



YUKON TERRITORY FLOOD MITIGATION CONCEPTUAL DESIGN OPTIONS

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Yukon Territory Flood Mitigation Conceptual Design Options

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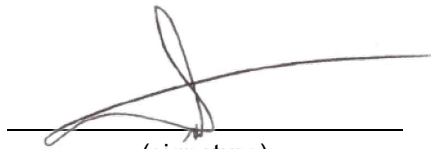
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Version History

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Executive Summary

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Executive Summary

Flooding has impacted many Yukon communities over the past several decades; most recently in 2021 (Southern Lakes Region and Carmacks), 2022 (Teslin, Carmacks, and Ross River), and 2023 (Dawson, Rock Creek). The Government of Yukon (YG) has identified a total of 19 communities that may be at risk from flood hazards including Upper Liard, Teslin, Carcross, Tagish, South M'Clintock and Army Beach, Whitehorse, Carmacks, Ross River, Pelly Crossing, Mayo, Dawson City, Old Crow, Marsh Lake East Shore, Swan Haven, Shallow Bay, Jackfish Bay, Deep Creek, Faro lagoons, wells and pump stations near the Pelly River, and Rock Creek. YG retained Stantec to produce conceptual flood mitigation options for each of the 19 communities (the Project).

The scope of work for this Project was to compile background information relevant for conceptual flood mitigation design, develop and describe one to three engineered flood mitigation options at the conceptual design level to reduce overland flood risk, prepare Opinion of Probable Costs (OPCs) and provide a qualitative evaluation for each of the conceptual options at each community. Three OPCs were developed for each option to evaluate capital costs, annual costs during a flood year, and annual costs during a non-flood year. Each option was qualitatively evaluated with respect to nine various criteria outlined within the report.

This Project considered five typical engineered flood mitigation approaches which included road raising, earthen dikes, structural dikes, platforms with temporary superbag dikes, and temporary sandbag dikes. Engineered flood mitigation options are provided for areas which are inundated under the 1:200-year WSE in the preliminary inundation analysis with a top elevation of the flood mitigations designed to reach the Design Flood Service Level plus a freeboard. The freeboard selected for this project was 0.5 m above the 1:200-year WSE for communities along rivers in order to provide some factor of safety to standing waves, variations in the hydrology, unknowns in the ice jams and other uncertainties. At lake a 2.0 m freeboard over the 1:200-year WSE was selected to account for waves along lakes. Conceptual design options for each of the 19 communities are detailed in the 19 corresponding appendices (Appendix A through Appendix S) with brief summaries outlined below.

Upper Liard (Appendix A) has experienced four documented flood events since 2005. Following the 2012 flood, a flood assistance package was offered by YG to 13 properties north and east of the Alaska Highway bridge to purchase the properties, complete required environmental remediation, and identify the area as flood prone and not suitable for development. Preliminary inundation analysis indicates 11 private properties, and one community feature/parcel would be susceptible to flooding in Upper Liard. Two engineered flood mitigation options including platforms with temporary superbag/sandbag dikes and road raising are presented for Upper Liard.

Teslin (Appendix B) experienced its highest flood on record in 1962 although extreme flooding requiring emergency response also occurred in 2021 and 2022. The Village of Teslin has commissioned separate flood mitigation designs between 2021 and present and have implemented several of the designed mitigations. Preliminary inundation analysis indicates 30 private properties and 4 community features/properties. Two engineered flood mitigation options including combinations of platforms with temporary superbag/sandbag dikes, road raising, and earthen dikes are presented for Teslin.

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Carcross (Appendix C) experienced flooding events requiring emergency response in 2007 and 2021. Preliminary inundation analysis indicates that 23 private residences and 11 community features/properties are likely susceptible to flooding. Three engineered flood mitigation options including combinations of platforms with temporary superbag/sandbag dikes, road raising, earthen dikes and structural dikes are presented for Carcross.

Tagish (Appendix D) experienced flooding events in 2007 and 2021. Preliminary inundation analysis indicates 39 private properties and three community features/properties are likely susceptible to flooding. Two engineered flood mitigation options including combinations of platforms with temporary superbag/sandbag dikes, road raising, earthen dikes and structural dikes are presented for Tagish.

Army Beach and South M'Clintock (Appendix E) experienced flooding events requiring emergency response in 2007 and 2021. Preliminary inundation analysis indicates 52 private properties and five community features (local roads/pathways) are likely susceptible to flooding. Three engineered flood mitigation options including combinations of platforms with temporary superbag/sandbag dikes, road raising, earthen dikes and structural dikes are presented for Army Beach and South M'Clintock.

Whitehorse (Appendix F) experienced flood events in the winters of 1963-1964, 1964-1965, 1978, and 2000-2001. These flood events are largely attributed to freeze-up ice jamming processes. Open water flooding risk is generally considered to be low at Whitehorse due to the flow restricting effects of upstream control structures (Miles Canyon, Yukon Energy dams). Preliminary inundation analysis indicates areas surrounding 2nd and 3rd Avenue, and at Marwell are likely susceptible to flooding. Two engineered flood mitigation options including platforms with temporary superbag dikes and earthen dikes are presented for Whitehorse.

Carmacks (Appendix G) experienced flooding in 2000, 2008, 2021, and 2022. Preliminary inundation analysis indicates 17 private properties and community features are susceptible to flooding. Two engineered flood mitigation options including combinations of platforms with temporary superbag/sandbag dikes, road raising, and structural dikes are presented for Carmacks.

Ross River (Appendix H) experienced flooding in 2013 and 2022. An existing earthen dike exists along the east side of the community. Preliminary inundation analysis indicates floodwaters would overtop the existing dike over a length of 120 m and will also enter the community downstream of the dike resulting in nine private properties and two community features being susceptible to flooding. Three engineered flood mitigation options including combinations of platforms with temporary superbag/sandbag dikes, improvements to the existing earthen dike, and new earthen dikes are presented for Ross River.

Pelly Crossing (Appendix I) does not have any documented historical flood events within the community. Preliminary inundation analysis indicates six private properties and community features are susceptible to flooding. One engineered flood mitigation option including platforms with temporary sandbag dikes is presented for Pelly Crossing.

Mayo (Appendix J) experienced freeze-up ice jam flooding in the winters of 2010-2011, 2011-2012, and 2012-2013. Flood bypass channels in the Mayo River and revised Yukon Energy flow regulation protocols during freeze-up were implemented in the mid-2010's. Mayo has an existing earthen dike which surrounds the community. Preliminary inundation analysis indicates that the crest of the dike is above the 1:200-year water surface elevation but substantial portions of the community inside the dike are below the 1:200-year WSE totalling 103 private properties and five community features. The existing dike has

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demonstrated instances of seepage/leakage. One engineered flood mitigation option is presented for Mayo, consisting of upgrades/replacement of the existing dike.

Dawson (Appendix K) has experienced numerous flood events dating back to 1898. Flooding has occurred by both ice jam and open water flood processes. Preliminary inundation analysis indicates that an estimated 765 private properties and community features are susceptible to flooding. Dawson has an existing dike which has generally performed well, however the city's stormwater outfalls to the Yukon River currently provide a pathway for floodwaters to enter the community. Two engineered flood mitigation options including combinations of platforms with temporary superbag/sandbag dikes, road raising, and earthen dikes are presented for Dawson.

Old Crow (Appendix L) has experienced numerous extreme flooding events since the 1930's (1932, 1973, 1989, and 1991). Preliminary inundation analysis indicates approximately 150 private properties and all community features (excluding the school) are susceptible to flooding. Two engineered flood mitigation options including combinations of platforms with temporary sandbag dikes, road raising, earthen dikes and structural dikes are presented for Old Crow.

Marsh Lake East Shore (Appendix M) experienced extreme flooding in 2021 requiring emergency response. Preliminary inundation analysis indicates 10 properties are susceptible to flooding. One engineered flood mitigation option including combinations of platforms with temporary sandbag dikes is presented for Marsh Lake East Shore.

Swan Haven (Appendix N) did not have any areas which were inundated under the preliminary inundation analysis, and therefore has no conceptual mitigation options were developed. Swan Haven is susceptible to land loss from erosion (outside the scope of this Project).

Shallow Bay (Appendix O) experienced high lake levels that affected shoreline properties in 2021. Preliminary inundation analysis indicates three properties are susceptible to flooding. One engineered flood mitigation option including combinations of platforms with temporary sandbag dikes is presented for Shallow Bay.

Jackfish Bay (Appendix P) experienced high lake levels that affected shoreline properties in 2021. Preliminary inundation analysis indicates eight private properties and one community feature (Jackfish Bay Road) are susceptible to flooding. Two engineered flood mitigation options including combinations of platforms with temporary sandbag dikes and road raising are presented for Jackfish Bay.

Deep Creek (Appendix Q) experienced high lake levels that affected shoreline properties in 2021. Preliminary inundation analysis indicates 15 private properties and one community feature (Deep Creek South Road) are susceptible to flooding. Three engineered flood mitigation options including combinations of platforms with temporary superbag/sandbag dikes, road raising, and structural dikes are presented for Deep Creek.

Faro Lagoons, Wells, and Pump Station (Appendix R) did not have any areas which were inundated under the preliminary inundation analysis, and therefore had no conceptual mitigation options presented. The land inside the road at the Faro lagoons is below 1:200-year WSE meaning it is susceptible to seepage during flood conditions. Seepage-specific designs are outside the scope of this Project.

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Rock Creek (Appendix S) experienced flood events in 1999, 2000, and 2023, due to both open water and ice jam processes. Preliminary inundation analysis indicates that five private properties and community features are susceptible to flooding. Two engineered flood mitigation options including combinations of platforms with temporary sandbag dikes and road raising are presented for Rock Creek.

This Project is a conceptual level design and has been completed early in the flood mitigation planning process. Numerous studies, design advancements, and community engagements will be needed for each community prior to flood mitigations being implemented. These include, but are not limited to, flood policy development, hydrology studies, hydraulic modelling, flood hazard mapping, erosion hazard mapping/river migration analysis, wind/wave analyses, beach processes and morphodynamics, geotechnical investigations, geohazard mapping, landslide-induced flood wave analysis, hydrogeological investigations, engagement with First Nation Governments, local governments, community members, the public, regulatory pathway mapping, regulatory applications, and property owner agreements. The findings of the above studies may alter the feasibility and evaluations of the conceptual design options presented in this Report.

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Acronyms / Abbreviations

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APEGBC	Association of Professional Engineers & Geoscientists British Columbia
CAF	Canadian Armed Forces
CEBC	Consulting Engineers of British Columbia
CGVD2013	Canadian Geodetic Vertical Datum
C/TFN	Carcross / Tagish First Nation
DFSL	Design Flood Service Level
CS	Community Services
FFA	Flood Frequency Analysis
FFE	First Floor Elevation
FNNND	First Nation of Na-cho Nyäk Dun
IDB	Infrastructure Development Branch
IMT	Incident Management Team
KDFN	Kwanlin Dün First Nation
km	kilometres
LFN	Liard First Nation
LS/CFN	Little Salmon / Carmacks First Nation
m	metres
OHWM	Ordinary High Water Mark
OPC	Opinion of Probable Cost
OPCC	Opinion of Probable Cost for Construction
ROI	Return on Investment
RRDC	Ross River Dena Council
SFN	Selkirk First Nation
TH	Trond'ëk Hwëch'in Government

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Acronyms / Abbreviations

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TKC	Ta'an Kwäch'än Council
TTC	Teslin Tlingit Council
WSE	Water Surface Elevation
YEC	Yukon Energy Corporation
YG	Government of Yukon
VGFN	Vuntut Gwichin First Nation

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Introduction

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1 Introduction

Flooding is the most costly natural disaster in Canada, resulting in over \$1 billion annually in direct damages to homes, property and infrastructure (NRCan 2023). With the increasing frequency and severity of natural disasters, these costs are also expected to increase. Mitigating flood risks is critical to increasing the resilience of impacted communities by adequately preparing for flooding events and recovering after flooding has occurred. To develop this resiliency, an understanding of flooding risks should be established, followed by the development of strategies to mitigate the risks. When a community can proactively invest in flood mitigation activities they can reduce recovery costs, productivity losses, economic losses, destruction of cultural assets and environmental damage – the United Nations (2019) has suggested that for every dollar invested in natural hazard reduction, six dollars can be saved.

Flooding has impacted many Yukon communities over the past several decades; most recently in 2021 (Southern Lakes Region and Carmacks), 2022 (Teslin, Carmacks, and Ross River), and 2023 (Dawson, Rock Creek). These flooding events had costly impacts on public infrastructure and private property across the territory.

The Government of Yukon (YG) has identified a total of 19 communities that may be at risk from flood hazards (Table 1).

Table 1 Yukon Communities Potentially Impacted by Flood Hazards

Upper Liard	Marsh Lake East Shore
Teslin	Swan Haven
Carcross	Shallow Bay
Tagish	Jackfish Bay
South M'Clintock and Army Beach	Deep Creek
Whitehorse	Faro Lagoons, Wells, and Pump Stations Near Pelly River
Carmacks	Rock Creek
Ross River	
Pelly Crossing	
Mayo	
Dawson City	
Old Crow	

In March of 2022, Stantec Consulting Ltd. (Stantec) completed the *Marsh Lake Flood Mitigation Options* (Stantec 2022) which described, evaluated, and provided cost estimates for multiple conceptual options for flood hazard mitigation at South M'Clintock and Army Beach (one of the most severely impacted communities during the 2021 flood). Following the completion of Stantec (2022), YG retained Stantec to produce similar deliverables for all 19 Yukon communities that may be impacted by flood hazards (the Project). The scope of work for this Project was to perform the following for each community:

1. Compile background information relevant for conceptual flood mitigation design.

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2. Develop and describe two to three engineered flood mitigation options at the conceptual design level (conceptual options) to reduce overland (surface water induced) flood risk to Yukon communities.
3. Perform high-level costing and qualitative evaluation for each of the two to three conceptual options at each community.

This Report documents the methods and results for the scope of work (items 1, 2, and 3) of this Project.

This Project has been completed prior to many of the required processes and studies required for flood mitigation design (refer to Section 3.2 and Section 3.6). This accelerated timeframe is at the request of YG for the purposes of facilitating YG's initial discussions within the government(s), communities, and public regarding flood mitigation in the Yukon.

2 Report Structure

The Report consists of a main body and a series of 21 separate appendices (Appendix A through Appendix U).

The main body consists of an Introduction (Section 1), a discussion of Report Structure (this section, Section 1), Design Basis including design objective, design scenario, typical conceptual mitigation designs, the approach for opinion of probable costs and qualitative evaluation, and assumptions (Section 1), a Summary of the Conceptual Design Options for each of the 19 Yukon communities (Section 4), a Closure Statement (Section 5), and References (Section 1).

