EROSION MITIGATION DESIGN IN THE ARCTIC CONSIDERING CLIMATE CHANGE IMPACTS

Fred Scott, Baird, fscott@baird.com
Fiona Duckett, Baird, duckett@baird.com
Lucas Arenson, BGC Engineering, larenson@bgcengineering.ca
Paul Kushner, University of Toronto, paul.kushner@utoronto.ca
Charles Klengenberg, Inuvialuit Regional Corporation, CKlengenberg@inuvialuit.com
Erwin Elias, Hamlet of Tuktoyaktuk, asao@tuktoyaktuk.ca

BACKGROUND

The Hamlet of Tuktoyaktuk is a low-lying peninsula in the Arctic on the Beaufort Sea that is vulnerable to coastal erosion and intermittent flooding. Most residences and buildings located near the coast have been relocated; those remaining are currently at risk of damage or destruction during storm events. In the longer term, cultural sites such as the graveyard are also at risk. Nearby Tuktoyaktuk Island, a beach/bluff system which shelters Tuktoyaktuk Harbour from waves, is eroding and if not protected may be gone by 2050. Baird was retained by the Hamlet of Tuktoyaktuk and Inuvialuit Regional Corporation (IRC) to assess erosion mitigation alternatives and select/implement a preferred design to protect the Hamlet (Figure 1) and Island (Figure 2), which comprise a total shoreline length of approximately 2 km.

Figure 1 – Hamlet of Tuktoyaktuk.

Figure 2 – Tuktoyaktuk Island.

CLIMATE CHANGE IMPACTS

Arctic air temperatures are warming at rates more than double the global average. This rapid warming of the Arctic is termed "Arctic amplification" and has been discussed in reports from the Intergovernmental Panel on Climate Change (IPCC). IPCC climate models project that a 2°C rise by 2100 at a global scale would result in a rise of 4 to 7°C in the Arctic, and a mean global increase of 3°C would equate to 7 to 11°C in the Arctic (Masson-Delmotte et al. 2018). Due to the significant impact that climate change has in the Canadian Arctic, it was a critical consideration in the erosion mitigation design process. The impacts for this project include increased water levels, a longer ice-free season, changes to sea ice characteristics, increased wave exposure and accelerated permafrost degradation.

A growing body of research has focused on the projected impacts of global warming on Arctic sea ice on a regional scale (e.g., Bushuk et al. 2017; Kushner et al. 2018). For this project, the Kushner group at the University of Toronto undertook data analysis on projected changes to the sea ice environment for the project area, focusing on projections for the periods of 2040-2060 and 2080-2100. It was projected that the current open water season which is from approximately June to October is likely to increase by two months by 2040-2060 and by three to four months by 2080-2100. The longer open water season will lead to increased exposure to waves and storm surge at the shoreline.

Relative sea level rise (RSLR) of 0.37 m for the year 2050 was used in the design, which was based on the 95th percentile of the RCP 8.5 emissions scenario of the IPCC 5th Assessment Report (AR5) for global sea level rise (James, 2015). The 95th percentile projection was used as a conservative estimate due to the uncertainty in climate change and Arctic amplification impacts. Global mean and regional SLR projections have since been updated in the IPCC 6th assessment report (Pörtner et al. 2019) to be slightly greater than what was estimated in the AR5 report, however, the 95th percentile projection from AR5 continues to be a conservative estimate.

DESIGN CONDITIONS

The design life for the structure was established as 30 years (to 2050). This timeframe was selected given the harsh Arctic conditions at the project site, including waves, surge, and ice exposure, and the added risks associated with permafrost degradation and climate change.

The 100-year return period wave and water level conditions were adopted as the design conditions for the project. At Tuktoyaktuk, the largest waves and water levels are generated by severe wind events. The wide and shallow continental shelf at Tuktoyaktuk results in large storm surges during sustained, strong onshore winds. Based on water level records at Tuktoyaktuk over the past 80 years, the largest storm surge was estimated to be 2.5 m. To determine extreme water levels by return period, the MIKE21 HD model was used, combining the surge, high tide and RSLR. Figure 3 shows a map of the estimated inundation areas at the project site based to the 100-year return period water levels for present and projected 2050 and 2100 conditions. The extreme wave conditions were modelled using the MIKE21 SW model for onshore winds with various return periods.

