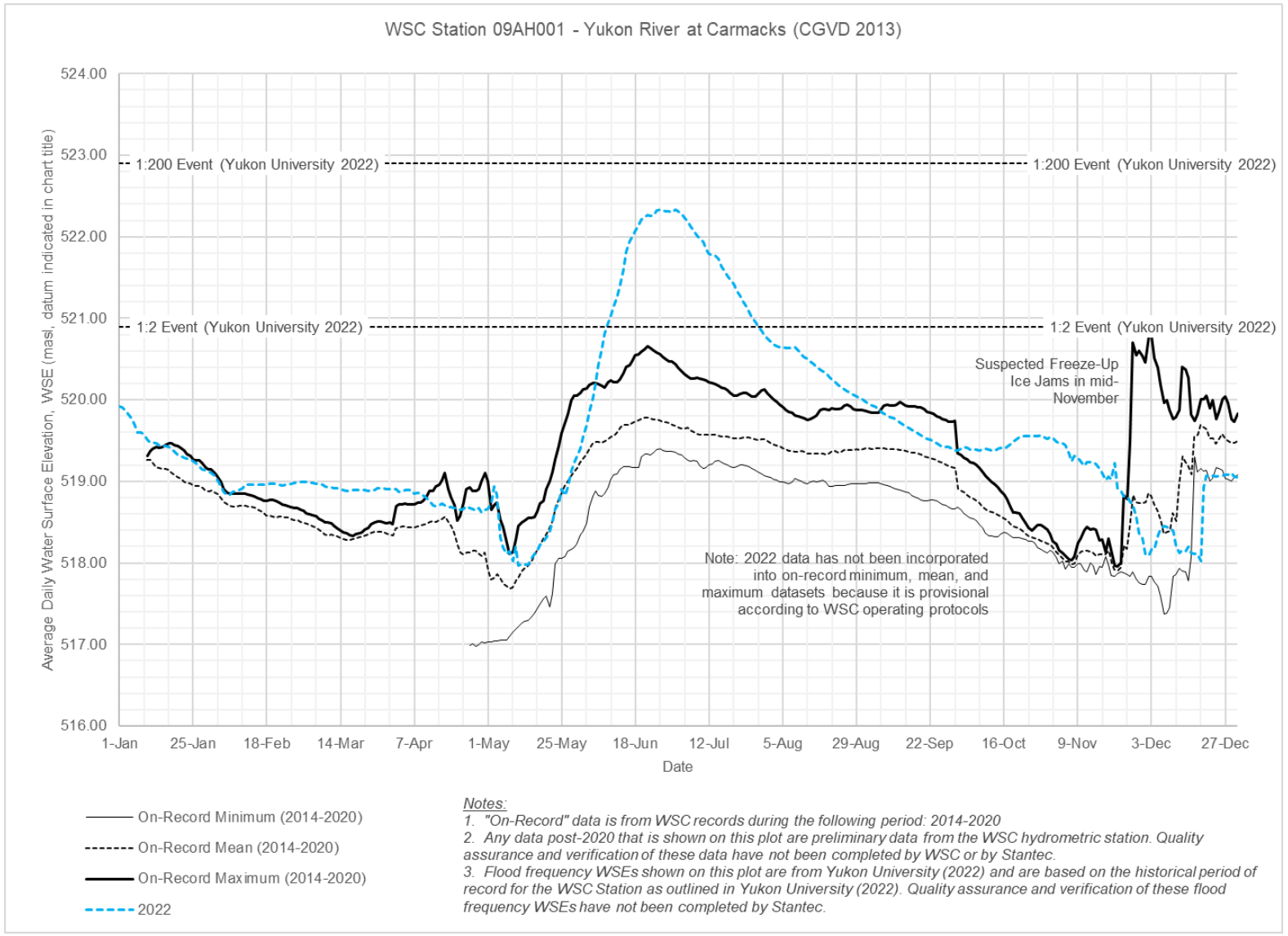


Figure G1 Historical Water Surface Elevations at WSC 09AH001 (Yukon River at Carmacks)

The contents of this appendix are subject to the project objectives, methods, assumptions, and limitations outlined in the main body of the Yukon Territory Flood Mitigation Conceptual Design Options report and in Appendix T.

G.1.11 PRELIMINARY INUNDATION MAPPING

Floodplain mapping and the associated flood policy is ultimately what is required for design and implementation of flood mitigations at communities. Hydraulic analysis and floodplain mapping have not been completed to date at Carmacks and is not within the scope of this Project. Stantec (2019) performed a flood risk study for a proposed cultural centre location upstream of the Klondike Highway bridge, however that study focused on the site of interest (not the community at large) and considered the 1:100-year event. An understanding of inundation extents under 1:200-year event is generally required for conceptual design of flood mitigations in this Project.

In lieu of floodplain mapping, Stantec performed preliminary existing conditions (no mitigation) inundation analysis for Carmacks using WSEs. This analysis combined the preliminary inundation at each of the main rivers in the Study Reach:

- The 1:200-year event WSE (522.90 m) at WSC Station 09AH001 from Yukon University (2022) and an assumed WSE slope of 0.05% downstream of the Klondike Highway bridge and 0.03% upstream of the Klondike Highway bridge (based on survey from Underhill 2022).
- The 1:200-year event WSE (523.7 m) at the River Drive bridge and an assumed WSE slope of approximately 0.18% on the Nordenskiold River. The straight-line slope was estimated using the WSEs from Turcotte et al. (2021) at River Drive bridge and the confluence with the Yukon River. The use of straight-line slope provides a conservative estimate of the WSEs compared to the non-linear approach used by Turcotte et al. (2021).

The resulting water surface at each river was overlain on the existing conditions topographic/bathymetric elevation data (GeoYukon 2023) and the limits of inundation were mapped. The outer boundary of the combined inundation (Yukon and Nordenskiold Rivers) was adopted as the overall preliminary inundation for the Study Area (Figure G2). The preliminary inundation analysis does not take into account flow pathways and blockages. That is, if the land in a given location is below the 1:200 WSE surface, it presents as inundated whether or not there is an overland flow path for the water to arrive there. The inundation analysis performed herein is provided for information only and is considered a high-level estimate of the flood inundation using the 1:200-year WSE estimates from Yukon University (2022) and Turcotte et al. (2021).

