Erosion Progression and Adaptation Strategy in a Northern Coastal Community

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ABSTRACT: The potential impacts of progressing shoreline erosion in northern coastal communities include significant and sustained loss of developed land, and the associated public health, safety and cost issues. Some of these impacts are being seen in the community of Tuktoyaktuk, Northwest Territories, located along a narrow peninsula reaching out into the Arctic Ocean. Since 1934, storms blowing in from the northwest, across the Beaufort Sea have eroded the land of the original permanent settlement. A concerted scientific effort has focused on monitoring, and analyzing the shoreline erosion and the potential influencing factors to the erosion. This information has provided a basis for a 25 year prediction of the shoreline erosion variation along the peninsula. In order to develop an appropriate adaptation strategy, an evaluation was completed on the erosion risk over a 25 year period to quantify both the value, and the cost versus benefit of protecting or relocating particular buildings.

1 COMMUNITY SETTING

The Hamlet of Tuktoyaktuk, Northwest Territories is an Inuvialuit community located on the shores of the Beaufort Sea, east of the Mackenzie Delta, at 69°27'N, 133°05'W, and it is the most northern community on mainland Canada. The population was estimated at 979 in 2000, with approximately 88 % of the population being Inuvialuit. The community has traditionally developed along this narrow spit of land reaching out into the Arctic Ocean providing open ocean on one side, and a sheltered harbour on the other side (Figure 1).

The Hamlet of Tuktoyaktuk has a mean annual temperature of -10°C, with a mean summer temperature of 4°C, and the mean winter temperature is -29°C. The ocean freezes in late October, and the ice breaks up in late June.

The tidal variation in the area ranges from 35 to 60 centimetres on average.

2 GEOLOGY, OCEANOGRAPHY, AND SHORELINE EROSION

The Tuktoyaktuk area lies within the Arctic Coastal Plain; the elevations of the area are low, with numerous lakes, coastal bays (often former lake basins), and permafrost related depressions. Thick layers of sand are found under most of the area, and beds of coarse and pebbly sands are also found in addition to occasional silty layer beds. Sands and gravels lie on top of the finer-grained materials along the peninsula. Most of the natural materials in the Tuktoyaktuk area have been completely saturated with water, and therefore contain excess ice, in large volumes in some cases.

The coastal areas of the Beaufort Sea are covered with ice for 8 to 9 months of the year. The ice-free distance from shore is usually more than 100 kilometres during the open water season. Storm winds, which occur most often in late August and September, come predominantly out of the west and northwest. The maximum storm surge tide created by wind in the Tuktoyaktuk area is about 2.5 metres above mean water level.

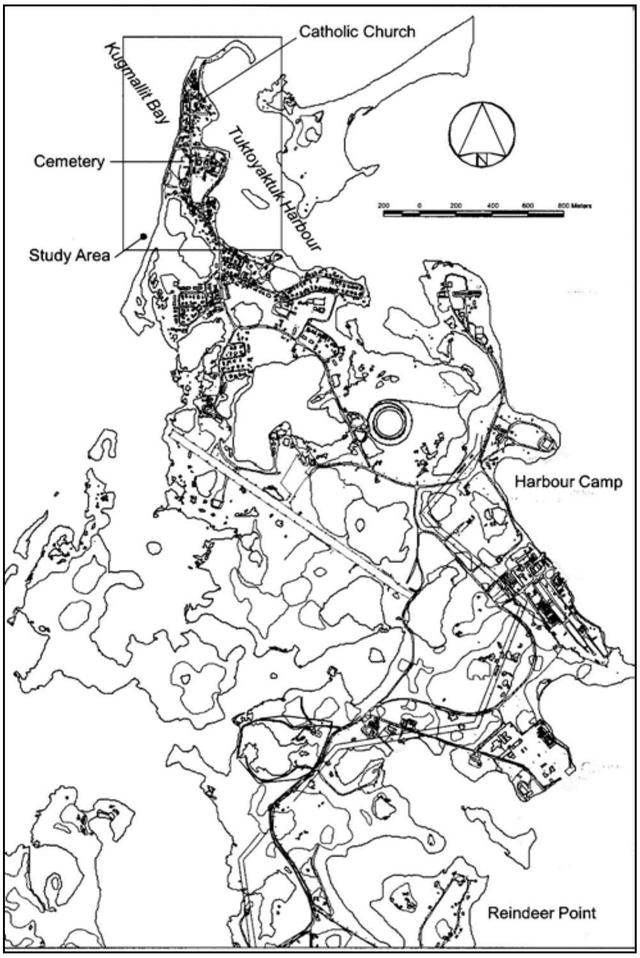

Figure 1: Study location

Erosion has been a feature of the Tuktoyaktuk area prior to the modern settlement of the community (see Figure 2). The long-term relative sea-level has been rising at a rate in the range of 1 to 4 mm per year for the past several thousand years and consequently, much of the coast is being eroded. The typical long-term erosion rates of coastal bluffs are around 1 to 2 metres per year.