The specifics of the flood hazard conceptual design options are provided for each individual community in Appendix A through Appendix S (i.e., 19 appendices for 19 communities). Each appendix contains the background information (existing conditions) and the mitigation options descriptions, opinion of probable costs, and evaluations for one community. Appendix T contains the Statement of General Conditions for this Report. Appendix U contains the comparison of demountable flood mitigation options from Stantec (2022).

3 Design Basis

3.1 Design Objective

The design objective of each of the conceptual engineering flood mitigation options (conceptual options) is to mitigate overland (surface water induced) flood hazards in Yukon communities through engineered flood mitigations.

The design objective does not include mitigation of groundwater seepage, although seepage considerations are discussed at a high level where relevant in the conceptual options for the various communities.

The design objective does not include mitigation of community-wide bank erosion hazards. Mitigation of erosion hazards throughout the communities would require numerous wind/wave and erosion studies for communities along lakes and river morphology studies for communities along rivers, which are outside of the scope of this Project. Bank stabilization on flood mitigation structures is included, where applicable.

3.2 Design Scenario

There are numerous studies and inputs required for flood hazard identification and flood mitigation design. Two of the major inputs are flood policy and flood mapping.

Flood policy includes (but is not limited to) identification of a design standard(s) (e.g., 1:200-year flood event = 0.5% Annual Exceedance Probability), development policies for design standard(s), various permitting for new construction to meet standards, emergency response thresholds/ranges, and method/approach for accounting for climate change in analysis and design works. At the time of writing, the Yukon does not have formal flood policy. Flood policy development is not in the scope of this Project.

In lieu of territorial flood policy, this Project makes assumptions regarding the design standard for flood mitigation (referred to in this Report as the Design Flood Service Level, or DFSL). DFSL is defined in this Project as:

$$DFSL = 1:200 \text{ year WSE} + \text{freeboard}$$

For communities on lakes, a freeboard of 2 m was adopted to account for potential wind/wave action, wave runup, and geotechnical stability requirements of the mitigation structure.

For communities on rivers, a freeboard of 0.5 m was adopted to account for geotechnical stability requirements of the mitigation structure.

The DFSL approaches outlined above are not based on detailed analyses and shall be considered a reasonable “test scenario” appropriate for the conceptual design in this Report. Flood policy and detailed analyses (e.g., wind/wave studies) on a site-specific basis will ultimately be required to inform freeboard requirements at/within each community. The DFSL approaches used in this Project do not represent an endorsement or recommendation for DFSL for future Yukon flood policy.

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Flood mapping consists of hydrologic and hydraulic studies identifying flood flows and elevations associated with design standard(s) (e.g., 1:200-year), and simulating/mapping the resulting flood hazards on the landscape. At the time of writing, flood mapping in various Yukon communities is in progress but no studies have been completed. Flood mapping is not in the scope of this Project but estimates of the 1:200-year inundations are required for use in the conceptual designs for the DFSL.

In lieu of completed floodplain mapping, this Project completes a preliminary inundation analysis whereby 1:200-year WSEs from previously published works or analyses are combined with estimates of WSE slope at each community. The values, sources, and preliminary inundation mapping of 1:200-year WSEs adopted for each community are presented in Appendix A through Appendix S. The use of these published 1:200-year WSEs in this Project does not represent Stantec's endorsement or recommendation for using these values in flood mapping or other purposes beyond those within the scope of this Project.

The details, feasibility, evaluation, and costing of the conceptual options in this Report are subject to change following development of flood policy, the selection of a design flood standard, and the completion of flood mapping for these communities.

3.3 Typical Conceptual Mitigation Designs

3.3.1 NON-ENGINEERED APPROACHES

As stated in Section 1, Stantec's scope of work was to develop conceptual engineering options for flood mitigation. Depending on the flood hazard vulnerabilities specific to a given community, non-engineered approaches may be appropriate and therefore should also be considered by Yukon communities.

Non-engineered approaches to flood mitigation that communities should consider are briefly described in Section 3.3.1.1 through Section 3.3.1.6 but are not included in the community-specific conceptual engineering designs (Appendix A through Appendix S).

3.3.1.1 Status Quo (Emergency Response-Based)

The status quo option would consist of YG adopting comparable flood mitigation approaches to those implemented during the emergency response of historical flooding in the territory. No improvements would be made to flood mitigation infrastructure and approaches, and flood mitigation would continue to be performed on a case-by-case, emergency response basis. For this option, future floods could cause damage to property and infrastructure unless YG were to deploy or coordinate deployment of emergency flood defense measures.

It is recommended that YG develop emergency preparedness and response policies/plans to guide government and property owner actions during flood events.

3.3.1.2 Mitigation Funding to Property Owners

The mitigation funding option would consist of grants, loans, or other funding provided by YG to property owners to install discrete flood mitigation measures on their private properties. The mitigation funding would be provided to individual property owners for improving the flood resiliency of a given property through measures aimed at reducing damage from future flood events (i.e., is not intended to be used for repairs from past flood damage). These mitigation measures may be engineered measures; however they

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would be undertaken by the individual property owner(s). Examples of mitigations that individual property owners could use the funding for include (but are not limited to) raising or flood-proofing of their structures, building permanent dikes on their property, preparing the ground for rapid deployment of a temporary sandbag or superbag dike, or the purchase of alternative demountable flood protection systems (refer to Appendix T). The mitigation funding to property owners' option would allow property owners to protect their own property on a lot-by-lot basis in a manner which they determine.

The funding model could vary depending on the requirements or desired outcome(s) of the funding agency. Components of the funding that can vary include:

- Amount of funding available, and method of calculation of eligible funding. For example, the funding amount may be determined on a per property basis, on a linear distance of water frontage basis, on a property area basis, or more specific criteria which includes difficulty of flood priority in particular areas.
- Administration of the funding. Funding may be provided up front to property owners, YG could reimburse contractors directly, the property owner may need to pay for the mitigation expenditures and be reimbursed by YG following inspection or approval of the mitigation, or payment could be applied to property taxes over several years to distribute the financial implications to the territory.
- Conditional requirements of the funding. For example, the funding may only be provided for an approved list of approved mitigation types, must provide flood defenses to a minimum level (e.g., design standard), or must be approved by certain agencies for funding eligibility. Future YG emergency flood response on the property may be made dependent on the type or level of mitigations implemented by the property owner. Funding may also be dependent on an audit process to validate that the approved mitigation measures were installed/implemented correctly.
- Amendments to land classification and flood policy following administration of funding. For example, once this funding is provided, affected properties may be officially designated as being within a flood hazard zone (or equivalent), which may then be connected to YG's emergency flood response policy for the affected properties (e.g., YG will not deploy public resources to protect private properties for flood events of less than a certain return period or threshold elevation).

The mitigation funding to property owners' option has been implemented for flood mitigation in Canadian jurisdictions in the past, including (but not limited to):

- Yukon, 2007/2008. Following the 2007 Marsh Lake flood event, YG offered loans of up to \$35,000 for property owners for flood mitigation (improvements) of primary residences or structures, or for flood recovery (repairs) of secondary structures (YG 2007). Documentation of the specific mitigations/improvements made by property owners was not available at the time of writing, although anecdotal reports indicate that the mitigations/improvements included structure/property raising and riprap/gabion basket installation. These mitigations likely reduced flood and erosion damages during the 2021 flood at Army Beach/South M'Clintock.

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- Manitoba, 1997. In response to the 1997 Red River flood, the Government of Manitoba reached an agreement with the Government of Canada for Disaster Financial Assistance Arrangement (DFAA) funding. Included in the agreement was up to \$100,000 of compensation available to individual property owners. The \$100,000 was for cost-sharing of projects for “losses of real and personal property” and for “flood proofing and enhanced diking” (Government of Manitoba 1997).
- Manitoba, 2015. Following the 2014 flooding, the Government of Manitoba initiated the 2015 Individual Flood Protection Initiative (IFPI) to provide financial assistance to owners of flood prone home, farm, and business buildings to implement flood defense measures for their property (Government of Manitoba 2015). The 2015 IFPI specified, among other program details, the eligible building types, acceptable flood defense methods (earthworks, structural works), minimum required elevations of the flood defense (Flood Protection Level), the reimbursable amounts (86% of eligible costs to a maximum cost-shared project cost of \$100,000), program procedures and submission requirements, and engineering/construction requirements (Government of Manitoba 2015).

The above examples above are not a complete list of relevant mitigation funding to property owner models. A thorough review of relevant flood mitigation models should be completed if this approach is to be pursued by YG.

If this approach is implemented, it is also recommended that YG include guidance for the property owners to improve program execution. This could be done in a similar way to other recent Canadian examples (e.g., Government of Manitoba 2015). Items in the program should include, but is not limited to, the following:

1. Pertinent components of territorial flood policy (flood mitigation design standard, implications of achieving protection levels, title amendments/land-classifications/encumbrances).
2. Flood elevations and flood hazard maps indicating which structures/properties are flood vulnerable.
3. Property/structure types that are eligible to receive mitigation funding (e.g., primary residence, secondary residence, sheds/garages, driveways, etc.).
4. Recommended/eligible mitigation types (e.g., dikes, erosion protection, seepage control, raising of property and structures, adaptation of sanitary systems, basement flood proofing, raising of electrical system and outlets, permanent seepage pumps, etc.) along with associated permitting, engineering, and construction guidelines or requirements.
5. Funding delivery model (reimbursable amounts, method of payment, documentation requirements).

3.3.1.3 Land Purchase/Exchange

The land purchase/exchange option consists of government purchase or exchange of the private properties that are flooded under a design event (which may be specified in territorial flood policy). Once the land has been purchased or exchanged by YG, it may be zoned/developed to match the flood hazard

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level at the location of interest (e.g., recreation or naturalized areas). Flood hazard zoning and allowable development may be components of a territorial flood policy.

The model for land purchase/exchange can vary. A willing-buyer, willing-seller arrangement between property owners and the buyer is likely to result in a more expedient transfer of land to YG or other government. Any property owners who are not willing to sell could be subject to expropriation. Under the *Expropriation Act* (YG 2002) of the Yukon states that a Minister may expropriate any land that the Minister deems necessary for public purposes. Discussions between YG and First Nation governments would be required if the lands to be purchased/exchanged are First Nation Settlement lands.

YG would need to submit a plan of the land to the land titles office and provide notice of the plan to property owners within 60 days of registering the plan. YG and property owners would need to agree on a compensation amount, and if no agreement is reached, a board of negotiation could be formed to mediate that process. If YG and the property owner still fail to reach an agreement, the case would be determined by a judge in the Supreme Court (YG 2002). Stantec recommends YG seek legal counsel if this option is chosen for further exploration.

Land purchase/exchange for flood prone properties has been completed in the Yukon in the past. A \$3.5 million flood assistance package was offered to owners of 11 flood-prone properties in Upper Liard in 2012 (YG 2012). The assistance package proposed that the flood-prone properties be purchased, required environmental remediation completed, and the area identified as flood prone and not suitable for development (YG 2012).

3.3.1.4 Regulation of Flow

Regulation consists of alteration of flow or water level regimes using diversion or storage to mitigate flood hazards to communities and infrastructure. Detailed hydrologic and hydraulic analyses are required to identify the opportunities for modification to operational protocols at existing facilities to reduce flood risk to communities, and to confirm that the action will not exacerbate flooding or other important river/lake functions elsewhere.

Regulation using upstream storage has more merit to communities which are located within the hydraulic influence of existing water control structures and reservoirs (e.g., dams). These communities include Carcross, Tagish, Army Beach and South M'Clintock, Whitehorse, Mayo, Marsh Lake East Shore, Swan Haven, Shallow Bay, Jackfish Bay, and Deep Creek. There are not existing facilities that are within the hydraulic influence of Upper Liard, Teslin, Carmacks, Ross River, Pelly Crossing, Dawson City, Old Crow, Faro Lagoons, Wells, and Pump Station, and Rock Creek.

One example of adaptive management enacted in the Yukon in the past is the temporary high-water protocol for the Lewes Dam in Clause 19.1 of the Yukon Energy Corporation's (YEC's) water license for the Whitehorse Rapids Generating Station and Lewes Dam (HY99-010, Amendment 1, Yukon Water Board 2021). The temporary clause was added in Amendment 1 to HY99-010 in response to extremely high snowpack in the Southern Lakes basin and permitted YEC to maintain a controlled minimum in Marsh Lake (at WSC Station 09AB004) that was 0.10 m lower than before the amendment, through to June 30, 2022. This lower controlled minimum WSE provided increased storage capacity in the Southern Lakes and reduced flood risk to the communities in the region.

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3.3.1.5 Management of Ice

Ice management actions are those which can alleviate or mitigate ice-jams to lower the associated flood risks. Examples of ice management actions include ice cover weakening and ice-setting flows on controlled systems, or alterations to ice bridge and snowmobile crossing locations to reduce ice thickness in areas vulnerable to ice jams. Detailed river ice studies are required to identify the management protocols which may reduce flood risk to communities without exacerbate flooding or other important river/lake functions elsewhere. Ice management strategies might be possible in communities where the dominant flood processes are driven by ice jams at either freeze up (e.g., Mayo, Carmacks) or break up (Rock Creek, Dawson, Old Crow).

3.3.1.6 Nature-Based Approaches

Nature-based flood mitigation approaches are being increasingly considered in North America. Nature-based approaches for flood mitigation typically fall into two general categories: i) re-establishing natural floodplains and ii) re-establishing natural flow regimes.

Category i) is reflected in the land purchase/exchange approach (Section 3.3.1.3). Structures and residences in the floodplain would be moved to alternative locations outside of the floodplain, and the land rezoned as appropriate for a floodplain. This would reduce flood hazards to humans and infrastructure through relocation and through potential reduction in WSEs from increased floodplain conveyance capacity.

Category ii) is most applicable in areas with flow regulation, or which have urbanized catchments and/or hardened channels upstream. Flow regulation approaches are addressed in Section 3.3.1.4. Urbanized catchments and hardened channels do not exist in the Yukon at a scale which impacts the flow regime.

Given the above, nature-based approaches to flood mitigation in this report are either not applicable or directly addressed in other non-engineered approaches.

3.3.2 ENGINEERED APPROACHES

There are a wide range of community-scale engineered approaches to flood mitigation which are available to communities. This Project focused on five typical engineered dike structures (typical engineered designs) which have a demonstrated history of reducing the risk of floodwaters entering each community and are regulated in neighbouring jurisdictions (Province of British Columbia 1996). These five typical engineered designs are: road raising, earthen dike, structural dike, easement with temporary superbag dikes, and temporary sandbag dikes. The general characteristics of each of these five typical engineered designs are described in Section 3.3.2.1 through Section 3.3.2.5, and generally follow the *Dike Design and Construction Guide: Best Management Practices for British Columbia* (BC MWLAP 2003).