North of the Klondike Highway bridge, the preliminary inundation results approximately 460 m of the Klondike Highway being overtopped. On the south side of the Klondike Highway bridge crossing along River Drive, the preliminary inundation encroaches on the boat launch area and properties toward the west end of the road. Approximately 1500 m of River Drive to the west end of the community is inundated; this would restrict access to residences to the north and south of the Nordenskiold River. The inside of the meander at the mouth of the Nordenskiold River is nearly entirely inundated, including two private properties. On the north side of the Yukon River, inundation encroaches on the LS/CFN development.

The preliminary inundation analysis indicated that an estimated 15 private residence properties (13 in the LS/CFN development and 2 along the Nordenskiold River) and 2 major community feature/property (River Road in 2 locations, Klondike Highway) would have at least 25% of their area inundated and classify as “inundated properties”.

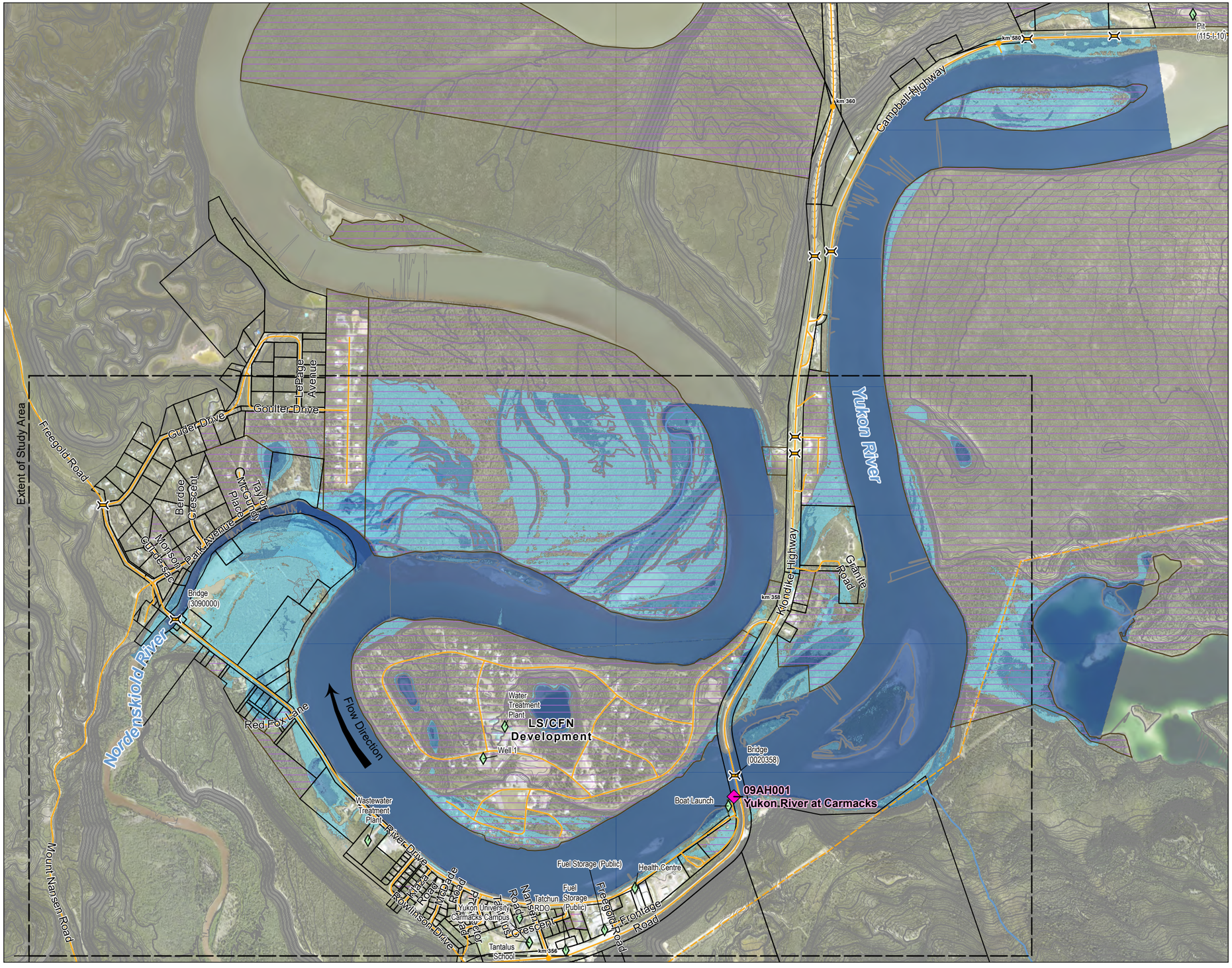


Figure No.

G2

Title

Existing Conditions and Preliminary Flood Inundation at Carmacks

Client/Project

144903232

Government of Yukon
Community Services | Infrastructure Development Branch
Yukon Territory Flood Mitigation Conceptual Design Options

Project Location

Carmacks, Yukon

Prepared by LLT on 2023-05-08
TR by JM on 2023-05-08

N

0 5 10 15 20 m

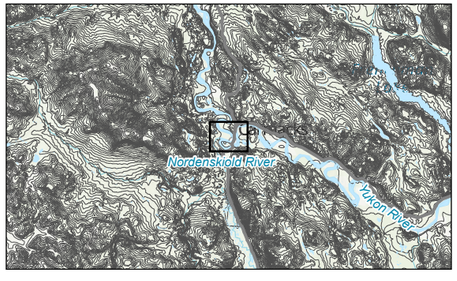
(At original document size of 11x17)
1:30,000

- WSC Station
- Culvert/ Bridge
- Community Infrastructure and Points of Interest
- Highway Kilometre Post
- Road
- Powerline
- Topographic Contour (10 m)
- Topographic Contour (2 m)
- Land Parcel - Surveyed
- First Nation Settlement Lands - Surveyed

Water Depth at 1:200 WSE Inundation (m)

- 0 - 1
- 1 - 2
- > 2

The preliminary inundation analysis does not take into account flow pathways and blockages. That is, if the land in a given location is below the 1:200 WSE surface, it presents as inundated whether or not there is an overland flow path for the water to arrive there.