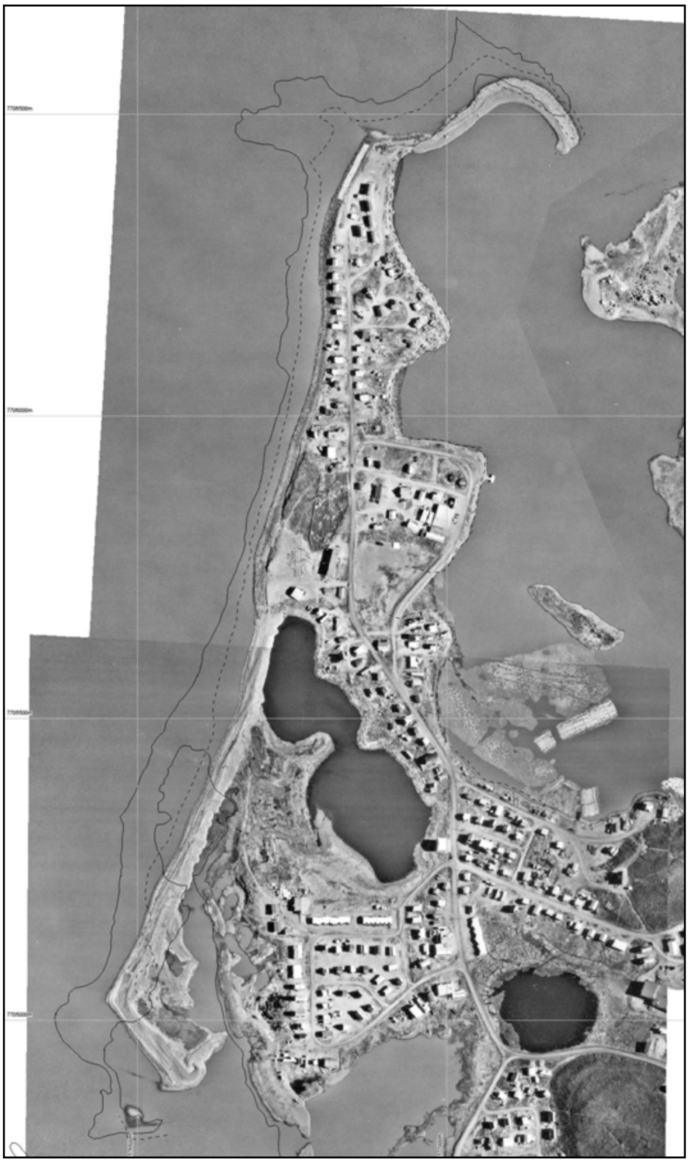

Figure 2: Historical progression of erosion 1947, 1972 and 2001.

3 PREVIOUS SHORELINE EROSION RELATED STUDIES

Shoreline erosion in the Canadian north is not a new phenomenon, but Tuktoyaktuk is the only community in northern Canada where shoreline erosion is having a significant and sustained impact with significant financial implications to the community infrastructure.

The study of shoreline erosion in Tuktoyaktuk was started in 1974; and consisted of a detailed engineering study to determine the most effective and economic way of addressing the erosion of the shoreline in the vicinity of the existing school. The initial study included the compilation of available data; consultation with technical specialists; limited topographic and bathymetric surveys; and model testing. The study proposed a trial shoreline erosion protection project, and a new stage to the collection of more field information. Another study was undertaken in 1976 (Government of Canada, 1976) as a program of trial protection using Longard tube technology. A 1986 study (Aveco, 1986) reviewed six main shoreline protection alternatives, as well as combinations of alternatives. The alternatives included Tarsiut caissons; beach nourishment; longshore protection; groin construction; Longard tubes; and an offshore breakwater. The report recommended beach nourishment as the most attractive alternative because it was cost effective, simple and did not require extensive preparation.