Engineered flood walls were not considered in the five typical designs. Engineered flood walls (whether permanent or with demountables) are a type of engineered dike which use a wall structure (instead of the compacted earthen core of a dike) to reduce the risk of flood water entering an area. Engineered flood walls may have merit for Yukon communities but are generally expensive compared to dikes and are therefore best suited for specific situations where space for flood mitigation measures is limited. Review of approximate costs and performance of engineered flood walls in the Yukon context indicated that at the

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conceptual level, there were no clear performance advantages over dikes which would justify the substantial additional cost.

The specifics of if, how, and where the typical engineered designs are applied at each community are dependent on preliminary inundation mapping, site topography, infrastructure locations, and lake/river boundaries at each community. The community-specific conceptual design options are presented in Appendix A through Appendix S. Each conceptual option consists of a combination of typical designs (or variations of) applied for the community's inundated areas, meaning the conceptual options are mutually exclusive.

Detailed design of selected options will need to be completed prior to construction. The designs consist of structures that will need to meet comparable industry-standard serviceable life requirements during the detailed design phase. Investigation into groundwater conditions may be necessary if/where seepage barriers are to be considered, because these barriers may block groundwater flow towards the river during non-flood conditions and therefore cause groundwater to rise.

3.3.2.1 Road Raising

Roads not only provide access to community infrastructure and private property, but they also can function as dikes when adequately designed and constructed. The typical cross-section of the road is illustrated in Figure 1 and is based on the standard road design for local roads per the City of Whitehorse's *Servicing Standards Manual* (City of Whitehorse 2020).

The road crest elevation will meet the DFSL. The typical road cross-section will include a 9 m travelled road width with cross-slopes from the road crest of approximately 2%, and embankment slopes of typically 3H:1V. Suitable fill (base and sub-base courses) will be suitably compacted and the travelled road surface will be finished with a bituminous surface treatment (BST) to the edge of the travelled way. The design of the earthen road core should include an evaluation of seepage and stability in accordance with BC MWLAP (2003).

The road embankment will be topsoiled and seeded with native grass species, although erosion protection (e.g., riprap) may be required on the wet side of the road. If existing access points to the lake or river will be blocked due to road construction or erosion protection, access points (i.e., ramps, stairs) may be installed.

The embankments will be kept free of woody vegetation for geotechnical stability reasons (BC MWLAP 2003; USACE 2019). The embankments will be subject to annual vegetation inspection/clearing and geotechnical stability inspections.

Internal drainage culverts (henceforth referred to as floodboxes, per BC MWLAP 2003) will be included at topographic low points. The floodboxes will i) allow drainage from inside the road to the lake or river during runoff events when the river/lake is low, and ii) prevent backflow from the river/lake through the culvert to the inside of the road during flood conditions in the river/lake. Examples of typical sections of potential floodbox arrangement are provided in Figure 2, as extracted from Figure 8-1 in USACE (2020).

Manually operated slide gates integrated into the river/lake side outlet structure or within a maintenance access hole are generally considered more reliable closure devices (i.e., what prevents back flow) than flap gates (USACE 2000). Pipe material should suit the individual site characteristics according to

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established design guidelines (e.g., USACE 2000; BC MWLAP 2003; USACE 2020). Regular inspections of the inlet and outlet should be performed to mitigate blockages. This Project has assumed that floodboxes will be required every 100 m of dike length (on average). Pumps and hoses should be held in reserve for the situation where the lake or river is high (i.e., above the culvert elevation) and a runoff event occurs on the inside of the road; in this scenario, internal drainage will need to be pumped over the road and into the river/lake.

If the raising of the road will impede water in the main waterbody from moving downstream (i.e., main watercourse flood conveyance), floodplain culverts may be included. These floodplain culverts are different from the floodboxes in that they will convey main watercourse floodwaters from one side of the embankment to the other during main watercourse flood conditions.

For this Project, the raised road design is considered at existing public roads, where raising the roads will reduce the risk of flood water entering the community. The raised road design is not considered for private roads. For driveways which connect to a road segment to be raised, driveway improvements will be made. Impacts to existing drainage systems, overhead utilities, buried utilities, and other site-specific community infrastructure will need to be addressed at the detailed design phase on a site-specific basis. This Project assumes that no part of the road footprint will encroach on private property and that the existing road is suitable (as determined in geotechnical analysis) to function as a dike.

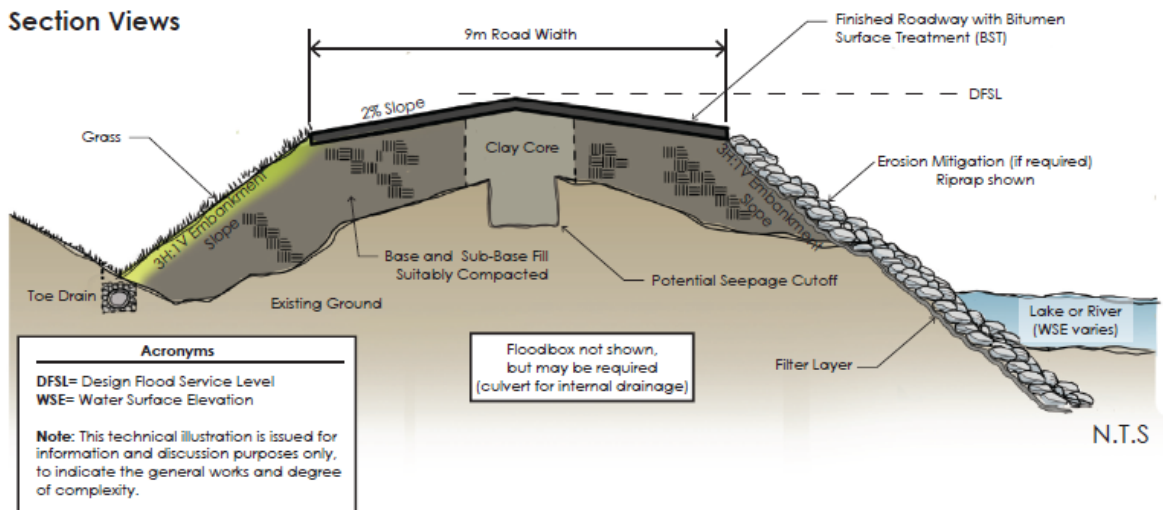


Figure 1 Typical Conceptual Design – Raised Road

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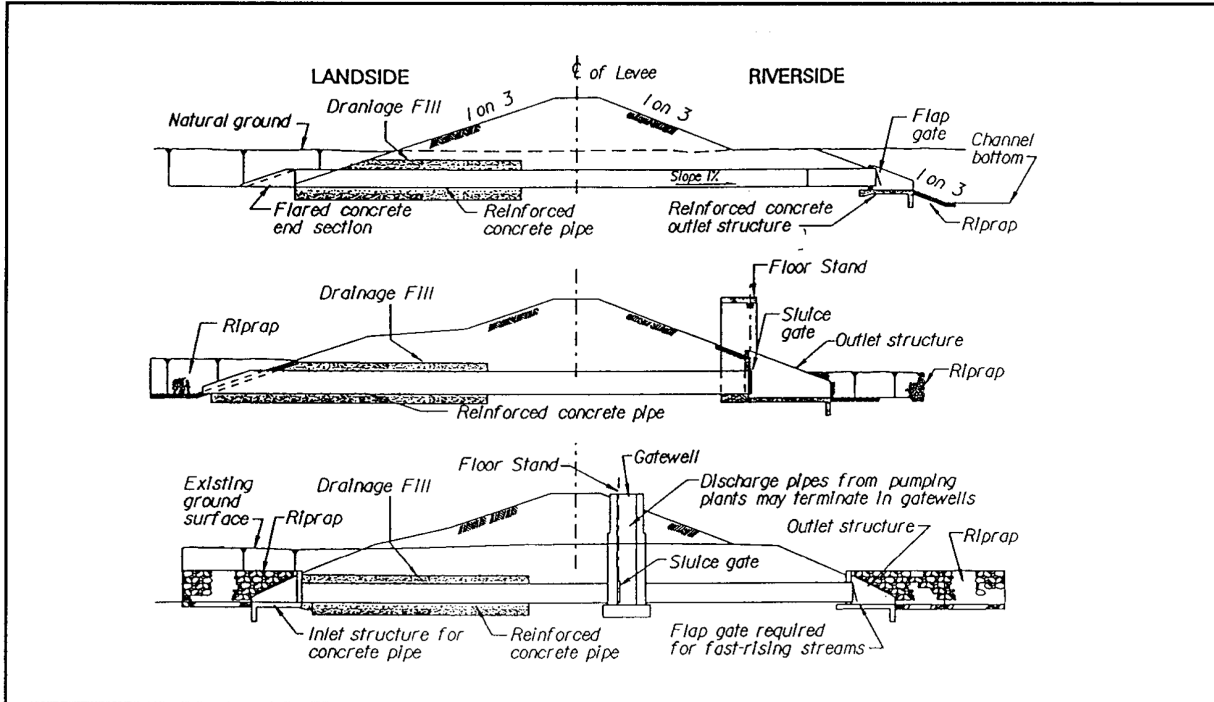


Figure 2 Examples of Typical Sections of Drainage Structures through Dikes (floodboxes), as originally provided in Figure 8-1 from USACE (2000)

3.3.2.2 Earthen Dike

The typical design of the earthen dike consists of a permanent flood defense dike comprised of suitably compacted soil (to be specified during detailed design) with a dike top elevation at the DFSL. The typical plan form and cross-section of the earthen dike design is conceptually illustrated in Figure 3.

The earthen dike will have a minimum top width of 3 m. Dike side slopes typically of 3H:1V although more gradual slopes may be required to meet slope stability and seepage requirements (to be determined during detailed design). Based on availability of clay material, the earthen dike has been assumed to have a 3 m wide (top width) clay core with a dike shell consisting of granular material for the side slopes of the dike. The clay core would have typical 0.5H:1V side slopes at the transition to the granular dike shell. The clay core is required for seepage requirements. The side slopes of the dike and the dike top will be topsoiled and seeded with native grass species, although erosion protection (e.g., riprap) may be required on the wet side of the dike. If existing access points to the lake or river will be blocked due to dike construction or erosion protection, access points (i.e., ramps, stairs, etc.) may be installed. Depending on the location of the earthen dike in a specific community and subject to community agreements, zoning, and priorities, the 3 m wide dike crest may function as a community pathway.

The dike footprint (top, side slopes) and a 5 m root-free zone on either side of the dike toe will be kept free of woody vegetation for geotechnical stability reasons (USACE 2019). The dike will be subject to annual vegetation inspection/clearing and geotechnical stability inspections. The dike will be spatially located in a way that balances community flood mitigation and disturbance/encroachment to property and infrastructure. However, depending on the community and property line configuration at a given community the dike's footprint or root-free zone may extend onto private property in certain locations

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which will require an easement to be established. The owner of the dike will be responsible for completing/procuring the requisite annual inspection and maintenance activities for the dike (e.g., vegetation clearing, stability assessments, easement payments).

Floodboxes will be required at topographic low points along the dike for internal drainage and also to prevent back flow during flood conditions on the river/lake. Manually operated slide gates integrated into the river/lake side outlet structure or within a maintenance access hole are generally considered more reliable closure devices (i.e., what prevents back flow) than flap gates (USACE 2000). Pipe material should suit the individual site characteristics (USACE 2000; BC MWLAP 2003). This Project has assumed that floodboxes will be required every 100 m of dike length (on average). Pumps and hoses should be held in reserve for the situation where the lake or river is high (i.e., above the floodbox elevation) and a runoff event occurs on the inside of the road; in this scenario, internal drainage will need to be pumped over the road and into the lake or river.

Depending on the anticipated duration of flooding at a given community and findings of hydrogeological studies, a clay seepage barrier may be designed and installed below the clay dike to reduce seepage rates. The clay seepage barrier would mitigate seepage through the dike during flood conditions. The seepage barrier design would not be permitted to impact regional groundwater conditions and processes.

For this Project, the earthen dike design is typically applied to areas where a continuous flood mitigation structure is appropriate for reducing flood risk for multiple properties or community infrastructure and there is adequate space for the required dike footprint (determined at the site scale based on conceptual design grading requirements).

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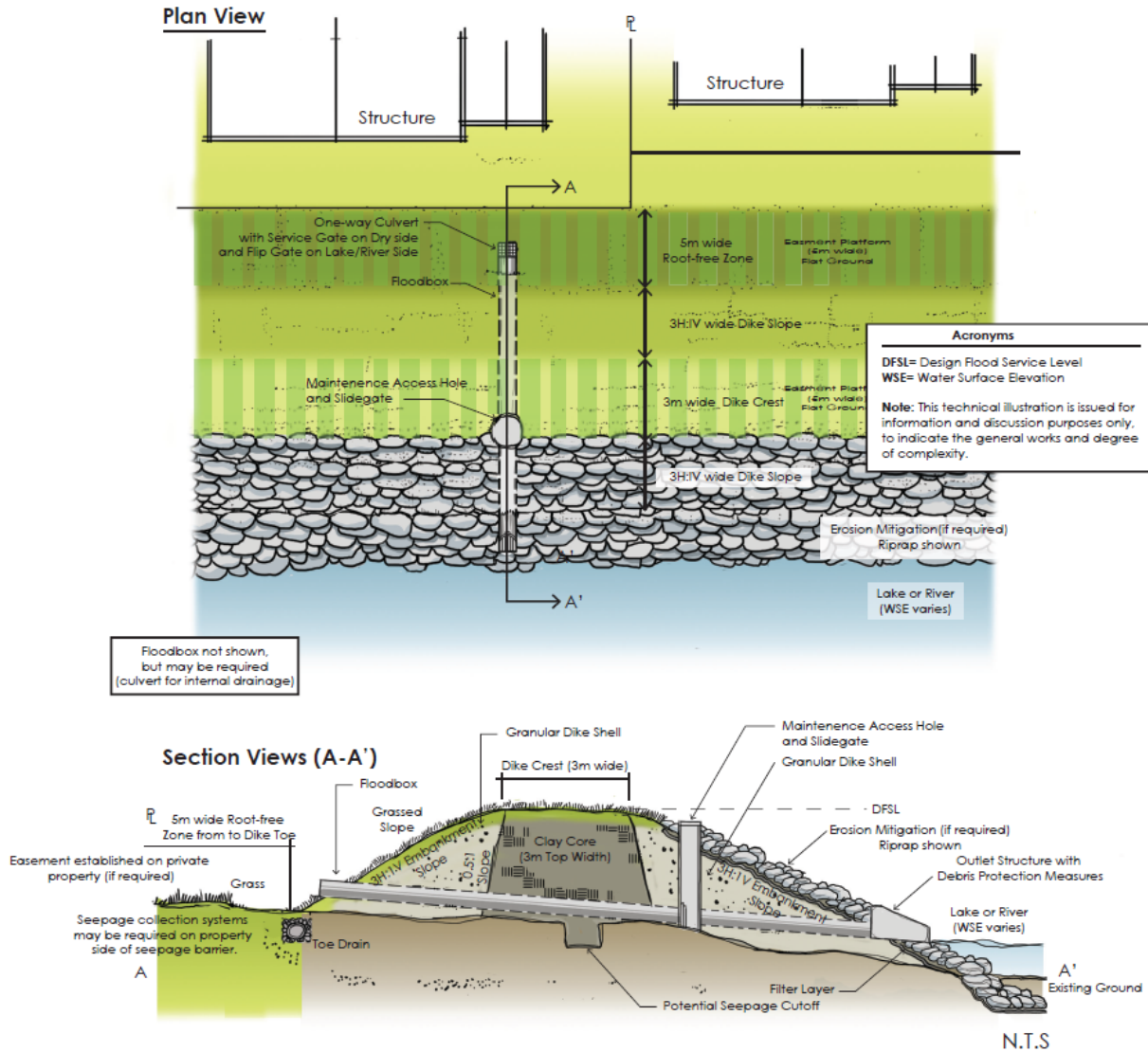


Figure 3 Typical Design – Earthen Dike

3.3.2.3 Structural Dike

The typical design of the structural dike consists of a permanent flood defense dike comprised of suitably compacted soil (to be specified in detailed design) with structural elements in place of the side slopes on the wet side of the dike to act as a retaining structure (resulting in a narrower dike structure). The structural dike will have a dike top elevation at the DFSL. The typical plan form and cross-section of the structural dike design is conceptually illustrated in Figure 4.