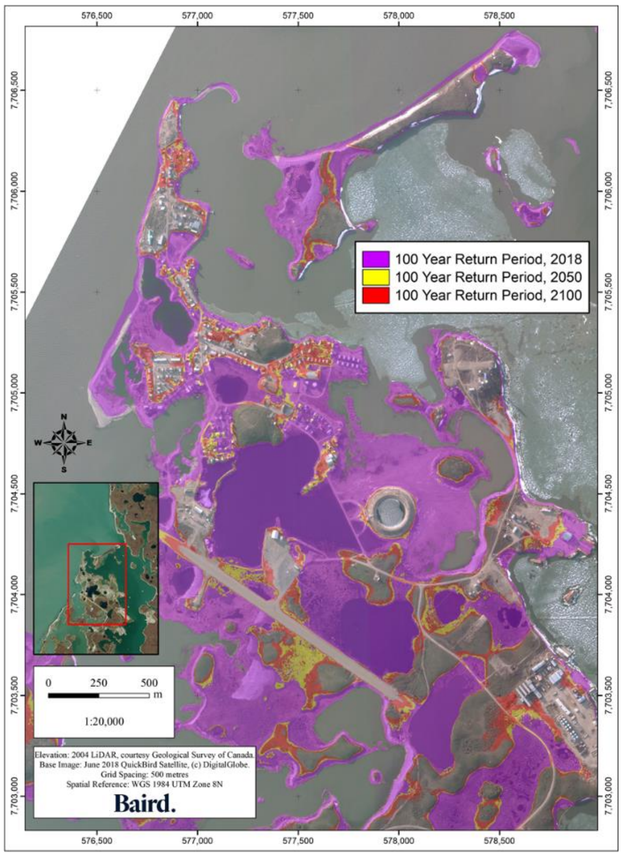

Figure 3 – Areas of flooding during MHHW plus 100-year surge for present sea levels, and for 2050 (RCP8.5 95%) and 2100 (RCP8.5 95%) relative SLR.

To better understand shoreline erosion at the project site, modeling was undertaken to estimate longshore sediment transport (LST) rates. As the shoreline of Tuktoyaktuk Hamlet and Tuktoyaktuk Island erode, the coarse sediment is deposited on the beach or in nearshore areas and is subject to longshore transport. The net LST was quantified for existing and future climate conditions using the 1D COSMOS sediment transport model. It was found that LST is predominantly towards the south along Tuktoyaktuk Hamlet and predominantly towards the east along Tuktoyaktuk Island. With no shoreline protection, the LST and erosion of the shoreline is projected to increase in the future as a result of increased wave action associated with RSLR and a longer open water season

Comfort Ice Engineering Ltd. examined ice-structure interactions with various shoreline protection concepts (Baird, 2020). It was determined that the greatest ice loads would occur during spring break-up when mobile ice floes may be pushed onshore by wind events. It is expected that climate change impacts will cause the ice to become thinner, but also more dynamic. It is also expected that there will be insignificant changes to ice pile-up at the shoreline in the future; however, the associated ice force is reliant on the ice thickness and therefore may reduce. Based on this information, the design of the shoreline protection system conservatively assumed present sea ice conditions.

Ground ice and permafrost contribute to the challenges of the shore protection design. The Tuktoyaktuk region is in a zone of continuous permafrost (approximately 500-600 m thick) and subsea permafrost is present offshore of the community and in the Beaufort Sea region (Smith & Doung, 2012; Natural Resources and Geomatics Canada, 1995). A field study was completed in 2020 to assess the geotechnical conditions at the project site, including boreholes and Electrical Resistivity Tomography (ERT). These data indicate that the shallow subsurface conditions along the shoreline of the Hamlet and Island generally consist of frozen fine sands with varying volumetric ice contents, and some silty clay layers with high plasticity. The volumetric ice contents of the top 2 to 3 m of the permafrost vary between approximately 40 and 100%, with salinities between 0.1 and 0.4%. As part of the design, ground temperatures were modelled with and without the proposed structures to assess the effect the structures will have on permafrost degradation and the stability of the structure foundation.

In addition, Baird participated in community consultations throughout the project to ensure that the stakeholder needs were addressed and to facilitate the sharing of local knowledge to assist in the design process.

DESIGN ALTERNATIVES

Baird developed three design alternatives for shoreline protection, including articulated concrete block mattress (ACBM), concrete slab, and quarried armour stone revetments. Each alternative was tested in a 1:20 scale physical model (undertaken using the facilities of the National Research Council of Canada), including tests with wave and water level conditions ranging in severity from the 2 to 500-year return period events. Physical model testing of the preliminary designs is shown in Figure 4. Modifications were made to each design concept based on the model results and updated quantity/cost estimates were prepared, with the armour stone revetment being identified as the most cost-effective solution.

Figure 4 – Physical model testing of preliminary designs.

SELECTED DESIGN

The selected design is comprised of a quarried armour stone revetment along the entirety of the exposed shoreline of Tuktoyaktuk Island and the majority of the Tuktoyaktuk Hamlet shoreline. The revetment will include two layers of 1 to 3 tonne stone with a toe berm and splash pad. Approximately 175,000 tonnes of stone will be required for construction which will be sourced from a quarry about 170 km from the project site. In the core of the structure, 10 cm of rigid styrofoam insulation will be placed over geotextile. The insulation was shown, through numerical modeling, to result in aggradation of permafrost over the lifetime of the structure and will therefore help maintain a solid foundation. A rendering of the quarried stone revetment at Tuktoyaktuk Hamlet is shown in Figure 5.

Figure 5 – Rendering of the selected design at the shoreline of the Hamlet of Tuktoyaktuk.

At the southern end of the Hamlet shoreline, beach nourishment will be placed where the existing barrier beach has previously been breached. Approximately 33,000 m^3 of sand and gravel sized sediment will be placed along and seaward of the existing barrier beach. It is proposed that initial and re-nourishment material will be sourced from a nearby spit south of the Hamlet. This will effectively re-circulate beach material since the spit is fed by the southerly net longshore transport of eroded material from the Hamlet shoreline and barrier beach.

Final design, construction plans, and specifications have been completed and the Hamlet and IRC have submitted a funding application to the Government of Canada, with construction pending. This proposed project will provide the community with viable options to adapt to long-term anthropogenic climate change, including delaying the need to relocate the community and its cultural sites, such as the graveyard, as the effects of climate change emerge.

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