A 1994 study (UMA, 1994) reviewed a wide range of shoreline erosion options and reduced the options to a shortlist of three for further consideration. A life cycle cost analysis was completed, and undertaken on all of the options, and compared to a gradual relocation of the community. Gradual relocation of the community produced the lowest life cycle cost of all the options considered.

4 SHORELINE EROSION PROTECTION AND PERFORMANCE

Experimental shore protection using the Longard tubes as bulkheads and groins was built in 1976. This erosion protection was somewhat successful, but vandalism was destroying the integrity of the geotextile in the Longard tubes. This shore protection system was destroyed by 1981, which coincided with increased storminess in the early 1980s.

A program of shoreline reclamation and beach nourishment was recommended and undertaken in 1987 (Aveco, 1986). Sand was dredged from the nearshore and placed on the beach with a sandbag system. From 1987 to 1993, the sandbags provided protection of the cliff, and acted as a form of time-release beach nourishment. Since no protection was provided for the toe of the sandbags, storms would undermine the sandbags causing them to break open, and completely spill, as well as collapse the bags higher on the slope.

In 1993, there was a severe storm that washed away the sandbags from over 50 percent of the area on which they were placed. Erosion of 4 to 8 metres occurred along most of the coastal bluff-backed shoreline, and the spits at the north and south ends were washed over and washed further toward the land.

In 1998, forty monolithic concrete slabs were installed (Trillium, 1997) over a gravel pad, which was overlain by non-woven geotextile on a 1:2 slope at the north end of the peninsula. Approximately 100 metres of coastline could be protected with the available materials and budget.

5 PREDICTION OF FUTURE SHORELINE POSITIONS

The analysis used to predict the future shoreline positions (Solomon, 2002) consisted of:

- establishing the historical shoreline retreat rate prior to construction of the current protection measures;
- assessing the physical characteristics of the existing shoreline protection measures;
- dividing the shoreline erosion area into segments based on common physical characteristics;
- estimating the maximum retreat for 10 and 25 year periods for each segment;
- estimating the most likely shoreline positions for each segment for the next 10 and 25 years; and
- reducing the maximum erosion based on the probability that the upper end of the shore protection measures would be overtopped.

The shoreline erosion area has 16 distinct segments based on its elevation, long-term retreat rate, shore protection attributes of elevation of the upper edge, slope, and materials. Erosion within each of these segments is influenced by the shore protection measures that would be overtopped by a storm surge and associated wave run-up within the 10 and 25 year time periods.

In order to calculate the areas which were at risk over 10 and 25 year time periods, the probability of overtopping was calculated for 10 year and 25 year intervals and used to help estimate the amount of erosion likely to occur during those time intervals. In cases where overtopping probability was very low, erosion was estimated to be minimal. If overtopping probability estimates were very high, then the maximum amount of erosion (based on historical long-term averages) was used. Intermediate overtopping probability estimates were used to define likely amounts of shoreline erosion, which were in between the minimum and maximum on a prorated basis (Figure 3). The water level return periods were combined with estimated wave run-up to determine the probability of over topping.

An ongoing sea level rise of nearly 3.5 mm per year, and the potential for an annual sea level rise greater than this due to climate warming was not included in the analyses.

Climate change impacts would also affect the extent of sea ice, and the length of the open water season. Along with this may come a change in the frequency and severity of storms. It is not known if all of these influences would be operating to increase the vulnerability of the Beaufort Coast, or if some events will counteract other events.