Notes

1. Coordinate System: NAD 1983 Yukon Albers
2. Data Sources: Government of Yukon; Government of Canada
3. Imagery Government of Yukon Geomatics Yukon; ESRI World Imagery

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Yukon

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G.2 Mitigation Options and Evaluation

The scope of this Project is to develop conceptual engineered flood mitigation options; these options for Carmacks are presented in this section. Non-engineered options presented in Section 3.3.1 of the main body of this Report (emergency response-based, mitigation funding to property owners, land purchase/exchange, regulation of flow, management of ice, nature-based approaches) should be considered as part of a comprehensive approach to flood mitigation in the Yukon.

Areas which are above the 1:200-year WSE in the preliminary inundation analysis but below the DFSL are not included in this Project. These areas may need to be included in future design advancements depending on the requirements of future territorial flood policy.

Based on the objectives and assumptions presented in the main body of this Report, two flood mitigation options were developed for Carmacks (Table G2) using combinations of the typical engineered flood mitigation designs from Section 3.3.2. Flood mitigations in the two options are provided for areas which are inundated under the 1:200-year WSE (522.90 m) in the preliminary inundation mapping (Figure G2). The top elevation of the flood mitigations is designed to reach the DFSL which in the case of Carmacks (river site) is assumed to be 523.40 m (i.e., 0.5 m above the 1:200-year WSE as outlined for river sites in Section 3.2).

Table G2 Summary of Conceptual Design Options

Location	Option 1	Option 2
	lower capital costs, higher response/maintenance	*higher capital costs, lower response/maintenance*
Klondike Highway North of Bridge	Platform with Temporary Superbag Dike	Road Raising (Potentially with Floodplain Culverts)
River Drive Near Boat Launch	Road Raising	
River Drive West Section	Platform with Temporary Superbag Dike	Road Raising
LS/CFN Development	Platform with Temporary Superbag Dike	Structural Dike
Private Properties Along Nordenskiold River	Temporary Sandbag Dikes	

Sections G.2.1 and G.2.2 provide a description, Class D costing, and qualitative evaluation of conceptual options specified in Table G2.

Other engineered flood mitigation approaches that may have merit but were not advanced to conceptual design in this Project include:

- Rerouting the Yukon River to a new channel alignment north of Carmacks to bypass the main part of the community. This option not advanced due to river destabilization risks, permitting requirements, and anticipated high cost.

G.2.1 OPTION 1

Description

The conceptual flood mitigations for Option 1 are illustrated in Figure G3.

Approximately 260 m of the Klondike Highway would have a temporary double superbag dike established on the east side of the highway (upstream side of the Yukon River). It is assumed that traffic control would not be needed given that the temporary superbag dike would be only on one side of the highway.

An approximately 400 m long segment of River Drive from the south abutment of the Yukon River Bridge to immediately west of the Carmacks Health Center (near the boat launch) would be permanently raised. The height of raise from existing ground would be 0.5 – 1.0 m to reach the DFSL. Permanent flood mitigation would be provided at this location under Option 1 because past flood responses have indicated this location is an emergency access point to the Yukon River for rescue operations. Riprap of adequate size would be required on the outer bank to mitigate erosion and ice damage hazards.

An approximately 1500 m segment of River Drive (from McDade Road to 270 River Drive) would function as a platform for a single temporary superbag dike to reach the DFSL during flood conditions. No raising of the existing road would be required.

On the north side of the Klondike Highway bridge at the LS/CFN subdivision, a 740 m long platform would extend along the river to provide flood mitigation for the residential properties. The platform would require raising of up to 0.5 m above the existing ground and would require a single temporary superbag dike to reach the DFSL during flood conditions. The platform footprint would encroach on multiple properties along the bank and slope stabilization measures may be required due to the topography of the riverbank and the added weight of fill and superbags along the top of bank.

Three individual properties located in the floodplain of the Nordenskiold River at the west end of River Drive would require temporary sandbag dikes around the structures during flood conditions. The depth of flooding around these properties is estimated to be less than 2 m and as such can be protected with the construction of sandbag dikes. The temporary sandbag dikes would be up to 2 m high to meet the DFSL with a total length of approximately 550 m.