The structural dike will have a minimum top width of 3 m. The structural element on the wet side of the dike is assumed to be sheet pile in this Project, however other structures such as concrete blocks or segmental block walls may be considered during detailed design. The structural element on the dry side of the dike is assumed to be concrete blocks or segmental blocks. Dike side slopes on the either side (sheet pile, concrete/segmental blocks) will be vertical. The top of the dike will be topsoiled and seeded

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with native grass species. If existing access points to the lake or river will be blocked due to the dike, then access points (i.e., ramps, stairs, etc.) may be installed. Depending on the location of the structural dike in a specific community and subject to community agreements, zoning, and priorities, the 3 m wide dike crest may function as a community pathway. Safety handrails will be installed on either side of the structural dike due to the fall-from-heights hazard on either side of the structural dike, per the *National Building Code of Canada* (NRCC 2020).

The dike footprint (top, side slopes) and a 5 m root-free zone on either side of the dike toe will be kept free of woody vegetation for geotechnical stability reasons (USACE 2019). The dike will be subject to annual vegetation inspection/clearing and geotechnical stability inspections. The dike will be spatially located in a way that balances community flood mitigation and disturbance/encroachment to property and infrastructure. However, depending on the community and property line configuration at a given community the dike's footprint or root-free zone may extend onto private property in certain locations which will require an easement to be established. The owner of the dike will be responsible for completing/procuring the requisite annual inspection and maintenance activities for the dike (e.g., vegetation clearing, stability assessments, easement payments).

Floodboxes will be required at topographic low points along the dike for internal drainage and to prevent back flow during flood conditions on the river/lake. Manually operated slide gates integrated into the river/lake side outlet structure or within a maintenance access hole are generally considered more reliable closure devices (i.e., what prevents back flow) than flap gates (USACE 2000). Pipe material should suit the individual site characteristics (USACE 2000; BC MWLAP 2003). This Project has assumed that floodboxes will be required every 100 m of dike length (on average). Pumps and hoses should be held in reserve for the situation where the lake or river is high (i.e., above the floodbox elevation) and a runoff event occurs on the inside of the road; in this scenario, internal drainage will need to be pumped over the road and into the lake or river.

Depending on the anticipated duration of flooding at a given community and findings of hydrogeological studies, the steel sheet pile wall may be extended several meters below the existing ground surface for stability, or to serve as a seepage barrier. The sheet pile seepage barrier would mitigate seepage through the dike during flood conditions. The clay seepage barrier would mitigate seepage through the dike during flood conditions. The seepage barrier design would not be permitted to impact regional groundwater conditions and processes. This Project assumes that the sheet pile will be installed to a depth equal to its height above ground, although deeper depths may be required to meet structural stability requirements (to be determined during detailed design). Hydrogeological assessments should also be completed during the detailed design phase to evaluate the impact to natural groundwater flow.

For this Project, the structural dike design is typically applied to areas where a continuous flood mitigation structure is appropriate for reducing flood risk for multiple properties or community infrastructure.

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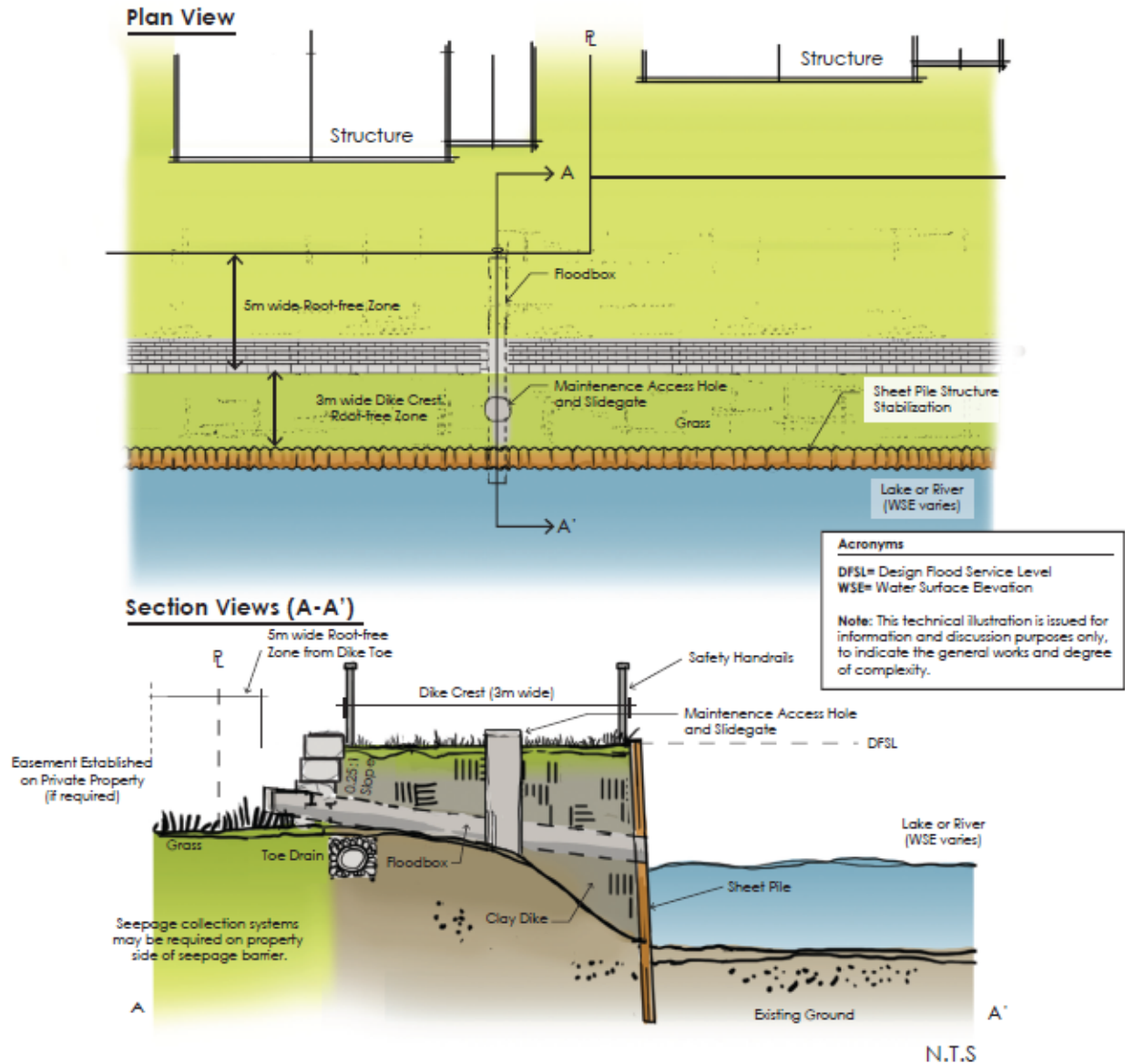


Figure 4 Typical Conceptual Design – Structural Dike

3.3.2.4 Platform with Temporary Superbag Dikes

The typical design of a platform with a temporary superbag dike will consist of a stable on-grade platform along the lake or river front. The typical plan form and cross-section of the platform with temporary superbag dikes design is conceptually illustrated in Figure 5 for non-flood years and flood years. Superbag dikes have been selected as the demountable in this typical design because a detailed review of demountables options in Stantec (2022) and included in Appendix T identified that they were among the most economical demountables. The Stantec (2022) investigation also noted that temporary superbag dikes are among the simplest to deploy; they were successfully installed in the Yukon in both 2021 and 2022 (i.e., in-territory deployment knowledge exists). Lastly, temporary superbag dikes are among the more durable demountables (compared to others like water dams), which is of particular importance for

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the Yukon context where waves, debris, and ice can damage demountables and degrade their effectiveness.

If and when a flood is forecasted, the cleared platform will allow for relatively efficient deployment of a temporary superbag dike, which will raise the elevation of the overall flood mitigation to the DFSL. The elevation profile of the platform will follow the existing ground elevation at the platform centreline; however filling may be required to achieve a platform elevation that is not more than 2 m below the DFSL. This is so that either a single superbag dike (1 m in height) or double superbag dike (2 m in height) will extend the mitigation to the DFSL. The cross-section will consist of a 5 m wide flat platform with 3H:1V side slopes. Based on availability of clay material, the areas where the land needs to be raised has been assumed to have a 3 m wide (top width) clay core with a shell consisting of granular material for the side slopes of the easement fill. The clay core would have typical 0.5H:1V side slopes at the transition to the granular shell. The clay seepage barrier would mitigate seepage through the dike during flood conditions. The seepage barrier design would not be permitted to impact regional groundwater conditions and processes.

In areas where the existing ground is not adequate in either structural integrity or elevation to act as a platform, compacted fillings, raising, or grading may be required to allow for the height of the 2 m of demountable flood barriers to be within 2 m of the DSFL. Erosion protection (e.g., riprap) may be required on the lake or river side of the platform. If access to the lake is blocked due to the placement of erosion protection, access points (i.e., ramps, stairs, etc.) may be installed.

In order for temporary superbag dikes to be deployed rapidly and properly in advance of a flood, formal response protocols (e.g., response thresholds, actions, timeframes, installation procedures) will need to be developed. The owner (e.g., YG or community) and the individual flood responders will need to be trained on those protocols. The requisite equipment and labour, machinery (e.g., loader and skidsteer with forks), and material (e.g., superbags, sand to fill bags) must be ready for response and mobilized such that dikes can be constructed in advance of the flood. Once flood waters recede, the owner will need to coordinate removal of the temporary superbag dikes and dispose/relocate the fill material and superbags to a suitable location. The performance of the easement with temporary superbag dikes typical design is heavily dependent on the ability of the owner and flood responders to successfully implement the above advanced planning, material delivery, installation, and quality control procedures.

If the alignment and width of the platform and grading extends onto private property, establishment of an easement may be required. The establishment of the easement would allow for inspections, vegetation maintenance, and (during a flood event) temporary superbag deployment.

Prior to adoption of the platform with temporary superbag dike design, an organization will have to be identified and appropriately resourced to install the superbag dikes within the timeline provided by the flood forecasting. This organization will also be responsible for removing the temporary superbag dike following abatement of the flood. The platform and side slopes will be kept free of woody vegetation and will be subject to annual geotechnical stability inspections.

Floodboxes may be required at topographic low points along the platform for internal drainage and to prevent back flow during flood conditions on the river/lake. Manually operated slide gates integrated into the river/lake side outlet structure or within a maintenance access hole are generally considered more reliable closure devices (i.e., what prevents back flow) than flap gates (USACE 2000). Pipe material should suit the individual site characteristics (USACE 2000; BC MWLAP 2003). This Project has assumed

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that floodboxes will be required every 100 m of platform length (on average). Pumps and hoses should be held in reserve for the situation where the lake or river is high (i.e., above the floodbox elevation) and a runoff event occurs on the inside of the platform or seepage through the dike occurs. In this scenario, internal drainage will need to be pumped over the platform and into the lake or river.

For this Project, the easement with temporary superbag dike design is typically applied to areas where a continuous flood mitigation structure is appropriate for reducing flood risk for multiple properties or community infrastructure.