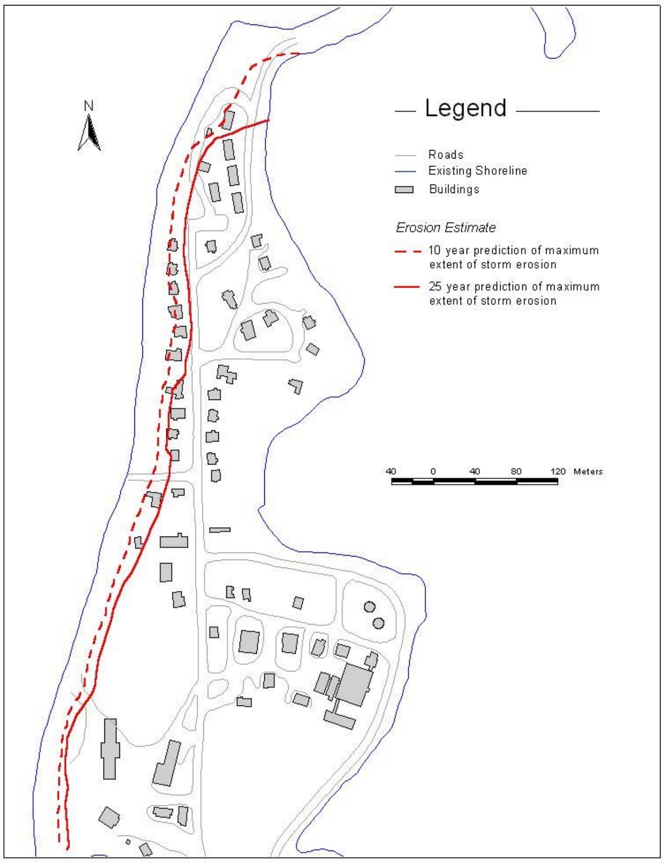

Figure 3: Progression estimates

6 BUILDING INSPECTION PROGRAM AND COMPILATION

A building inspection, evaluation and rating (EBA, 2002) provided a context of risk within which to consider the potential shoreline erosion progression for the next 10 to 25 years. The assessment encompassed a preliminary inventory of buildings with photographs, coordinates, and a limited external inspection.

A building rating protocol was developed to quantify the variables associated with the building compilation, and present a potential importance of a particular building. Existing building use, building physical condition, building zoning bylaw conformance, building age and building land tenure were utilized to evaluate the significance of a building in a decision analysis format.

A decision analysis format of rating was applied to the building rating, and a relative ranking was completed for all of the variables of the buildings. The higher values for buildings identified those buildings that may demand greater consideration regarding the decision making (Figure 4).

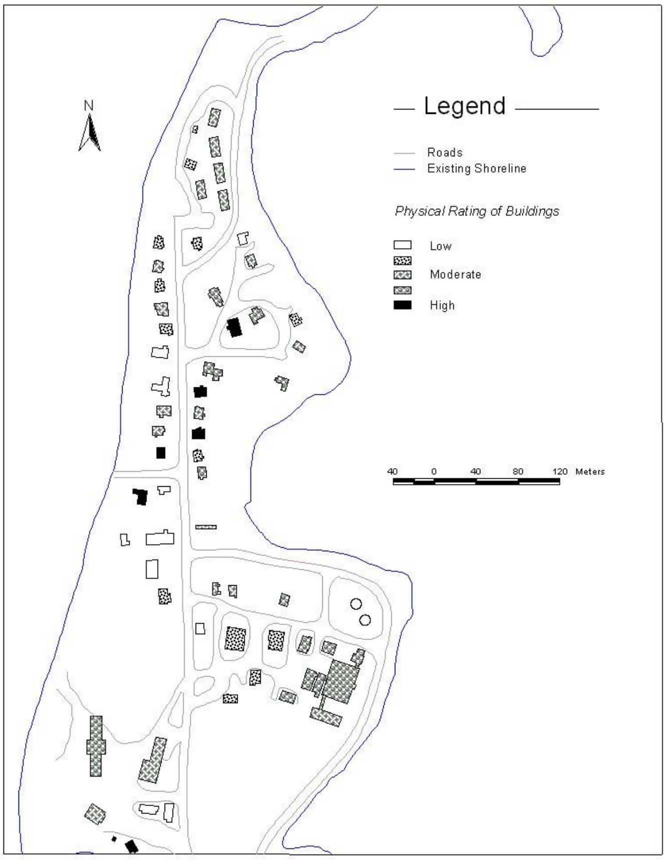

Figure 4: Building rating

7 COMMUNITY CONSULTATION

A community questionnaire was developed and completed for 30 households (EBA, 2002). The purpose of the questionnaire was to gain an understanding of community members' views of a desirable community to live in, given the erosion of the Tuktoyaktuk Peninsula and the land administration challenges associated with this. The questionnaire concerned surroundings, personal dwellings, and neighbourhoods.

The most significantly valued community services with regard to proximity to a residence are the nursing station, the school, and the store. The most significantly valued views are that of the ocean, and the wide open space. The most significantly valued characteristic of a "new" personal dwelling was a good quality house followed closely by a house with a big yard.

The most significantly valued characteristic with regard to a neighbourhood was a concentrated area like the north end of Tuktoyaktuk, as opposed to widely spaced housing areas to the south. The questionnaire results presented a significant margin with a preference for a concentrated area.