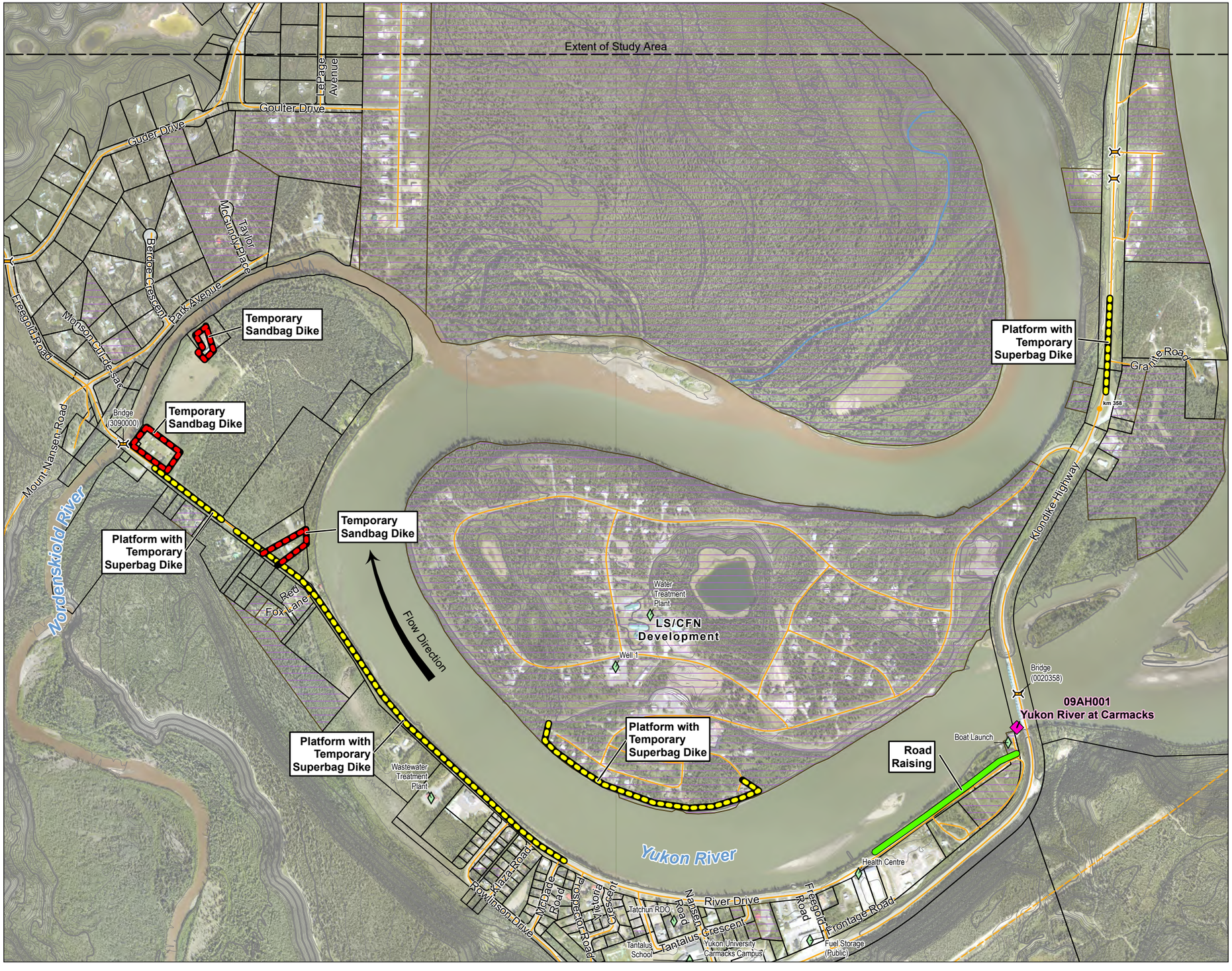


Figure No.

G3

Title

Carmacks Conceptual Flood Mitigation Design - Option 1

Client/Project 144903232

Government of Yukon
Community Services | Infrastructure Development Branch
Yukon Territory Flood Mitigation Conceptual Design Options

Project Location
Carmacks, Yukon

Prepared by LLT on 2023-08-18
TR by JM on 2023-08-18

N

0 50 100 150 200 m

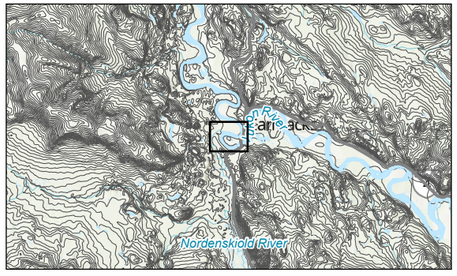
(At original document size of 11x17)
1:30,000

- WSC Station
- Culvert/ Bridge
- Community Infrastructure and Points of Interest
- Highway Kilometre Post
- Road
- Powerline
- Topographic Contour (10 m)
- Topographic Contour (2 m)
- Land Parcel - Surveyed
- First Nation Settlement Lands - Surveyed

Proposed Mitigation Feature

- Earthen Dike
- Platform with Temporary Superbag Dike
- Road Raising
- Structural Dike
- Temporary Sandbag Dike

CONCEPTUAL DESIGN
This document is for general information only and is not for permits, tendering, or construction.



Notes
1. Coordinate System: NAD 1983 Yukon Albers
2. Data Sources: Government of Yukon; Government of Canada
3. Imagery Government of Yukon Geomatics Yukon; ESRI World Imagery

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Class D OPC

The Class D OPC's for capital and annual costs are summarized in Table G3, considering the Class D level of accuracy (+/-50%). Table G3 also provides the Class D OPCs on a per inundated property basis (from Section G.1.11).

Table G3 Option 1 Summary of Class D OPCs

	Class D OPC	Number of Inundated Properties (Section G.1.11) [1,2]	Class D OPC per Inundated Property [1]
Capital Cost	$ 11,826,500 - $ 17,739,750	17	$ 695,677 - $ 1,043,515
Annual Cost (Flood Year)	$ 2,688,800 - $ 4,033,200		$ 158,165 - $ 237,248
Annual Cost (Non-Flood Year)	$ 26,400 - $ 39,600		$ 1,553 - $ 2,330

[1] As described in Section G.1.11, the inundated properties from the preliminary inundation analysis consists of 15 private residences and 2 major community features.
[2] A substantial number of additional residential properties (not counted in the 16 inundated properties) north of the Nordenskiold River bridge would have access preserved by flood mitigations on River Drive.

The components, assumed unit costs, and estimated quantities which produce the Class D OPCs are detailed in Table G4 (capital costs), Table G5 (annual cost, flood year), and Table G6 (annual cost, non-flood year).