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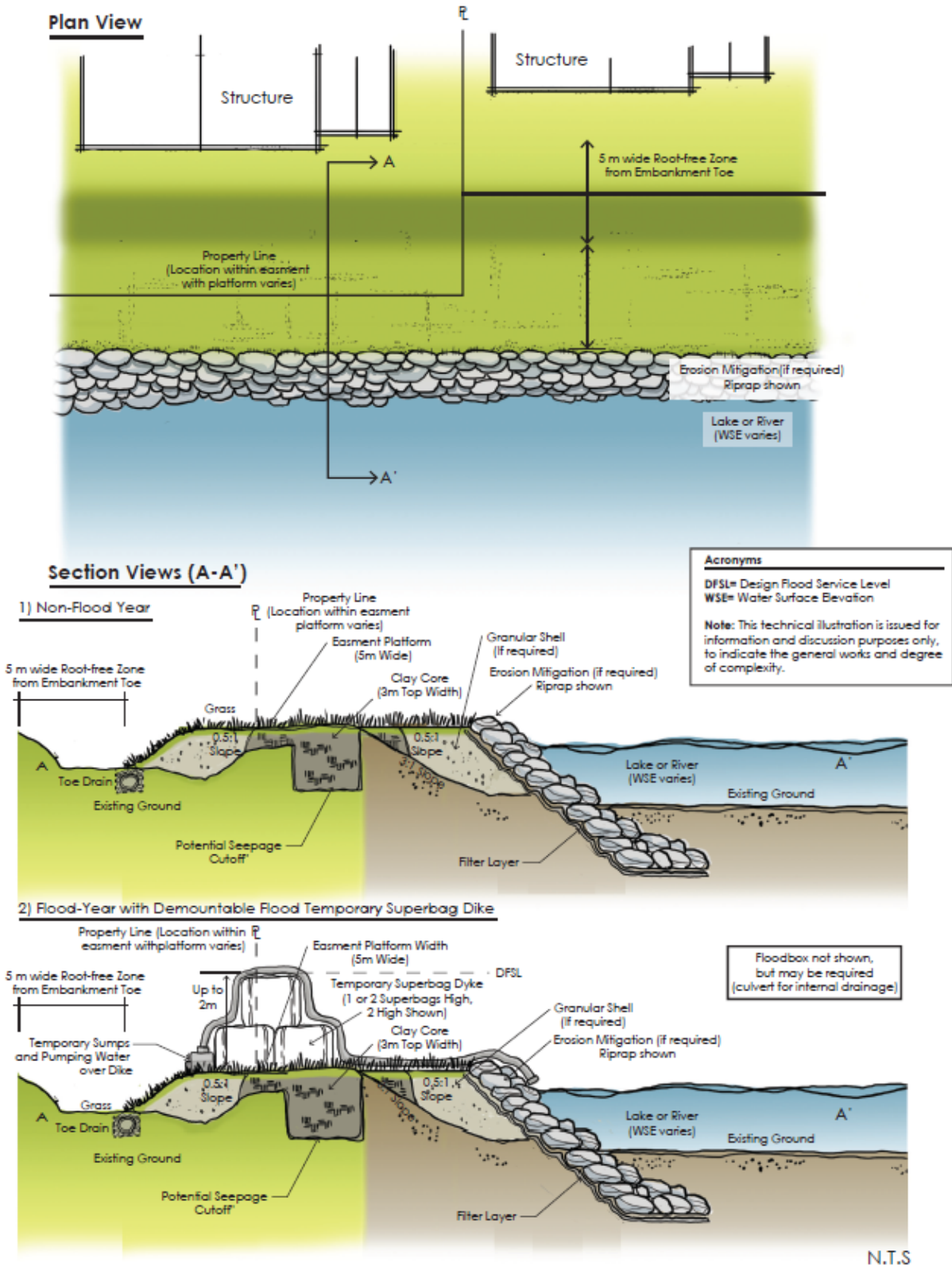


Figure 5 Typical Conceptual Design – Easement with Temporary Superbag Dike

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3.3.2.5 Temporary Sandbag Dikes

The typical design of a temporary sandbag dike consists of individual sandbags placed in layers of alternating orientation (perpendicular to flow, parallel to flow) to form a dike with a trapezoidal cross-section. A layer of polyethylene sheet is typically weaved vertically between the sandbag layers, creating an impermeable barrier within the sandbag dike. The typical plan and cross-section of the temporary sandbag dike design is conceptually illustrated in Figure 6 (as adapted from the *Sandbag Dike Construction* document available from the Government of Manitoba 2023) for non-flood years and flood years. Recommendations for installation of temporary sandbag dikes are provided by Government of Manitoba (2023).

In order for temporary sandbag dikes to be deployed rapidly and properly in advance of a flood, formal response protocols (e.g., response thresholds, actions, timeframes, communications for community members) will need to be developed. Community members will benefit from formal training or instruction on sandbag dike construction. The requisite material (e.g., sandbags, sand to fill bags) must be ready for response and delivered to the community such that community members can construct dikes before the flood. Sandbags will need to be stored in a secure, dry location prior to use. The filling of the individual bags can be completed by specialized pieces of equipment for increased deployment efficiency. Biodegradable bags and ties are recommended in case some sandbags are missed in the removal operation. Community members will need clear direction on protocols for dike removals once flood waters recede. The performance of the easement with temporary sandbag dikes typical design is heavily dependent on the ability of the owner to successfully implement the above advanced planning, material delivery, and communication procedures.

For this Project, temporary sandbag dikes are applied for ring dikes at private properties located within the Study Area of a given community, but away from the main developed area of the community. Extending the main community flood mitigations to these individual private properties is unlikely to have favourable economics; in this situation, temporary sandbag ring dikes are a suitable mitigation. This Project assumes that the requisite number of sandbags and earthen material for the ring dikes will be supplied and delivered to a centralized location in the community. Prior to adoption of this typical design, that organization will need to be identified and appropriately resourced. The organization will not construct or remove the ring dikes at the individual properties; construction and removal of the sandbag ring dikes will be completed by private property owners, community volunteers, or others.

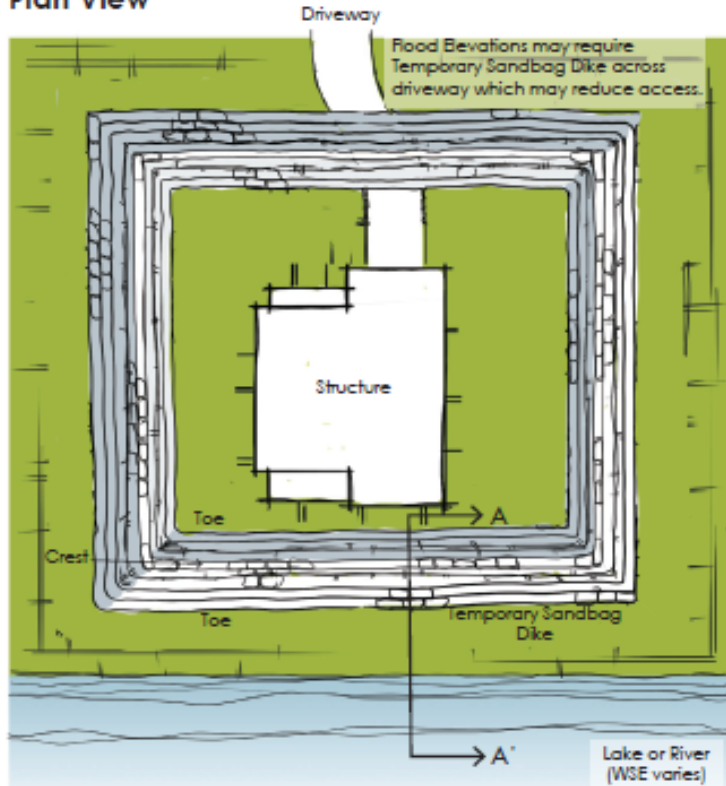
Due to the temporary nature of sandbag dikes, floodboxes are typically not included. Therefore, pumps and hoses should be held in reserve for the situation where the lake or river is high (i.e., above the floodbox elevation) and a runoff event occurs on the inside of the temporary sandbag dike or seepage through/under the dike occurs. In this scenario, water on the inside of the temporary sandbag dike will need to be pumped over the dike and into the lake or river.

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Plan View



Section Views (A-A')

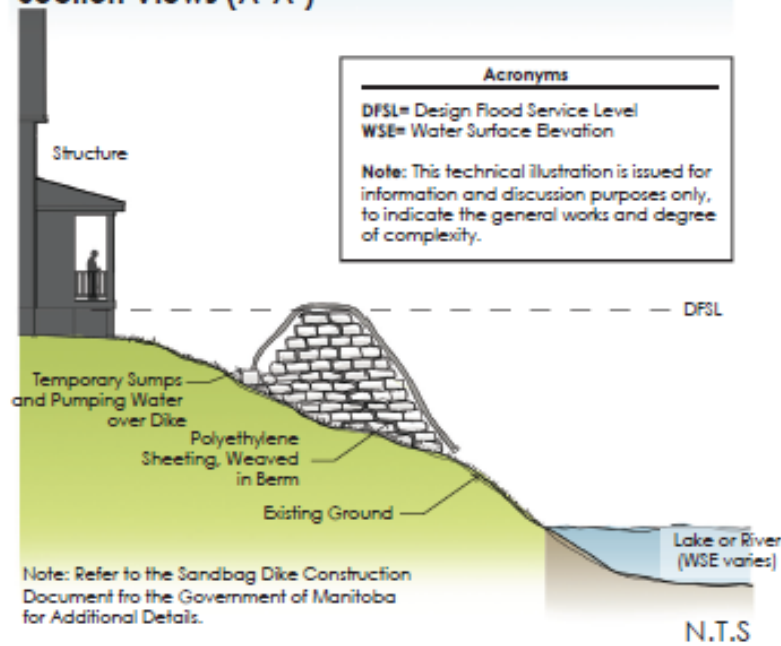


Figure 6 Typical Conceptual Design – Temporary Sandbag Dike (adapted from Government of Manitoba 2023)

3.4 Opinion of Probable Cost

Opinion of Probable Costs (OPCs) for the conceptual options use quantities estimated from conceptual design grading combined with estimated unit costs of materials, equipment, and labour.

Quantities are estimated in AutoCAD Civil 3D 2019 using conceptual grading considering the typical design parameters (Section 3.3.2) and the existing topographic/bathymetric data (e.g., LiDAR from GeoYukon 2023) at the given community. Unit costs are based on historical project data available to Stantec at the time of writing. Where costing for individual line items is not available in either the location of the community or the current time period, costs have been adjusted using a location factor and temporal price index data:

- Location Factor: A literature review of location adjustment factors for construction costing in North America (Ontario Construction Secretariat 2001) shows that there is limited data available outside of Vancouver and Toronto. To supplement location data in the Yukon, the *Index of Remoteness* (Statistics Canada 2023a) has been used to scale costs between communities.

The Index of Remoteness was not originally developed to reflect the difference of construction costs of different communities but is applied in this Project as a proxy for regional construction cost differences, as no such published resource exists. Construction costing data in each of the 19 communities was not made available to Stantec at the time of writing this report and if the reader has additional construction cost data in the location of work, it is suggested that they use this data to determine more accurate costs. The adjustment of costs based on location can be shown with the following formula:

$$C_i = C_o \frac{F_{Lo}}{F_{Li}}$$

Where C_i is the adjusted unit cost in Canadian Dollars (\$CAD) for the target location, C_o is the unit cost in the base location in Canadian Dollars (\$CAD), F_{Lo} is the remoteness index for the base location and F_{Li} is the remoteness index for the target location (Table 2).

- Temporal Price Index: As with location adjustment factors, a reliable temporal price index, particularly for heavy civil construction is not available in Canada. To provide adjustment for of unit costs that have been obtained from previous years, Stantec has selected to use the 2022, *Non-Residential Building Price Construction Index* (BCPI) (Statistics Canada 2023b). This index tracks non-residential construction costs in eleven major Canadian cities. The aggregate index of the eleven tracked cities has been used to adjust unit costs obtained in alternative years. The adjustment of costs based on time can be shown with the following formula:

$$C_i = C_o \frac{F_{To}}{F_{Ti}}$$

Where C_i is the adjusted unit cost in Canadian Dollars (\$CAD) for the target location, C_o is the unit cost in the base location in Canadian Dollars (\$CAD), F_{To} is the aggregate BCPI for the base location and F_{Ti} is the aggregate BCPI for the target location.

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As a result of the above costing approach, estimated quantities and unit costs (in 2023 \$CAD) vary by community and are therefore summarized in Appendix A through Appendix S.

Three separate Class D Opinion of Probable Cost (OPC) estimates are produced for each conceptual option, at each community in Appendix A through Appendix S:

1. Capital cost – the estimated cost of constructing the conceptual option.
2. Annual cost during a flood year – the combined cost of enacting and maintaining the full flood mitigation configuration during a year where a flood does occur.
3. Annual cost during a non-flood year – the cost of maintenance and storage (if applicable) for the conceptual during a year where a flood does not occur.

A 20% construction contingency is included in the above OPCs.

In accordance with the Class D definition in CEBC and APEGBC (2009), the Class D OPC estimates:

1. Are prepared for projects with little or no site information.
2. Indicate the approximate magnitude of cost of the proposed project.
3. Are calculated using approximate values, contingencies, professional judgement, and/or analogies to similar projects.
4. Have an expected accuracy range of $\pm 50\%$.

The Class D OPCs are provided in ranges. The lower range is the value produced by the estimated quantities and assumed unit costs. The upper range is the lower range +50%, accounting for the accuracy range of Class D OPCs.

The following are not included in the Class D OPCs:

- Easements, where necessary given platform alignment. Easement payments to property owners can vary in both payment model (single vs. annual payments) and in amount (based on property owner negotiations). This makes them difficult to quantify in this conceptual design phase where property owner engagement on easement compensation has not occurred.
- Aesthetic improvements to flood mitigations (e.g., community trails, signage, lookout points, ornamental structural slope stabilization).
- Pre-construction costs (e.g., additional studies, designs, consultation, and engagement, permitting) required if the option was to be advanced. We note that these pre-construction costs often represent 10% - 25% of the overall cost of a project.

Table 2 Location Factors for Yukon Communities

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Community	Location Factor (LCAF)
Upper Liard, YT	1.59
Teslin, YT	1.43
Carcross, YT	1.28
Tagish, YT	1.34
Army Beach, YT	1.25
Whitehorse, YT	1.00
Carmacks, YT	1.42
Ross River, YT	1.57
Pelly Crossing, YT	2.05
Mayo, YT	2.03
Dawson City, YT	1.56
Old Crow, YT	2.11
Marsh Lake, YT	1.25
Swan Haven, YT	1.25
Shallow Bay, Jackfish Bay, & Deep Creek, YT	1.12
Faro, YT	1.55
Rock Creek, YT	1.56

3.4.1 PER METRE COSTING

The Class D OPCs provided in Appendix A through Appendix S contain represent costing for specific configurations of the typical flood mitigation designs at the respective community. Alternative combinations/configurations of typical flood mitigation designs may be of interest for the communities. To facilitate these high-level discussions, Table 3 provides per-metre costs for the five typical flood mitigation designs at various heights using unit costs as discussed in Section 3.4. The location factors to adjust costs for each of the communities are included in Table 2. Erosion mitigation (riprap) and slope stabilization are included for one side of each of the road raising, earthen dike, and easement platform with temporary superbag dikes.

Communities may use the values in these tables to inform high-level feasibility discussions of alternative configurations. The use of per-metre costs for alternative combinations/configurations will result in OPCs that have substantially wider accuracy ranges than the Class D OPCs produced in this Report.

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Table 3 Per Metre Costs for Typical Flood Mitigation Designs

Description	Height	Per Meter Cost ^{2,3}
Road Raising	1.0m	\$1,640.00
Road Raising	2.0m	\$2,960.00
Road Raising	3.0m	\$4,520.00
Road Raising	4.0m	\$6,320.00
Earthen Dike	1.0m	\$4,700.00
Earthen Dike	2.0m	\$6,670.00
Earthen Dike	3.0m	\$8,710.00
Earthen Dike	4.0m	\$12,320.00
Structural Dike	1.0m	\$8,280.00
Structural Dike	2.0m	\$13,190.00
Structural Dike	3.0m	\$18,150.00
Structural Dike	4.0m	\$23,160.00
Platform with Temporary Superbag Dikes ¹	1.0m	\$1,550.00
Platform with Temporary Superbag Dikes ¹	2.0m	\$3,280.00
Platform with Temporary Superbag Dikes ¹	3.0m	\$5,420.00
Platform with Temporary Superbag Dikes ¹	4.0m	\$7,950.00
Temporary Sandbag Dikes	1.0m	\$285.00
Temporary Sandbag Dikes	2.0m	\$570.00
Temporary Sandbag Dikes	3.0m	\$855.00
Temporary Sandbag Dikes	4.0m	\$1,140.00
NOTES:		
¹ Height provides is the height from existing ground to the constructed platform; temporary superbag dikes would be added on top of the platform.		
² Per-metre costs do not take into account location factors; location factors in Table 2 should be applied when considering the per-metre costs at a specific communities.		
³ Per-metre costs do not include mobilization/demobilization and site preparation capital costs, nor do they reflect annual costs associated with the various flood mitigations.		