8 BUILDING RISK AND PROTECTION

The building risk for the 10-year maximum erosion estimate (EBA, 2002) may impact up to 10 buildings along the shoreline (Figure 5). These buildings may be impacted to a point that they would be considered vulnerable to damage or destruction unless they are relocated or demolished, or a well-engineered and constructed shoreline protection system is in place. One of these 10 buildings has a high rating based upon the physical rating of the buildings. The remainder of the buildings have a moderate to low rating.

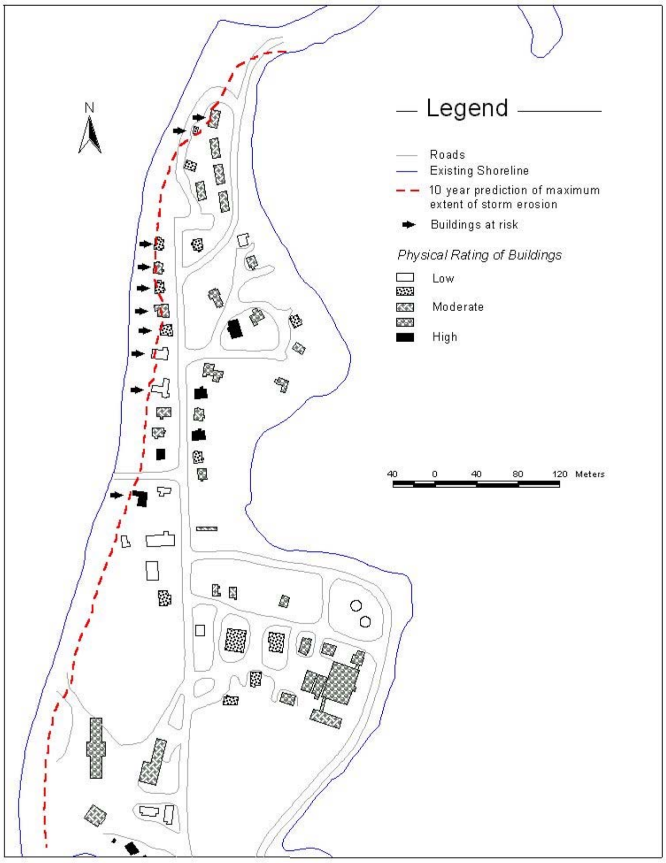

Figure 5: Maximum community impact – 10 Years

The building risk for the 25 year maximum erosion estimate (EBA, 2002) may impact up to 15 buildings along the shoreline (Figure 6). Of these 15 buildings, two have a high rating based upon the physical rating of the buildings. The remainder of the buildings have a moderate to low rating.

Past engineering related investigations and reports have provided information with regard to the technical means to potentially slow the rate of erosion on the Tuktoyaktuk shoreline. However, based upon the information developed in the shoreline erosion analysis, it may be impossible to ultimately stop any further erosion even with the appropriately engineered and constructed protection measures. The nature of storms impacting Tuktoyaktuk is changing and therefore a very severe storm surge could in fact overcome any protection mechanism instituted along the Tuktoyaktuk shoreline.

Difficulty in limiting erosion is due to the combination of the low coastal elevation, ice content, rising sea level, limited sediment supply and ongoing erosion of neighbouring, unprotected shores. The factors are likely exacerbated by longer open water seasons, accelerated sea level rise, and more rapid permafrost degradation.