Table G4 Option 1 Capital Costs Class D OPC

Item No.		Description of Work	Units	Qty.	Unit Price	Amount
Section 1A		**Option 1: General Conditions**				
	a)	Mobilization/Demobilization	LS	1	$543,160.00	$543,160.00
	b)	Site Preparation/Restoration	LS	1	$108,700.00	$108,700.00
					Total 1A	$651,860.00
Section 1B		**Option 1: Earthworks & Landscaping, Platform (LS/CFN)**				
	a)	Clearing and Grubbing	M2	11080.00	$10.00	$110,800.00
	b)	Topsoil Stripping and Stockpiling, 300mm Depth	M3	3300.00	$25.00	$82,500.00
	c)	Platform Topsoil	M2	4420.00	$20.00	$88,400.00
	d)	Platform Seeding	M2	4420.00	$5.00	$22,100.00
	e)	Geotextile Fabric/Filter Layer	M2	7350.00	$10.00	$73,500.00
	f)	Embankment Fill, Clay Core	M3	440.00	$100.00	$44,000.00
	g)	Embankment Fill, Granular Shell	M3	850.00	$50.00	$42,500.00
	h)	Riprap	MT	8600.00	$141.00	$1,212,600.00
	i)	Seepage Cutoff Wall-Clay, 1m Width	M3	7800.00	$100.00	$780,000.00
	k)	Toe Drain: Perforated Pipe, Geotextile and Drain Rock	M	740	$300.00	$222,000.00
	l)	Slope Stabilization	M	740	$3,000.00	$2,220,000.00
					Total 1B	$4,898,400.00
Section 1C		**Option 1: Floodboxes, Platform (LS/CFN)**				
	a)	Reinforced Concrete Pipe	M	200	$1,000.00	$200,000.00
	b)	Gatewell Manhole c/w Sluice Gate	EA	10	$17,500.00	$175,000.00
	c)	Concrete Headwall	EA	20	$5,000.00	$100,000.00
	d)	Flap Gate	EA	10	$3,000.00	$30,000.00
	e)	Riprap	MT	200	$141.00	$28,200.00
					Total 1C	$533,200.00
Section 1D		**Option 1: Road Raising (River Rd. East)**				
	a)	Rough Grading	M2	6850	$5.00	$34,250.00
	b)	Subgrade Preparation	M2	6850	$5.00	$34,250.00
	c)	80mm Minus Granular Subbase, Variable Depth	M3	6460	$40.00	$258,400.00
	d)	100mm Minus Granular Base, 100mm Depth	M3	450	$50.00	$22,500.00
	e)	BST Surfacing	M2	3750	$50.00	$187,500.00
	f)	Riprap	MT	2270	$141.00	$320,070.00
					Total 1D	$856,970.00

The contents of this appendix are subject to the project objectives, methods, assumptions, and limitations outlined in the main body of the Yukon Territory Flood Mitigation Conceptual Design Options report and in Appendix T.

Contingency (20%)	$1,388,086.00
Subtotal	$8,328,516.00
Location Adjustment Factor (LCAF)	1.42
Capital Costs Base Price	$11,826,500.00
Capital Costs Upper Bound	$17,739,750.00

Table G5 Option 1 Annual Costs During a Flood Year Class D OPC

Item No.	Description of Work	Units	Qty.	Unit Price	Amount
Section 1E	**Option 1: Annual Costs, Flood Year**				
a)	Inspections	LS	1	$100,000.00	$100,000.00
b)	Minor Repairs & Vegetation Management	LS	1	$10,000.00	$10,000.00
c)	Storage of Superbags and Sandbags	LS	1	$500.00	$500.00
d)	Superbags c/w Sandfill (2.0m)	M	2430	$500.00	$1,215,000.00
e)	Sandbags c/w Sandfill (1.0 - 2.0m)	M	544	$464.00	$252,416.00
				Total 1E	$1,577,916.00
				Contingency (20%)	$315,583.20
				Subtotal	$1,893,499.20
				Location Adjustment Factor (LCAF)	1.42
				Annual Cost, Flood Year Base Price	$2,688,800.00
				Annual Cost, Flood Year Upper Bound	$4,033,200.00

Table G6 Option 1 Annual Costs During a Non-Flood Year Class D OPC

Item No.	Description of Work	Units	Qty.	Unit Price	Amount
Section 1F	**Option 1: Annual Costs, Non-Flood Year**				
a)	Inspections	LS	1	$5,000.00	$5,000.00
b)	Minor Repairs & Vegetation Management	LS	1	$10,000.00	$10,000.00
c)	Storage of Superbags and Sandbags	LS	1	$500.00	$500.00
				Total 1F	$15,500.00
				Contingency (20%)	$3,100.00
				Subtotal	$18,600.00
				Location Adjustment Factor (LCAF)	1.42
				Annual Cost, Non-Flood Year Base Price	$26,400.00
				Annual Cost, Non-Flood Year Upper Bound	$39,600.00

The contents of this appendix are subject to the project objectives, methods, assumptions, and limitations outlined in the main body of the Yukon Territory Flood Mitigation Conceptual Design Options report and in Appendix T.

Qualitative Evaluation

Table G7 summarizes the performance of Option 1 with respect to the evaluation criteria which were previously outlined in the main body of this Report.

Table G7 Option 1 Qualitative Evaluation

Criteria No.	Criteria Title	Evaluation	Anticipated Performance Rating
1	Viability and Reliability under Extreme Conditions	moderate flood duration (several weeks); wind/wave impacts minimal; superbags susceptible to damage from high velocities and debris on Yukon River; potential for damage from ice jamming and ice flow may damage temporary sandbag dikes along Nordenskiold; potential for bank erosion; risk of vandalism and degradation risk increases with duration that the temporary dikes are deployed; seepage control measures may be required	Low Performance
2	Time to Implementation	medium regulatory risk; minimal baseline studies required; moderate property owner agreements required; moderate design of the platform and road raising segment required; hydraulic modelling, erosion mitigation and river migration studies required during detailed design.	Medium Performance
3	Capital Cost Per Inundated Property	reduced capital costs in exchange for increased operational and maintenance costs when compared to permanent flood mitigation infrastructure (Option 2); per-inundated-property capital cost is $695,677/property	Medium Performance
4	Maintenance and Storage	storage required for moderate number of superbags and sandbags; stockpiling of material required for superbags/sandbags; platform along north side of river will require inspections, maintenance, and vegetation clearing; floodbox maintenance required	Medium Performance
5	Response and Activation	temporary superbag dikes require training, labour, and a timely response in a flood scenario to be effective; moderate length of temporary superbag dike; property-owner deployed temporary sandbag dikes; floodbox slide gates would need to be manually closed prior to arrival of flood and opened following abatement of the flood	Low Performance
6	Aesthetics and Community Function	minimal change to existing landscape during non-flood conditions; temporary alteration of private/community function during flood conditions from temporary superbag and sandbag dikes	High Performance
7	Future Adaptability	two-high temporary superbag dikes or additional raising of road at boat launch may be completed in future for enhanced flood mitigation; additional sandbags may be provided for raising temporary sandbag dikes; permanent increases in height to platform structure will require engineering study and is likely to require widening of structure	High Performance
8	Alteration of Existing Hydraulics, Erosion/ Sedimentation, Ice Processes, and Slope Stability	temporary superbag dike on Klondike Highway anticipated to have relatively minor/negligible effect on overall flood conveyance of the Yukon River; relatively minor intrusions into Yukon River that are not anticipated to disrupt existing river processes; slope stabilization measures may be required over a length of 0.7 km	Medium Performance
9	Disaster Mitigation and Adaptation Function (DMAF) Applicability	high return on investment (ROI) given the private properties and access routes within the community that would be mitigated from flooding as a result of improvements	High Performance

G.2.2 OPTION 2

Description

The conceptual flood mitigations for Option 2 are illustrated in Figure G4. The main difference between Option 1 and Option 2 is that Option 2 includes permanent flood mitigations (instead of temporary measures) to reach the DFSL.