3.5 Qualitative Evaluation

The anticipated performance (low-, medium-, high-performance) of each conceptual option is qualitatively evaluated with respect to nine different evaluation criteria based on the information available at the time of writing. Each conceptual option is evaluated as if it were the only option being implemented at that community (i.e., options are mutually exclusive). A brief description of the qualitative evaluation approach is provided below. This evaluation has been included within each community section (Appendices A through S).

The listed order of the evaluation criteria is not indicative of any recommended priority level or weighting. Prioritization and/or assigning of criteria weights are best completed by YG and other partners who will be owning or funding flood mitigations in the Yukon.

1. Viability and Reliability under Extreme Conditions. Flooding processes in the Yukon have unique characteristics. First, the duration of flooding may last for several weeks or even months. Second, at lake sites, flood conditions may be coupled with significant wind and wave events which adds water level fluctuation and erosion risks. Third, the cold climate introduces complexities to geotechnical engineering and may pose ice erosion risks to defense structures if they are to maintain structural integrity over their lifespan. Evaluation of this criteria consists of a qualitative assessment of a conceptual option's ability to maintain structural integrity and flood mitigation performance under these unique Yukon conditions:

- Low performance: repairs or adaptive management actions will likely be required for the mitigations during and after each flood event.
- Medium performance: repairs or adaptive management actions may be occasionally required following flood events.
- High performance: likely to provide adequate flood mitigation under unique flood conditions over multiple flood events; repairs or adaptive management actions unlikely to be required.

2. Time to Implementation. The time to implement the option to a constructed, flood response-ready state is important for project planning. Required activities that can impact the time to implementation include baseline data collection requirements, community engagement, detailed design, regulatory processes, and construction duration. Evaluation of this criteria consists of a qualitative assessment of anticipated time to implementation of the conceptual option according to the following quantitative ranges.

- Low performance: anticipated to take >5 years to implement.
- Medium performance: anticipated to take 2–5 years to implement.
- High performance: anticipated to take <2 years to implement.

The evaluation of this criterion does not consider the response and activation time for a given option (e.g., assembling demountables) in the above ranges. The time estimates used in this qualitative evaluation assume that the requisite funding has been obtained, flood mapping (including wind/wave analyses) and flood policy for the territory/community is in place, and that community agreements and regulatory processes (as applicable) proceed on a typical timeframe based on Stantec's experience.

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Included in the time to implementation criteria is the general risk of regulatory delays, defined as:

- *Low risk:* Temporary sandbag dikes. These are emergency measures that only require reporting to YESAB after the fact. Easements above OHWM on Crown land. While these involve moving of earth and are subject to a YESAB evaluation, they do not require a water licence and the YG is its own regulator.
- *Medium risk:* Work below the OHWM will require a YESAB evaluation and a Water Licence. Work on Settlement lands require permission from the First Nation in addition to any regulatory requirement. Raising roads on Crown land also carries a medium risk as it can be classed as maintenance and repair to an existing structure of installation. Requirements for road raising should be confirmed on a case by case basis
- *High risk:* All dikes. Dikes are subject to YESAB evaluation and carry a high risk of delays due to public concerns.

3. Capital Cost per Inundated Property. Capital costs required to implement the option (including financial resources, human resources, and administrative/political effort) relative to the amount of inundated infrastructure is a crucial consideration in any engineering project. Evaluation of this criterion consists of a qualitative assessment of Class D OPCs on a per inundated property basis (from preliminary inundation analysis) for the option according to the following quantitative ranges.

- Low performance: not economical, Class D OPC base price >\$800,000 per inundated property
- Medium performance: moderately economical, Class D OPC base price between \$300,00 - \$800,000 per inundated property
- High performance: relatively economical, Class D OPC base price <\$300,000 per inundated property

The above ranges span the extent of values for Class D OPC capital cost per inundated property observed in this Project and are not based on any published studies quantifying flood mitigation performance on a per-property basis.

4. Maintenance and Storage. The flood events being considered in the options development are high in severity and low in frequency (refer to Section 3.1). Therefore, in most years, the option will not be activated but will need to be maintained and may have components requiring storage. Evaluation of this criterion consists of a qualitative assessment of maintenance and storage requirements to keep the option ready to perform should a flood occur.

- Low performance: high maintenance and storage requirements
- Medium performance: medium maintenance and storage requirements
- High performance: low maintenance and storage requirements

5. Response and Activation. Some conceptual options may require a degree of response or action to provide the requisite flood mitigation if and when a flood is forecasted. Evaluation of this criterion consists of a qualitative assessment of financial and human resources to i) enact the flood mitigation

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configuration upon notification that a flood is forecasted, and ii) maintain the flood mitigation option during the flood event.

- Low performance: multiple locations within the community requiring deployment of temporary superbag or sandbag dikes; community may be relatively remote.
- Medium performance: modest deployments of superbag and sandbag dikes; community not relatively remote.
- High performance: permanent structures only; no deployment of superbag/sandbag dikes.

6. Aesthetics and Community Function. Installation of engineered flood mitigations will alter the existing aesthetics of the land in the community and may positively or negatively impact community functions. Evaluation of this criterion consists of a qualitative assessment of impact on these existing community aesthetics and functions:

- Low performance: option is highly likely to result in undesirable aesthetics and/or removal/impedance of important community functions.
- Medium performance: option has moderate aesthetic appeal and/or has minimal impact to community functions.
- High performance: option does not have aesthetics that noticeably change from existing conditions and/or provides a net benefit to community functions.

7. Future Adaptability. Flood levels, flood mitigation approaches, and flood policy may change in future years (e.g., new flood processes develop, DFSL may be raised). Evaluation of this criterion consists of a qualitative assessment of the ability of the option to be upgraded and/or adapted for a wide range of potential requirements in the future.

- Low performance: option cannot be upgraded and/or adapted for future conditions.
- Medium performance: option may be suitable for upgrades and/or adapted for future conditions.
- High performance: option is suitable for upgrades and/or adaptations for future conditions.

The evaluation of this criterion does not consider additional flood mitigations for areas in the community which become inundated during future increases to flood WSEs and/or DFSL.

8. Alteration of Existing Hydraulics, Erosion/Sedimentation, Ice Processes, and Slope Stability. Rivers and lakes are complex biophysical systems. Making changes at one location in these systems can—depending on the action—increase flood or erosion hazards elsewhere by altering hydraulics, erosion/sedimentation, and/or ice processes. In addition, placement of additional material along the top edge of riverbanks and lake shore banks could result in slope stability failures of the banks and therefore undermine the flood mitigation infrastructure. Evaluation of this criterion consists of a qualitative assessment of how likely the option is to avoid increasing hazards to humans:

- Low performance: likely to alter hydraulic, erosion/sedimentation, river ice processes, and/or slope stability and the alteration is likely to increase hazards to humans receives a low performance rating.

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- Medium performance: likely to alter hydraulic, erosion/sedimentation, river ice processes, and/or slope stability but the alteration is unlikely to increase hazards to humans.
- High performance: unlikely to alter hydraulic, erosion/sedimentation, river ice processes, and/or slope stability.

9. Disaster Mitigation and Adaptation Funding (DMAF) Applicability. Infrastructure Canada's DMAF program is a federal funding program that invests in disaster mitigation and adaptation projects through grant opportunities. The federal government has invested over \$3.4 billion into this program since 2018 and project must be at least \$1 million in size to be considered. The program targets communities across Canada who have experienced natural disasters (including flooding, permafrost thaw, sea level rise, and storms) due to climate change through the implementation of natural and structural infrastructure. Funding cycles are not regular; the first intake for the program was July 2021 and the second intake for the program is July 2023. It is unknown whether there will be future intakes to this program. Applications for projects are evaluated in a two-stage process; applications undergo an initial eligibility screening, and then there is a full evaluation of the project. Eligible applicants include a province or territory, a public sector body, a Canadian public or not-for-profit entity (if working in collaboration with a municipality) and private sector bodies. Additionally, Indigenous governing bodies, Indigenous Development Corporations, and not-for profit organizations who improve Indigenous outcomes, can apply.

Project evaluations are made on eight merit criteria:

- **Natural Hazard Risk Assessment:** proposal should consider likelihood of hazard risk and socio-economic impacts of hazard using four indicators: a) loss of lives/missing people, b) % people directly affected, c) % local economic loss and d) % population without essential services. Quantitative data must be provided and evidence that includes reports/Indigenous Traditional Knowledge will strengthen natural hazard risk assessment.
- **Community Resilience:** proposal should demonstrate improvements for the population that is exposed to the natural hazard. Critical infrastructure impacts and service disruptions or economic disruptions should be minimized, for example. Quantitative assessment of the four indicators listed above for the natural hazard risk assessment is also taken into account for this criterion.
- **Return on Investment:** proposal should demonstrate that asset reduces/avoids losses due to future natural disasters over the asset lifecycle.
- **Project Rationale:** proposal should show why infrastructure solution is the best option for addressing the natural hazard risk.
- **Innovation:** proposal should provide innovative solution that considers partnerships, replicability/scalability, where possible.
- **Natural Hazard Risk Transfer:** proposal should consider upstream and downstream effects of the natural hazard risk.
- **Strategic Alignment:** proposal and project should align with national and provincial adaptation and mitigation measures and land-use plans.

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- Project Co-Benefits: proposals will offer other benefits to the community including environmental or cultural value or provide employment opportunities.

The highest scoring proposed projects across these eight merit criteria are funded by the Government of Canada. Evaluation of this criteria consists of a qualitative assessment of the suitability/eligibility (low, medium high) of the option for DMAF funding, compared to the other options developed at all the Yukon communities. The qualitative performance score is not an assessment of the options' likelihood for DMAF funding success.

- Low performance: within the conceptual options presented in this Report, relatively poor likelihood of receiving funding.
- Medium performance: within the conceptual options presented in this Report, relatively moderate likelihood of receiving funding.
- High performance: within the conceptual options presented in this Report, relatively high likelihood of receiving funding.

3.6 General Assumptions

Additional assumptions included in the options development, evaluation, and costing are listed below:

1. Numerous studies are required for advancement of flood mitigation design beyond the conceptual design options presented in this Project. These studies include, but are not limited to, flood policy development, hydraulic modelling, flood hazard mapping, erosion hazard mapping/river migration analysis, wind/wave analyses, beach processes and morphodynamics, geotechnical investigation (including permafrost), geohazard mapping, landslide-induced flood wave analysis, hydrogeological investigations, engagement with First Nation Governments, local governments, community members, and the public, regulatory pathway mapping, regulatory applications, and property owner agreements. The findings of the above studies may alter the feasibility and evaluations of the conceptual design options presented in this Report.
2. For options involving temporary superbag dikes and temporary sandbag dikes, the individual options and their costing and evaluation assumes that the owner will successfully mobilize and implement the temporary superbag dikes and deliver the sandbags and material required for the temporary sandbag dikes to the community.
3. Transportation infrastructure between communities as well as the bridges within communities were not within the scope of this Project.
4. Floodboxes are included within the engineered flood mitigations. Backflow prevention measures at other culverts throughout the communities are not included. Detailed culvert inventory of each community is required to identify community-wide floodbox/backflow prevention requirements.

4 Summary

Flooding is the most costly natural disaster in Canada (NRCan 2023). Mitigating flood risks is critical to increasing the resilience of impacted communities by adequately preparing for flooding events.

Flooding has impacted many Yukon communities over the past several decades; most recently in 2021 (Southern Lakes Region and Carmacks), 2022 (Teslin, Carmacks, and Ross River), and 2023 (Dawson, Rock Creek). These flooding events had costly impacts on public infrastructure and private property across the territory.

The Government of Yukon (YG) has identified a total of 19 communities that may be at risk from flood hazards: Upper Liard, Teslin, Carcross, Tagish, South M'Clintock and Army Beach, Whitehorse, Carmacks, Ross River, Pelly Crossing, Mayo, Dawson City, Old Crow, Marsh Lake East Shore, Swan Haven, Shallow Bay, Jackfish Bay, Deep Creek, Faro lagoons, wells, and pump stations near the Pelly River, and Rock Creek.

4.1 Scope of Work

The Government of Yukon retained Stantec to produce conceptual flood mitigation options for each of the aforementioned 19 Yukon communities (the Project). More specifically, the scope of work for this Project is to i) compile background information relevant for conceptual flood mitigation design, ii) develop and describe two to three engineered flood mitigation options at the conceptual design level to reduce overland (surface water induced) flood risk to Yukon communities, and iii) perform high-level costing and qualitative evaluation for each of the two to three conceptual options at each community.

This Project is a conceptual level design and has been completed early in the flood mitigation planning process. Numerous studies, design advancements, and community engagements will be needed for each community prior to flood mitigations being implemented. These include, but are not limited to, flood policy development, hydrology studies, hydraulic modelling, flood hazard mapping, erosion hazard mapping/river migration analysis, wind/wave analyses, beach processes and morphodynamics, geotechnical investigation (including permafrost), geohazard mapping, landslide-induced flood wave analysis, hydrogeological investigations, engagement with First Nation Governments, local governments, community members, and the public, regulatory pathway mapping, regulatory applications, and property owner agreements. The findings of the above studies may alter the feasibility and evaluations of the conceptual design options presented in this Report.

4.2 Conceptual Design Approach

The Yukon does not have flood policy or flood mapping. Stantec makes the following assumptions in order to complete the conceptual design options:

- Preliminary inundation mapping represents an initial estimate (suitable for conceptual design) of areas in each community requiring flood mitigation, using the 1:200-year (0.5% AEP) event WSE and applicable WSE slope from existing published studies.

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- Design Flood Service Level (DFSL) of 0.5 m above the preliminary inundation analysis WSE in rivers, and 2.0 m above the preliminary inundation analysis WSE in lakes

Flood mitigation approaches can be engineered or non-engineered. Non-engineered approaches include emergency response-based approaches, mitigation funding to property owners, land purchase/exchange, regulation of flow, management of ice, and nature-based approaches. Conceptual design of non-engineered approaches are not in the scope of this Project, but should be considered as part of a comprehensive approach to flood mitigation in the Yukon. Transportation infrastructure between communities as well as the bridges within communities were not within the scope of this Project.