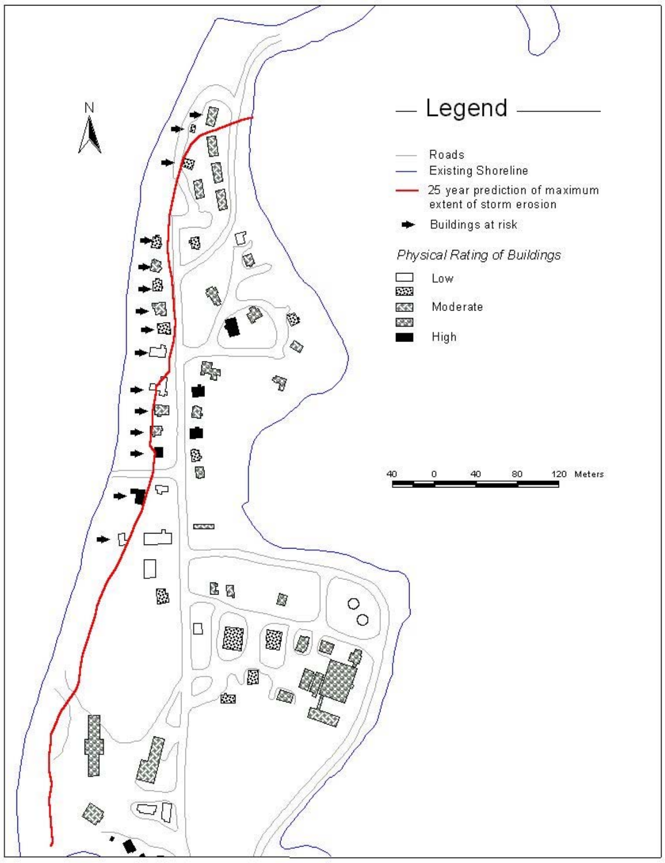

Figure 6: Maximum community impact – 25 Years

The three most appropriate options for reducing shoreline erosion (UMA, 1994) are:

- annual replenishment of the bank with sand and gravel, which has an estimated $600,000 Cdn capital cost and a $2.8 million Cdn life cycle cost.
- stacked overlapping gravel bags, which have an estimate $5.5 million Cdn capital cost and a $9.6 million Cdn life cycle cost.
- concrete mats tied together with chains, which have an estimated $8.1 million Cdn capital cost and a $9.1 million Cdn life cycle cost.

Each of these options, or a close variation of it has been implemented on a trial basis along a portion of the shoreline, however, none of the trial programs was subject to a comprehensive monitoring program. Therefore, the long term performance measure of each of these options is incomplete. Based upon the limited inspection programs the most comprehensive option, and hence the most expensive option of concrete mats appears to have the best opportunity to provide complete protection of the shoreline.

9 COST VERSUS BENEFIT FOR BUILDING PROTECTION

A cost versus benefit analysis of building protection clearly indicates from life cycle costs that building relocation would have the lowest life cycle cost. This conclusion is based upon a purely technical and economic perspective, and does not address the needs of the community residents.

The protection of buildings falls within the priority of building protection, and the resources available. Complete protection of the entire peninsula from future shoreline erosion is very expensive, with a cost of more than $8 million Cdn. Partial protection of buildings with "highest" value may create technical and political challenges.

The protection of a building with unprotected or "less" protected areas to either side may be subject to ultimate erosion destruction because of the nature of the erosion advancing around the unprotected areas. The protection of a building that has a higher benefit or value may be the cause of political problems, since benefit or value is somewhat subjective, and differing opinions on this benefit or value may produce strongly divided groups within the community.

From a technical perspective as well, any shoreline protection measures must consider the potential failure mechanisms and provide the appropriate engineering and construction resources to address these failure mechanisms.

10 DEVELOPMENT OPPORTUNITIES WITHIN COMMUNITY

A number of development opportunities have been identified for the Hamlet of Tuktoyaktuk (UMA, 2001). The community core offers a variety of historical, recreational and wetland areas of interest to residents. The community core area also offers a number of amenities including the ocean access and views to the east and west. Some future residential areas are feasible throughout the community, however, the ultimate development of the areas may be limited by access, availability, waste management practices, and desirability to the community. The demand for residential land in the Hamlet of Tuktoyaktuk is projected to maintain a steady increase over the next 20 years and the overall number of houses is expected to increase by 30 to 50 %.

The residential land available in the Hamlet of Tuktoyaktuk is somewhat deceiving because the number of vacant building sites are few, and the community has an abundance of abandoned residential units. The opportunity for community redevelopment may provide the necessary flexibility to the land administration challenges concerning the shoreline erosion in the community.

As infrastructure priorities within the community continue to compete for finite financial resources, the long term impacts of shoreline erosion may be considered along with responsibilities of the Hamlet administration, and the interest of the community stakeholders to develop a balanced strategy to address this problem.

11 CONCLUSIONS

Shoreline erosion is progressing in the Hamlet of Tuktoyaktuk and may impact over 15 buildings in the next 10 to 25 years based upon a prediction of shore erosion positions. The progress of the shoreline erosion may not be reduced from the 10 and 25 year predictions if the shoreline erosion protection systems are not well engineered and constructed to consider all the factors that may destroy shoreline protection systems or render them ineffective. The construction of such shoreline erosion protection systems will be very expensive.

The Hamlet of Tuktoyaktuk has the administrative means to control land development in the shoreline erosion risk area. These measures should be applied for all future development in the shoreline erosion risk area in order to minimize the risk of loss of life and property, health and safety hazards, disruption of commerce and governmental services, extraordinary public expenditures for erosion protection and relief.

These administrative means need to be applied with community consideration and consultation in order for the community to decide the priorities for the limited financial resources available.

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