As with Option 1, the approximately 400 m segment at the east end of River Road would be raised to maintain emergency access to the Yukon River for the RCMP. Raising of River Drive may require slope stabilization measures installed along the riverbank of the Yukon River due to the added weight from the new soil for the raised road. Riprap of adequate size would be required on the outer bank to mitigate erosion and ice damage hazards.

Approximately 260 m of the Klondike Highway north of the bridge would be permanently raised by 1.0 – 1.5 m in order to reach DFSL. Floodplain culverts beneath the raised road have not been included in this conceptual design because the amount of flood conveyance over the Klondike Highway is expected to be minimal compared to the overall flow in the Yukon River; therefore, preventing overtopping is assumed to have negligible effect on overall Yukon River flood conveyance. The need for floodplain culverts beneath the raised road would be further evaluated during detailed design.

On the south side of the Yukon River approximately 1,500 m of the western portion of River Drive extending from McDade Road to 270 River Drive would be raised by approximately 0.5 – 0.75 m (compared to existing ground). Raising this segment of River Drive would maintain access to dwellings and businesses located west of the Nordenskiold River and mitigate overland flooding to the south of River Drive. Raising of River Drive may require slope stabilization measures installed along the riverbank of the Yukon River due to the added weight from the new material for the raised road. Riprap of adequate size would be required on the outer bank to mitigate erosion and ice damage hazards. The footprint of the road widening would be approximately 15 m and does not extend onto private properties, with all work above the OHWM.

On the north side of the Klondike Highway bridge at the LS/CFN subdivision, a 750 m long structural dike would be constructed along the north bank of the Yukon River. The crest of the structural dike would be 1.0 – 2.0 m higher than existing ground.

As with Option 1, the three properties located in the floodplain of the Nordenskiold River would require the construction of temporary sandbag dikes around the structures during flood conditions.

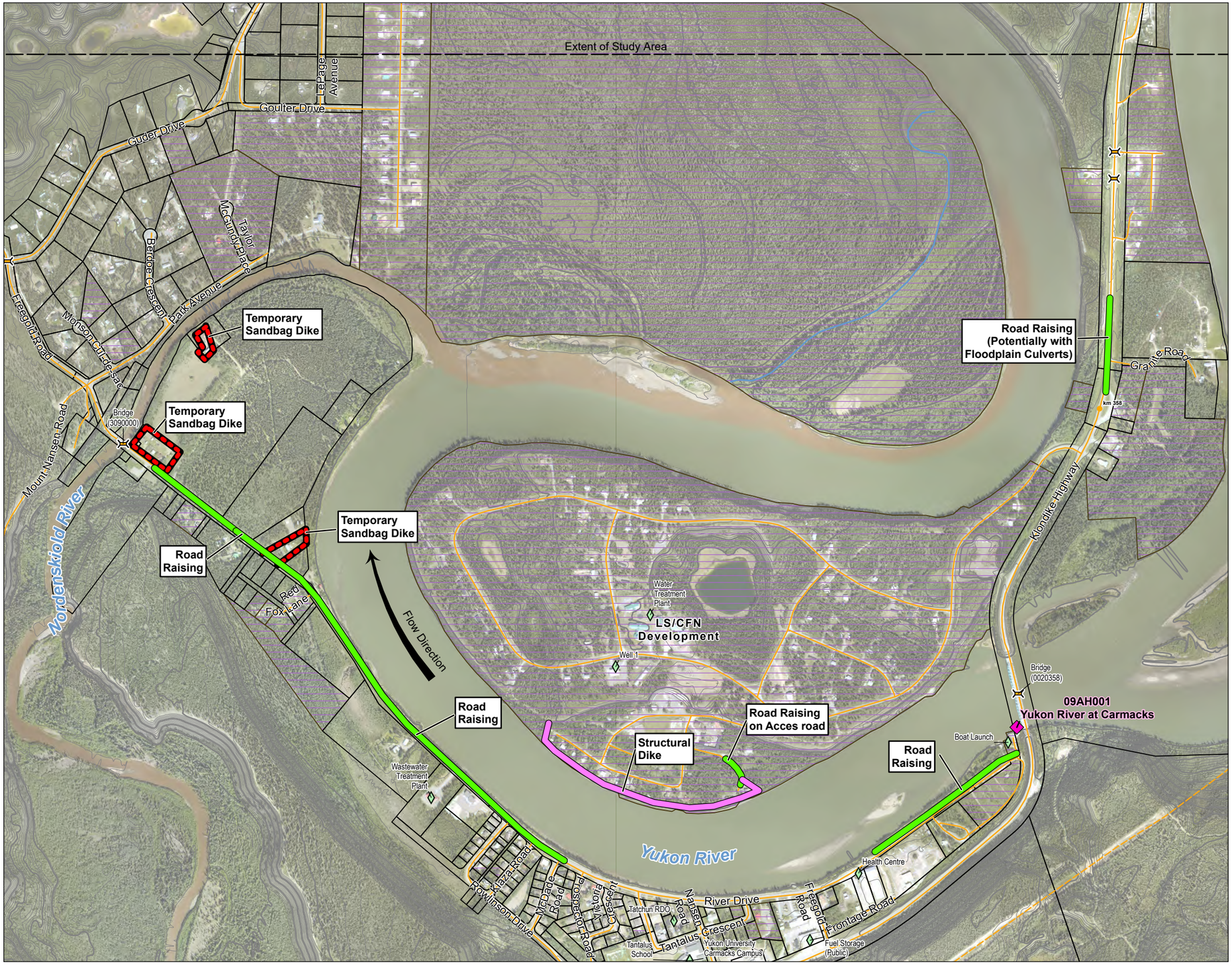


Figure No.