This Project considered five typical engineered flood mitigation approaches which have a demonstrated history of reducing the risk of floodwaters entering each community and are regulated in neighbouring jurisdictions (Province of British Columbia 1996). These five typical designs are i) road raising, ii) earthen dike, iii) structural dike, iv) platform with temporary superbag dike, and v) temporary sandbag dike. The general characteristics of each of these five typical engineered designs generally follow the *Dike Design and Construction Guide: Best Management Practices for British Columbia* (BC MWLAP 2003).

At each community, conceptual flood mitigation options are provided for areas which are inundated under the 1:200-year WSE in the preliminary inundation analysis. The top elevation of the flood mitigations in each of the options is designed to reach the DFSL. Each conceptual option is a standalone “package” of flood mitigations at various locations in the community, using combinations of the five typical designs listed above. This means that each of the conceptual options are mutually exclusive.

Three separate Class D Opinion of Probable Costs (OPCs) in accordance with the definition from CEBC and APEGBC (2009) (accuracy range of +/-50%) are completed for each of the conceptual options: i) capital cost, ii) annual cost during a flood year, and iii) annual cost during a non-flood year. The Class D OPCs are developed from quantities estimated from conceptual design grading and estimated unit costs of materials, equipment, and labour. Unit costs are based on historical project data available to Stantec at the time of writing and are adjusted as necessary for each community using a location factor.

The anticipated performance (low, medium, or high performance) of each conceptual option is qualitatively evaluated with respect to nine (9) different evaluation criteria: i) viability and reliability under extreme conditions, ii) time to implementation, iii) capital cost per inundated property, iv) maintenance and storage, v) response and activation, vi) aesthetics and community function, vii) future adaptability, viii) alteration of existing hydraulics, erosion/sedimentation, ice processes, and slope stability, and ix) Disaster Mitigation and Adaptation Fund (DMAF) applicability.

4.3 Community-Specific Results

Conceptual design options for each of the 19 communities are detailed in 19 corresponding appendices (Appendix A through Appendix S). Class D OPCs and qualitative evaluation results for the conceptual options at each community are summarized in Table 4. Development of a territorial flood policy and completion of flood mapping are crucial next steps for advancement of flood mitigation at all Yukon communities.

Upper Liard (Appendix A) has experienced four documented flood events since 2005. Following the 2012 flood, a flood assistance package was offered by YG to 13 properties north and east of the Alaska Highway bridge properties to purchase the properties, complete required environmental remediation, and

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identify the area as flood prone and not suitable for development. Excluding those 13 properties, preliminary inundation analysis indicates that 11 private properties and one community feature/parcel (approximately 700 m of the Alaska highway) would be susceptible to flooding in Upper Liard. Two options are presented for Upper Liard: Option 1 considers typical designs with lower capital costs and higher response/maintenance costs, and Option 2 considers typical designs with higher capital costs and lower response/maintenance costs. Qualitative performance of both options is mixed, with Option 2 generally scoring higher with the exception of capital cost, aesthetics and community function, and future adaptability. Among the list of required baseline studies, floodplain mapping and river erosion/migration analyses are of particular importance for informing advancement of any flood mitigation designs at Upper Liard.

Teslin (Appendix B) experienced its highest flood on record in 1962 although extreme flooding requiring emergency response also occurred in 2021 and 2022. The Village of Teslin has commissioned separate flood mitigation designs between 2011 and present, and have implemented several of the designed mitigations. Preliminary inundation analysis indicates multiple locations across Teslin are likely susceptible to flooding: private properties, government buildings, and businesses west of the Nisutlin Bay bridge (30 private properties and 4 community features/properties in total). Two conceptual design options are presented for Teslin: Option 1 considers typical designs with lower capital costs and higher response/maintenance costs, and Option 2 considers typical designs with higher capital costs and lower response/maintenance costs. Qualitative performance of both options is mixed, with Option 1 scoring higher on time to implementation, capital costs, aesthetics and community function, and future adaptability and Option 2 scoring higher on viability and reliability under extreme conditions. Among the list of required baseline studies, floodplain mapping, wind/wave analyses, and beach erosion studies are of particular importance for informing advancement of any flood mitigation designs at Teslin.

Carcross (Appendix C) experienced flooding events requiring emergency response in 2007 and 2021. Preliminary inundation analysis indicates that the north and south side of the narrows as well as the north side of the community along Grayling Bay are susceptible to flooding, totalling 23 private residences and 11 community features/properties. Three conceptual options are presented: Option 1 considers typical designs with lower capital costs and higher response/maintenance costs, and Option 2 and Option 3 consider typical designs with higher capital costs and lower response/maintenance costs. Qualitative performance was mixed across the options. Of note, all three options had high performance for DMAF applicability due largely to the relatively high amount of infrastructure susceptible to flooding. Among the list of required baseline studies, floodplain mapping, wind/wave analyses, hydrogeology studies, and beach erosion studies are of particular importance for informing advancement of any flood mitigation designs at Carcross.

Tagish (Appendix D) experienced flooding events in 2007 and 2021. Preliminary inundation analysis indicates three main areas susceptible to flooding: on the west side of the Tagish River, on the east side of the community, and at California Beach totalling 39 private residences and three community features/properties. Two conceptual options are presented for Tagish: Option 1 considers typical designs with lower capital costs and higher response/maintenance costs and Option 2 considers typical designs with higher capital costs and lower response/maintenance costs. Qualitative performance was mixed across the two options. Option 1 performs higher on time to implementation, future adaptability, and DMAF applicability and Option 2 performs higher on viability and reliability under extreme conditions and response and activation. Among the list of required baseline studies, floodplain mapping, wind/wave

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analyses, and beach erosion studies are of particular importance for informing advancement of any flood mitigation designs at Tagish.

Army Beach and South M'Clintock (Appendix E) experienced flooding events requiring emergency response in 2007 and 2021. Preliminary inundation analysis indicates that relatively large areas of the Army Beach/South M'Clintock peninsula are susceptible to flooding, totalling 52 private properties and five community features (local roads/pathways). Three conceptual options are presented: Option 1 considers typical designs with lower capital costs and higher response/maintenance costs, and Option 2 and Option 3 consider typical designs with higher capital costs and lower response/maintenance costs. Qualitative performance was mixed across the options. Option 2 and Option 3 performance was comparable, and scored higher than Option 1 on viability and reliability under extreme conditions, maintenance and storage, and response and activation. Option 1 scored higher than Option 2 and 3 for time to implementation, capital cost, aesthetics and community function, and DMAF applicability. Among the list of required baseline studies, floodplain mapping, wind/wave analyses, and beach erosion studies are of particular importance for informing advancement of any flood mitigation designs at Army Beach and South M'Clintock.

Whitehorse (Appendix F) experienced flood events in the winters of 1963-1964, 1964-1965, 1978, and 2000-2001. These flood events are largely attributed to freeze-up ice jamming processes. Flow regulation processes associated with the Whitehorse Rapids Generating Station are understood to have reduced the risk of freeze-up ice jams in recent years. Open water flooding risk is generally considered to be low at Whitehorse due to the flow restricting effects of upstream control structures (Miles Canyon, Yukon Energy dams). Preliminary inundation analysis indicates two main areas which are susceptible to flooding: areas surrounding 2nd and 3rd Avenue, and at Marwell. Water would enter these areas from low spots along the west bank of the Yukon River. Two conceptual options are presented to block the overland flow paths into Whitehorse: Option 1 considers platforms with temporary superbag dikes (decreased capital cost, increased response/maintenance) and Option 2 considers earthen dikes (increased capital cost, decreased response/maintenance). Qualitative performance is generally high across both options, with Option 1 scoring higher on time to implementation and capital cost and Option 2 performing higher on viability and reliability under extreme conditions, maintenance and storage, and response and activation. Both options had high performance for DMAF applicability, largely due to the industrial/commercial properties that would have flooding mitigated by the options. Among the list of required baseline studies, floodplain mapping, hydraulic analysis for the design flood event, ice jam studies, and periodic operational reviews regarding freeze-up ice jam risks are of particular importance for informing advancement of any flood mitigation designs at Whitehorse.

Carmacks (Appendix G) experienced flooding in 2000, 2008, 2021, and 2022. Preliminary inundation analysis indicates areas along River Road (south side of Yukon River), a section of the Klondike Highway north of the bridge, and properties in the Little Salmon/Carmacks First Nation development (north side of the Yukon River) are susceptible to flooding (total of 17 private properties and community features). Although not within the scope of the overland flow conceptual designs in this Project, high flows in the Yukon River have (in 2021 and 2022) raised surrounding groundwater and caused high inflow and infiltration into the sanitary sewer system which has put the wastewater treatment plan at risk. Two conceptual options are presented for Carmacks: Option 1 considers typical designs with lower capital costs and higher response/maintenance costs and Option 2 considers typical designs with higher capital costs and lower response/maintenance costs. Qualitative performance was mixed across the two options. Option 1 performs higher on time to implementation, capital cost, aesthetics and community function, and

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future adaptability and Option 2 performs higher on viability and reliability under extreme conditions and response and activation. Both options scored high for DMAF applicability, driven largely by the infrastructure and access routes that would have flooding mitigated. Among the list of required baseline studies, floodplain mapping (including joint probability analysis for the Yukon River and Nordenskiöld River), and ice jam studies are of particular importance for informing advancement of any flood mitigation designs at Carmacks.

Ross River (Appendix H) experienced flooding in 2013 and 2022. An existing earthen dike exists along the east (upstream) side of the community. Preliminary inundation analysis indicates floodwaters would overtop the existing dike in a 120 m long low point and will also enter the community downstream of the dike. This results in a total of nine private properties and two community features being susceptible to flooding. Three conceptual options are presented for Ross River. Option 1 considers typical designs with lower capital costs and higher response and activation costs around the outer extent of the community. Option 2 and Option 3 consist of partial removal of the existing dike and establishment of the flood mitigation line farther south, allowing for increased floodplain conveyance. Qualitative performance is generally low across all options, largely due to the complexity of the hydraulics and ice processes on the Pelly River at Ross River. Among the list of required baseline studies, floodplain mapping, ice jam studies, and geotechnical investigation of the existing dike are of particular importance for informing advancement of any flood mitigation designs at Ross River.

Pelly Crossing (Appendix I) does not have any documented historical flood events within the Study Area. Based on the preliminary inundation analysis, areas susceptible to flooding include the campground on the southwest side of the bridge and a property on the northwest side of the bridge (totalling six private properties and community features). One conceptual option (Option 1) is presented for Pelly Crossing, consisting of temporary sandbag dikes for the affected properties. Option 1 has high performance for time to implementation, capital cost, maintenance and storage, future adaptability, and alteration of existing hydraulics, erosion/sedimentation, ice processes, and slope stability. Option 1 has medium or low performance for the rest of the evaluation criteria. Among the list of required baseline studies, floodplain mapping and ice jam studies are of particular importance for informing advancement of any flood mitigation designs at Pelly Crossing.

Mayo (Appendix J) experienced freeze-up ice jam flooding in the winters of 2010-2011, 2011-2012, and 2012-2013. Flood bypass channels in the Mayo River and revised Yukon Energy flow regulation protocols during freeze-up were implemented in the mid-2010's; freeze-up ice jams have not presented flood risks to the community since their establishment. Mayo has an existing earthen dike which surrounds the community. Preliminary inundation analysis indicates that the crest of the dike is above the 1:200-year water surface elevation but substantial portions of the community inside the dike are below the 1:200-year WSE (totalling 103 private properties and five community features including the health centre, fire hall, recreation complex, YEC's diesel generating plant and Northern Tutchone Regional Duty Office). The existing dike has demonstrated instances of seepage/leakage. One option (Option 1) is presented for Mayo, consisting of upgrades/replacement of the existing dike. Qualitative performance is generally high for Option 1, largely due to the substantial area and features that would have flood hazards mitigated. Among the list of required baseline studies, floodplain mapping (including joint probability analysis for the Stewart River and Mayo River), ice jam studies, hydrogeology studies, and geotechnical investigation of the existing dike are of particular importance for informing advancement of any flood mitigation designs at Mayo.

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Dawson City (Appendix K) – including the city centre and Klondike River valley – has experienced numerous flood events dating back to 1898. Flooding has occurred by both ice jam and open water flood processes. Preliminary inundation analysis indicates that substantial portions of the city centre and locations in the Klondike River valley are susceptible to flooding. In total, an estimated 765 private properties and community features are susceptible to flooding in the Study Area. Dawson has an existing dike which has generally performed well upgrades in the 1980's, however the city's stormwater outfalls to the Yukon River currently provide a pathway for floodwaters to enter the community. Two conceptual options are presented: Option 1 considers typical designs with lower capital costs and higher response/maintenance costs and Option 2 considers typical designs with higher capital costs and lower response/maintenance costs. Qualitative performance was mixed across the two options. Option 1 performs higher on time to implementation and capital cost and Option 2 performs higher on viability and reliability under extreme conditions, response and activation, maintenance and storage, and DMAF applicability. Among the list of required baseline studies, floodplain mapping (including joint probability analysis for the Yukon River and Klondike River), ice jam studies, hydrogeology studies, and geotechnical investigation of the existing dike are of particular importance for informing advancement of any flood mitigation designs at Dawson.

Old Crow (Appendix L) has experienced numerous extreme flooding events since the 1930's (1932, 1973, 1989, and 1991). Flooding events typically occur as a result of ice jam processes. Preliminary inundation analysis indicates that nearly the entire fly-in community is susceptible to flooding (approximately 150 private properties and all community features except for the school), making Old Crow one of the most flood-vulnerable communities in the Yukon. Two options are presented: Option 1 consists of dikes around the community and connecting to high ground to the north, and Option 2 consists of a dike encircling the community. Qualitative performance of the two options are generally low, largely due to the complexity of flood processes, scale of required works, and likely impact to existing hydraulics, erosion/sedimentation, and ice processes on the Porcupine River. Among the list of required baseline studies, floodplain mapping, ice jam studies, and geotechnical/permafrost investigations are of particular importance for informing advancement of any flood mitigation designs at Old Crow.

Marsh Lake East Shore (Appendix M) experienced extreme flooding in 2021 requiring emergency response. Preliminary inundation analysis indicates that 10 properties in various locations along the Marsh Lake east shoreline are susceptible to flooding. One option is presented, consisting of deployment of temporary sandbag dikes around the affected private properties. Qualitative performance is generally high, with the exception of viability and reliability under extreme conditions and DMAF applicability. Among the list of required baseline studies, floodplain mapping and wind/wave analyses are of particular importance for informing advancement of any flood mitigation designs at Marsh Lake East Shore.

Swan Haven (Appendix N) did not have any areas which were inundated under the preliminary inundation analysis, and therefore has no conceptual mitigation options developed. Swan Haven is susceptible to land loss from erosion (outside the scope of this Project). Wind/wave analyses and natural beach processes should be studied at Swan Haven.

