Options for Near-Term Infrastructure Protection
Kotlik, Alaska
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Executive Summary:

Purpose

Alaska Native Tribal Health Consortium's (ANTHC's) Center for Environmentally Threatened Communities (CETC) visited Kotlik from September 18, 2018 to September 21, 2018 with the goals of surveying homes threatened by erosion, assessing the risk to the residents, and meeting with members of the Kotlik Village Council and the City of Kotlik. This report assesses options to address the community's four highest priorities regarding environmental hazards: relocating threatened homes, community-wide erosion protection, identification of a long-term relocation site, and addressing erosion impacts to the landfill. The report presents scopes of work and conceptual cost estimates for possible options to address three of the four priorities.

Problem

According to the Draft 2018 Denali Commission Statewide Threat Assessment, Kotlik is one of the Alaskan communities most vulnerable to infrastructure impacts associated with erosion, permafrost, and flooding. Community residents have observed a significant increase in bank erosion, ranging from one to five feet of bank lost each year. In addition to erosion, Kotlik is threatened by permafrost degradation and flooding. Since 2007, permafrost studies performed by the United States Geological Survey (USGS) have shown trends of increased temperature fluctuations in permafrost, an overall increase in permafrost temperature, and increased depth of permafrost. Furthermore, the advent of decreased sea ice and increased incidence of flood events have been observed in the Kotlik area. When combined, these discrete hazards can accelerate the rate of harmful environmental trends. We estimate that 120 structures are currently threatened, including approximately 47 homes. Immediate actions are necessary to protect community infrastructure and the lives, livelihoods, and cultures of Kotlik residents.

Potential Solutions

To address the community's top priorities regarding environmental hazards, we recommend the following:

<u>Community Priority 1: Relocate threatened homes</u>*:* We recommend relocating threatened homes to the old airport site. This includes preparing the site, providing access via a boardwalk, extending the electric distribution system, moving homes, and building new homes to replace those that cannot be relocated.

<u>Community Priority 2: Erosion protection</u>*:* Due to the high cost of a structural solution, we recommend a managed retreat strategy.

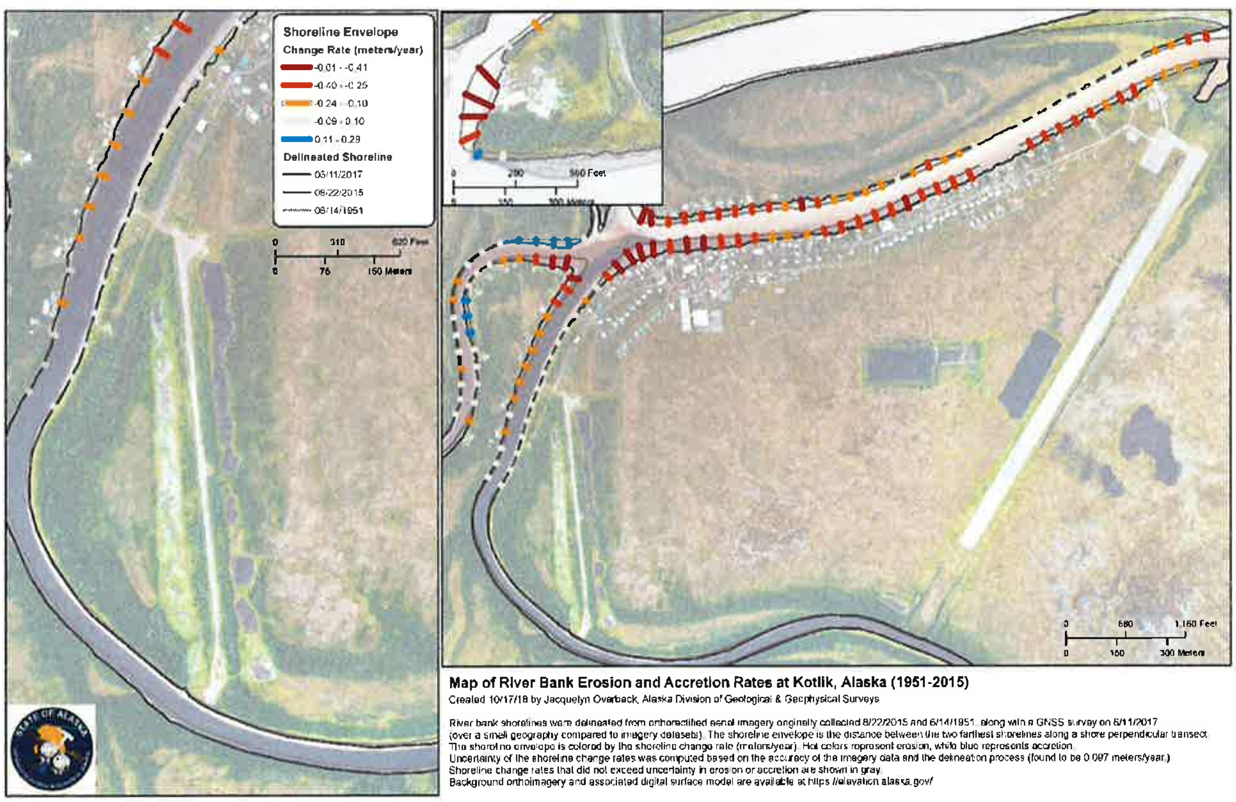
<u>Community Priority 3: Identify the safest site for long-term relocation</u>: Analysis of this priority is outside of the scope of this report. ANTHC will support Kotlik with their efforts to gather information regarding risks and the feasibility of relocating to another site.