G4

Title

Carmacks Conceptual Flood Mitigation Design - Option 2

Client/Project 144903232

Government of Yukon
Community Services | Infrastructure Development Branch
Yukon Territory Flood Mitigation Conceptual Design Options

Project Location
Carmacks, Yukon

Prepared by LLT on 2023-08-18
TR by JM on 2023-08-18

N

0 50 100 150 200 m

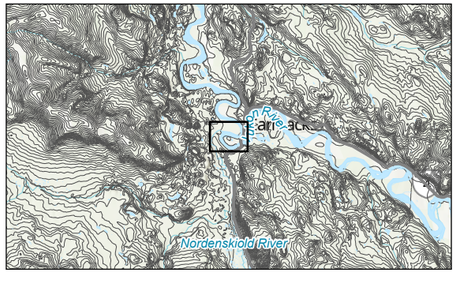
(At original document size of 11x17)
1:30,000

- WSC Station
- Culvert/ Bridge
- Community Infrastructure and Points of Interest
- Highway Kilometre Post
- Road
- Powerline
- Topographic Contour (10 m)
- Topographic Contour (2 m)
- Land Parcel - Surveyed
- First Nation Settlement Lands - Surveyed

Proposed Mitigation Feature

- Earthen Dike
- Platform with Temporary Superbag Dike
- Road Raising
- Structural Dike
- Temporary Sandbag Dike

CONCEPTUAL DESIGN
This document is for general information only and is not for permits, tendering, or construction.



Notes
1. Coordinate System: NAD 1983 Yukon Albers
2. Data Sources: Government of Yukon; Government of Canada
3. Imagery Government of Yukon Geomatics Yukon; ESRI World Imagery

Stantec Yukon

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Class D OPC

The Class D OPC's for capital and annual costs are summarized in Table G8, considering the Class D level of accuracy (+/-50%). Table G3 also provides the Class D OPCs on a per inundated property basis (from Section C.1.11).

Table G8 Option 2 Summary of Class D OPCs

	Class D OPC	Number of Inundated Properties (Section G.1.11) [1,2]	Class D OPC per Inundated Property [1]
Capital Cost	$ 22,914,900 - $ 34,372,350	17	$1,347,936 - $2,021,903
Annual Cost (Flood Year)	$ 334,200 - $ 501,300		$ 19,659 - $ 29,489
Annual Cost (Non-Flood Year)	$ 103,100 - $ 154,650		$ 6,065 - $ 9,098

[1] As described in Section G.1.11, the inundated properties from the preliminary inundation analysis consists of 15 private residences and 2 major community features.
[2] A substantial number of additional residential properties (not counted in the 16 inundated properties) north of the Nordenskiold River bridge would have access preserved by flood mitigations on River Drive.

The components, assumed unit costs, and estimated quantities which produce the Class D OPCs are detailed in Table G9 (capital costs), Table G10 (annual cost, flood year), and Table G11 (annual cost, non-flood year).

Table G9 Option 2 Capital Costs Class D OPC

Item No.		Description of Work	Units	Qty.	Unit Price	Amount
Section 2A		**Option 2: General Conditions**				
	a)	Mobilization/Demobilization	LS	1	$1,200,690.00	$1,200,690.00
	b)	Site Preparation/Restoration	LS	1	$240,200.00	$240,200.00
					Total 2A	$1,440,890.00
Section 2C		**Option 2: Earthworks & Landscaping, Structural Dike (LS/CFN)**				
	a)	Clearing and Grubbing	M2	2800	$10.00	$28,000.00
	b)	Topsoil Stripping and Stockpiling, 300mm Depth	M3	830	$25.00	$20,750.00
	c)	Dike Topsoil	M2	2220	$20.00	$44,400.00
	d)	Dike Seeding	M2	2220	$5.00	$11,100.00
	e)	Dike Fill	M3	3740	$100.00	$374,000.00
	f)	Sheet Pile Wall	M2	2290	$1,700.00	$3,893,000.00
	g)	Modular Block Wall	M2	1150	$900.00	$1,035,000.00
	h)	Handrails	M	1480	$140.00	$207,200.00
	i)	Toe Drain: Perforated Pipe, Geotextile and Drain Rock	M	740	$300.00	$222,000.00
	j)	Slope Stabilization	M	740	$3,000.00	$2,220,000.00
					Total 2C	$8,055,450.00
Section 2D		**Option 2: Storm Sewers, Structural Dike**				
	a)	Reinforced Concrete Pipe	M	200	$1,000.00	$200,000.00
	b)	Gatewell Manhole c/w Sluice Gate	EA	10	$17,500.00	$175,000.00
	c)	Concrete Headwall	EA	20	$5,000.00	$100,000.00
	d)	Flap Gate	EA	10	$3,000.00	$30,000.00
	e)	Riprap	MT	200	$141.00	$28,200.00
					Total 2D	$533,200.00
Section 2E		**Option 1: Road Raising (River Rd., Klondike Highway)**				
	a)	Rough Grading	M2	30900	$5.00	$154,500.00
	b)	Subgrade Preparation	M2	30900	$5.00	$154,500.00
	c)	80mm Minus Granular Subbase, Variable Depth	M3	20650	$40.00	$826,000.00
	d)	100mm Minus Granular Base, 100mm Depth	M3	2540	$50.00	$127,000.00
	e)	BST Surfacing	M2	19210	$50.00	$960,500.00
	f)	Riprap	MT	8480	$141.00	$1,195,680.00
					Total 2E	$3,418,180.00

The contents of this appendix are subject to the project objectives, methods, assumptions, and limitations outlined in the main body of the Yukon Territory Flood Mitigation Conceptual Design Options report and in Appendix T.