Shallow Bay (Appendix O) experienced high lake levels that affected shoreline properties in 2021. Preliminary inundation analysis indicates that three properties along Shallow Bay Road are susceptible to flooding. One option is presented for Shallow Bay, consisting of deployment of temporary sandbag dikes around the affected private properties. Qualitative performance is generally high, with the exception of viability and reliability under extreme conditions and DMAF applicability. Among the list of required

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baseline studies, floodplain mapping and wind/wave analyses are of particular importance for informing advancement of any flood mitigation designs.

Jackfish Bay (Appendix P) experienced high lake levels that affected shoreline properties in 2021. Preliminary inundation analysis indicates that eight private properties and one community feature/property (Jackfish Bay Road) are susceptible to flooding. Two options are presented for Jackfish Bay: both consist of temporary sandbag dikes around affected private properties but Option 1 considers a temporary superbag dike along Jackfish Bay Road, while Option 2 considers permanent road raising. Qualitative performance of both options are generally high and comparable, however Option 1 scores higher on time to implementation and capital cost while Option 2 scores higher on response and activation and DMAF applicability. Among the list of required baseline studies, floodplain mapping and wind/wave analyses are of particular importance for informing advancement of any flood mitigation designs.

Deep Creek (Appendix Q) experienced high lake levels that affected shoreline properties in 2021. Preliminary inundation analysis indicates that 15 private properties and one community feature/property (Deep Creek South Road) are susceptible to flooding. Three options are presented for Deep Creek: Option 1 considers typical designs with lower capital costs and higher response/maintenance costs, Option 3 considers typical designs with higher capital costs and lower response/maintenance costs, and Option 2 represents a middle ground between the two extremes. Qualitative performance is mixed. Of note, as capital costs increase across the options, time to implementation, aesthetics and community function, and future adaptability score lower. Among the list of required baseline studies, floodplain mapping and wind/wave analyses are of particular importance for informing advancement of any flood mitigation designs.

Faro Lagoons, Wells, and Pump Station (Appendix R) did not have any areas which were inundated under the preliminary inundation analysis, and therefore no conceptual mitigation options are presented. The land inside the road at the Faro lagoons is below 1:200-year WSE meaning it is susceptible to seepage during flood conditions. Seepage may also be a concern for the wells and pump stations and may cause lagoon liners to float and dislodge. Seepage-specific designs are outside the scope of this Project. Among the list of required baseline studies, geotechnical and hydrogeological study be performed to evaluate the seepage and stability risk to the road, lagoons, wells, and pump stations.

Rock Creek (Appendix S) experienced flood events in 1999, 2000, and 2023, due to both open water and ice jam processes. Preliminary inundation analysis (open water only) indicates that five private properties and community features (roads) are susceptible to flooding. Flooding is likely to be more severe under ice jam processes however there is insufficient ice jam data/studies at Rock Creek to inform ice jam inundation scenarios. Two conceptual options are presented: Option 1 considers typical designs with lower capital costs and higher response/maintenance costs, and Option 2 considers typical designs with higher capital costs and lower response/maintenance costs. Qualitative performance was mixed across the options. Option 1 scored higher than Option 2 on time to implementation and capital cost, while Option 2 scored higher than Option 1 on viability and reliability under extreme conditions and maintenance and storage. Among the list of required baseline studies, floodplain mapping, ice jam studies, and hydrogeology studies are of particular importance for informing advancement of any flood mitigation designs at Rock Creek.

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Table 4 Summary of Yukon Territory Flood Hazard Mitigation Conceptual Design Options

Appendix	Community	Option	Class D Opinion of Probable Costs			Qualitative Evaluation									
			Capital Cost	Annual - Flood Year	Annual - Non-flood Year	Viability and Reliability	Time to Implementation	Capital Cost per Inundated Property	Maintenance and Storage	Response and Activation	Aesthetics and Community Function	Future Adaptability	Alteration of Existing Hydraulics, Erosion/Sedimentation, Ice Processes, and Slope Stability	DMAF Applicability	
A	Upper Liard	Option 1	None	\$1,991,500 - \$2,987,250	\$1,100 - \$1,500	Low Performance	Medium Performance	High Performance	High Performance	High Performance	Low Performance	High Performance	High Performance	Low Performance	High Performance
		Option 2	\$8,891,600 - \$13,337,400	\$407,900 - \$611,850	\$20,000 - \$30,000	Medium Performance	Medium Performance	Low Performance	High Performance	High Performance	High Performance	Medium Performance	High Performance	Low Performance	High Performance
B	Teslin	Option 1	\$39,587,500 - \$59,381,250	\$2,891,800 - \$4,337,700	\$26,600 - \$39,900	Medium Performance	Medium Performance	Low Performance	Low Performance	Low Performance	Low Performance	Medium Performance	High Performance	High Performance	Medium Performance
		Option 2	\$68,796,900 - \$103,195,350	\$1,021,400 - \$1,532,100	\$103,800 - \$155,700	High Performance	Low Performance	Low Performance	Medium Performance	Medium Performance	Low Performance	Medium Performance	Medium Performance	High Performance	Medium Performance
C	Carcross	Option 1	\$26,532,500 - \$39,798,750	\$2,437,700 - \$3,656,550	\$23,800 - \$35,700	Low Performance	Medium Performance	Medium Performance	Low Performance	Low Performance	Low Performance	Medium Performance	High Performance	High Performance	High Performance
		Option 2	\$72,260,100 - \$108,390,150	\$271,903 - \$407,854	\$92,928 - \$139,392	High Performance	Low Performance	Low Performance	High Performance	High Performance	Low Performance	Medium Performance	High Performance	High Performance	High Performance
		Option 3	\$61,548,600 - \$92,322,900	\$419,174 - \$628,762	\$92,928 - \$139,392	High Performance	Low Performance	Low Performance	Medium Performance	High Performance	Low Performance	Medium Performance	High Performance	High Performance	High Performance
D	Tagish	Option 1	\$22,829,900 - \$34,244,850	\$3,324,000 - \$4,986,000	\$24,900 - \$37,350	Low Performance	Medium Performance	Medium Performance	Low Performance	Low Performance	Low Performance	High Performance	Medium Performance	High Performance	
		Option 2	\$60,092,300 - \$90,138,450	\$121,404 - \$182,106	\$97,284 - \$145,926	High Performance	Low Performance	Low Performance	Medium Performance	High Performance	Low Performance	Low Performance	Medium Performance	Medium Performance	
E	Army Beach and South M'Clintock	Option 1	\$25,486,700 - \$38,230,050	\$8,477,300 - \$12,715,950	\$90,800 - \$136,200	Low Performance	Medium Performance	Medium Performance	Low Performance	Low Performance	Medium Performance	High Performance	High Performance	Medium Performance	
		Option 2	\$58,785,400 - \$88,178,100	\$339,750 - \$509,625	\$23,250 - \$34,875	High Performance	Low Performance	Low Performance	High Performance	High Performance	Low Performance	Low Performance	High Performance	Low Performance	
		Option 3	\$59,387,800 - \$89,081,700	\$339,750 - \$509,625	\$23,250 - \$34,875	High Performance	Low Performance	Low Performance	High Performance	High Performance	Low Performance	Low Performance	High Performance	Low Performance	

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Appendix	Community	Option	Class D Opinion of Probable Costs			Qualitative Evaluation								
			Capital Cost	Annual - Flood Year	Annual - Non-flood Year	Viability and Reliability	Time to Implementation	Capital Cost per Inundated Property	Maintenance and Storage	Response and Activation	Aesthetics and Community Function	Future Adaptability	Alteration of Existing Hydraulics, Erosion/Sedimentation, Ice Processes, and Slope Stability	DMAF Applicability
F	Whitehorse	Option 1	\$1,032,700 - \$1,549,050	\$330,600 - \$495,900	\$18,600 - \$27,900	Low Performance	High Performance	High Performance	Medium Performance	Medium Performance	High Performance	High Performance	High Performance	High Performance
		Option 2	\$3,329,400 - \$4,994,100	\$132,000 - \$198,000	\$18,000 - \$27,000	High Performance	Medium Performance	High Performance	High Performance	High Performance	High Performance	High Performance	High Performance	High Performance
G	Carmacks	Option 1	\$11,826,500 - \$17,739,750	\$2,688,800 - \$4,033,200	\$26,400 - \$39,600	Low Performance	Medium Performance	Medium Performance	Medium Performance	Low Performance	High Performance	High Performance	Medium Performance	High Performance
		Option 2	\$22,914,900 - \$34,372,350	\$334,200 - \$501,300	\$103,100 - \$154,650	High Performance	Medium Performance	Low Performance	Medium Performance	High Performance	Low Performance	Medium Performance	Medium Performance	High Performance
H	Ross River	Option 1	\$8,410,100 - \$12,615,200	\$829,900 - \$1,244,900	\$38,600 - \$57,900	Low Performance	Low Performance	Medium Performance	Low Performance	Low Performance	High Performance	High Performance	Low Performance	Low Performance
		Option 2	\$5,795,600 - \$8,693,400	\$773,300 - \$1,160,000	\$29,200 - \$43,800	Low Performance	Low Performance	Medium Performance	Low Performance	Low Performance	Medium Performance	High Performance	Medium Performance	Low Performance
		Option 3	\$11,332,200 - \$16,998,300	\$264,600 - \$396,900	\$38,600 - \$57,900	High Performance	Low Performance	Low Performance	Medium Performance	High Performance	Low Performance	Medium Performance	Medium Performance	Low Performance
I	Pelly Crossing	Option 1	None	\$509,200 - \$763,800	\$1,200 - \$1,800	Low Performance	High Performance	High Performance	High Performance	Medium Performance	Medium Performance	High Performance	High Performance	Low Performance
J	Mayo	Option 1	\$54,845,700 - \$82,268,550	\$267,960 - \$401,940	\$36,540 - \$54,810	Medium Performance	Medium Performance	Medium Performance	High Performance	High Performance	High Performance	High Performance	High Performance	High Performance
K	Dawson City	Option 1	\$51,532,700 - \$77,299,050	\$8,546,600 - \$12,819,900	\$29,000 - \$43,500	Low Performance	Medium Performance	High Performance	Low Performance	Low Performance	High Performance	High Performance	High Performance	Medium Performance
		Option 2	\$70,829,300 - \$106,243,950	\$4,666,900 - \$7,000,350	\$29,000 - \$43,500	Medium Performance	Low Performance	High Performance	High Performance	High Performance	Medium Performance	High Performance	High Performance	High Performance
L	Old Crow	Option 1	\$86,836,600 - \$129,954,900	\$542,500 - \$813,750	\$39,200 - \$58,800	Low Performance	Low Performance	Medium Performance	High Performance	Medium Performance	Low Performance	Medium Performance	Low Performance	Medium Performance
		Option 2	\$187,675,200 - \$281,512,800	\$542,500 - \$813,750	\$39,200 - \$58,800	Low Performance	Low Performance	Low Performance	High Performance	Medium Performance	Low Performance	Medium Performance	Low Performance	Medium Performance
M	Marsh Lake East Shore	Option 1	None	\$1,001,600 - \$1,502,400	\$800 - \$1,200	Low Performance	High Performance	High Performance	High Performance	Medium Performance	Medium Performance	High Performance	High Performance	Low Performance
N	Swan Haven	No mitigation options.												

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Appendix	Community	Option	Class D Opinion of Probable Costs			Qualitative Evaluation								
			Capital Cost	Annual - Flood Year	Annual - Non-flood Year	Viability and Reliability	Time to Implementation	Capital Cost per Inundated Property	Maintenance and Storage	Response and Activation	Aesthetics and Community Function	Future Adaptability	Alteration of Existing Hydraulics, Erosion/Sedimentation, Ice Processes, and Slope Stability	DMAF Applicability
O	Shallow Bay	Option 1	None	\$677,800 - \$1,016,820	\$672 - \$1,008	Low Performance	High Performance	High Performance	High Performance	Medium Performance	Medium Performance	High Performance	High Performance	Low Performance
P	Jackfish Bay	Option 1	None	\$883,300 - \$1,324,950	\$700 - \$1,050	Low Performance	High Performance	High Performance	Medium Performance	Medium Performance	High Performance	High Performance	High Performance	Low Performance
		Option 2	\$503,200 - \$754,800	\$648,100 - \$972,150	\$700 - \$1,050	Low Performance	Medium Performance	High Performance	Medium Performance	High Performance	High Performance	High Performance	High Performance	High Performance
Q	Deep Creek	Option 1	None	\$713,200 - \$1,069,800	\$700 - \$1,050	Low Performance	High Performance	High Performance	Medium Performance	Medium Performance	High Performance	High Performance	High Performance	Low Performance
		Option 2	\$4,664,300 - \$6,996,450	\$577,700 - \$866,550	\$700 - \$1,050	Low Performance	Medium Performance	High Performance	Medium Performance	Medium Performance	High Performance	High Performance	High Performance	Low Performance
		Option 3	\$7,056,00 - \$10,584,000	\$384,000 - \$576,000	\$700 - \$1,050	Low Performance	Low Performance	Medium Performance	Medium Performance	Medium Performance	Medium Performance	Medium Performance	High Performance	Low Performance
R	Faro Lagoons, Wells, and Pump Station	No mitigation options.												
S	Rock Creek	Option 1	None	\$2,194,500 - \$3,291,750	\$900 - \$1,350	Low Performance	High Performance	High Performance	Medium Performance	Medium Performance	High Performance	High Performance	Low Performance	Low Performance
		Option 2	\$1,262,100 - \$1,893,150	\$369,300 - \$553,950	\$900 - \$1,350	Low Performance	Low Performance	High Performance	High Performance	Medium Performance	High Performance	High Performance	Low Performance	Low Performance

5 Closure

This report has been prepared for the sole benefit of the Government of Yukon and its agents, and may not be used by any third party without the express written consent of Stantec Consulting Ltd. Any use, which a third party makes of this report, is the responsibility of such third party. Use of this report is subject to the Statement of General Conditions provided in Appendix T. It is the responsibility of the Government of Yukon who is identified as “the Client” within the Statement of General Conditions, and its agents to review the conditions and to notify Stantec Consulting Ltd. should any of these not be satisfied. The Statement of General Conditions addresses the following:

1. Use of the report.
2. Basis of the report.
3. Standard of care.
4. Interpretation of site conditions.
5. Varying or unexpected site conditions.
6. Planning, design, or construction.

We appreciate the opportunity to assist you in this project. Stantec remains committed to supporting the Government of Yukon and our fellow Yukoners with the ongoing territorial flooding challenge. We trust the above information meets with your present requirements.

Should you have any questions or require further information, please do not hesitate to contact us.

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APPENDICES