Contingency (20%)	$2,689,544.00
Subtotal	$16,137,264.00
Location Adjustment Factor (LCAF)	1.42
Capital Costs Base Price	$22,914,900.00
Capital Costs Upper Bound	$34,372,350.00

Table G10 Option 2 Annual Costs During a Flood Year Class D OPC

Item No.	Description of Work	Units	Qty.	Unit Price	Amount
Section 2F	**Option 2: Annual Costs, Flood Year**				
a)	Inspections	LS	1	$25,000.00	$25,000.00
b)	Minor Repairs & Vegetation Management	LS	1	$50,000.00	$50,000.00
c)	Storage of Sandbags	LS	1	$500.00	$500.00
d)	Sandbags c/w Sandfill (1.0m - 2.0m)	M	260	$464.00	$120,640.00
				Total 2F	$196,140.00
				Contingency (20%)	$39,228.00
				Subtotal	$235,368.00
				Location Adjustment Factor (LCAF)	1.42
				Annual Cost Flood Year Base Price	$334,200.00
				Annual Cost, Flood Year Upper Bound	$501,300.00

Table G11 Option 2 Annual Costs During a Non-Flood Year Class D OPC

Item No.	Description of Work	Units	Qty.	Unit Price	Amount
Section 2G	**Option 2: Annual Costs, Non-Flood Year**				
a)	Inspections	LS	1	$10,000.00	$10,000.00
b)	Minor Repairs & Vegetation Management	LS	1	$50,000.00	$50,000.00
c)	Storage of Sandbags	LS	1	$500.00	$500.00
				Total 2G	$60,500.00
				Contingency (20%)	$12,100.00
				Subtotal	$72,600.00
				Location Adjustment Factor (LCAF)	1.42
				Annual Cost, Non-Flood Year Base Price	$103,100.00
				Annual Cost, Non-Flood Year Upper Bound	$154,650.00

Qualitative Evaluation

Table G12 summarizes the performance of Option 2 with respect to the evaluation criteria which was previously outlined in the main body of the *Yukon Territory Flood Mitigation Conceptual Design Options* report.

Table G12 Option 2 Qualitative Evaluation

Criteria No.	Criteria Title	Evaluation	Anticipated Performance Rating
1	Viability and Reliability under Extreme Conditions	permanent structures would withstand moderate flood duration (several weeks); wind/wave impacts and damage risks from ice/debris would be mitigated by erosion mitigation measures; potential for damage from ice jamming and ice flow may damage temporary sandbag dikes along Nordenskiold; seepage control measures may be required	High Performance
2	Time to Implementation	geotechnical investigations required including borehole drilling to address bank stability and construction requirements for dikes and road raising; erosion mitigation and river migration studies require during detailed design; need for floodplain culverts to be investigated during detailed design; high regulatory risk; moderate property owner agreements required; moderately high anticipated design effort; moderate anticipated construction effort	Medium Performance
3	Capital Cost Per Inundated Property	increased capital costs in exchange for decreased operational and maintenance costs when compared to options requiring substantial temporary deployments (Option 1); per-inundated-property capital cost is $1,347,936/property	Low Performance
4	Maintenance and Storage	minimal storage requirements (sandbags for low number of temporary sandbag dikes); structural dike will require inspections, maintenance, and vegetation clearing; periodic road inspections may be required; floodbox maintenance required	Medium Performance
5	Response and Activation	2 property-owner deployed temporary sandbag dikes; floodbox slide gates would need to be manually closed prior to arrival of flood and opened following abatement of the flood	High Performance
6	Aesthetics and Community Function	substantial permanent alteration of existing landscape and river views by structural dike, structural dike (1.0 - 2.0 m in height); dike crests may be established as community features (e.g., walking paths) if the community members are supportive.	Low Performance
7	Future Adaptability	temporary superbag dike may be deployed on structural dike crest and raised roads in future for enhanced flood mitigation; additional sandbags may be provided for raising temporary sandbag dikes; permanent increases in height to dike and road are possible but will require engineering study and are likely to require widening of structure	Medium Performance
8	Alteration of Existing Hydraulics, Erosion/ Sedimentation, Ice Processes, and Slope Stability	road raising of Klondike Highway anticipated to have relatively minor/negligible effect on overall flood conveyance of the Yukon River; relatively minor intrusions into Yukon River that are not anticipated to disrupt existing river processes; slope stabilization measures may be required over a length of 0.7 km	Medium Performance
9	Disaster Mitigation and Adaptation Function (DMAF) Applicability	high return on investment (ROI) given the private properties and access routes within the community that would be mitigated from flooding as a result of improvements	High Performance

G.2.3 SUMMARY TABLES

Table G13 summarizes the Class D costing for each of the conceptual design options.

Table G13 Summary of Class D OPCs

	Option 1 Class D OPCs	Option 2 Class D OPCs
Capital Cost	$ 11,826,500 - $ 17,739,750	$ 22,914,900 - $ 34,372,350
Annual Cost (Flood Year)	$ 2,688,800 - $ 4,033,200	$ 334,200 - $ 501,300
Annual Cost (Non-Flood Year)	$ 26,400 - $ 39,600	$ 103,100 - $ 154,650

Table G14 provides a summary of the evaluation of each of the conceptual design options.

Table G14 Summary of Qualitative Evaluation of Conceptual Options

Criteria No.	Criteria Title	Option 1	Option 2
1	Viability and Reliability under Extreme Conditions	Low Performance	High Performance
2	Time to Implementation	Medium Performance	Medium Performance
3	Capital Cost Per Inundated Property	Medium Performance	Low Performance
4	Maintenance and Storage	Medium Performance	Medium Performance
5	Response and Activation	Low Performance	High Performance
6	Aesthetics and Community Function	High Performance	Low Performance
7	Future Adaptability	High Performance	Medium Performance
8	Alteration of Existing Hydraulics, Erosion/ Sedimentation, Ice Processes, and Slope Stability	Medium Performance	Medium Performance
9	Disaster Mitigation and Adaptation Function (DMAF) Applicability	High Performance	High Performance