<u>Priority 4: Address erosion impacts to the community landfill:</u> We recommend bank stabilization at the current landfill site.

Problem: Bank Erosion and Melting Permafrost

Kotlik is located in a low-lying area in the northwest quadrant of the Yukon-Kuskokwim River Delta. The community sits at the confluence of the Kotlik and Little Kotlik Rivers near Apoon Pass. The community sits at sea level. Ground water is at the surface in much of the community. Travel over ground in the community is limited in the summer season, requiring boardwalks for foot and ATV traffic. Water and sewer service is provided via a piped system for much of the community, but residents living on the east and west islands must haul water and use honey buckets for wastewater collection and removal.

Severe bank erosion has been observed for the past several years on the banks of the Kotlik River, Little Kotlik River, and Apoon Pass. Anecdotal reports from multiple community members state that the river has lost as much as 20 feet of bank over the past ten years. It is theorized that the severe erosion is caused from a combination of warming permafrost and significant mechanical erosion from storms, flooding, and marine traffic (wakes). A USGS permafrost monitoring station has shown a marked increase in permafrost depth, a general trend of warming permafrost, and wider variation in active layer temperature since 2007 (report findings can be seen in Appendix M). Additionally, erosion monitoring stations located at various locations throughout the community show regular losses of one to four feet of bank per year.



Map of River Bank Erosion and Accretion Rates at Kotlik, Alaska (1951-2015)
Created 10/17/18 by Jacquelyn Overbeck, Alaska Division of Geological & Geophysical Surveys

River bank shorelines were delineated from orthorectified aerial imagery originally collected 8/22/2015 and 6/14/1951, along with a GNSS survey on 6/11/2017 (over a small geography compared to imagery datasets). The shoreline envelope is the distance between the two farthest shorelines along a shore perpendicular transect. The shoreline envelope is colored by the shoreline change rate (meters/year). Hot colors represent erosion, while blue represents accretion. Uncertainty of the shoreline change rates was computed based on the accuracy of the imagery data and the delineation process (found to be 0.097 meters/year.) Shoreline change rates that did not exceed uncertainty in erosion or accretion are shown in gray. Background orthoimagery and associated digital surface model are available at https://elevation.alaska.gov/

A bank protection feasibility study was completed in 2003 by MWH Engineers. This report concludes that bank failures are caused primarily through planar/slab failure by sliding or toppling, or slumping combined with wave action. The report also contained a projection of bank failure to 2050 that can be seen in Appendix N.

A bank stabilization project was completed by the Army Corps of Engineers in 1986, during which an articulated concrete mat was installed to protect the bank. As of this writing, all areas where the concrete mat system was installed have suffered significant erosion. The community reports that the bank revetments installed in 1986 did provide sufficient bank stabilization up to the mid 2000's. It is likely that the revetments provided adequate protection from the mechanical erosion affecting the area while the permafrost was stable, but, once the permafrost began to melt, the ice providing structural support behind the revetments deteriorated. This has contributed to accelerated erosion.

The increased rate of bank erosion over the past ten years is due to a combination of events. The first of these events is the increase in permafrost temperature and increase in depth of permafrost, as documented in the USGS study. With the depth of permafrost increasing, the depth of active layer has increased as well. The additional depth of the active layer, along with the wider temperature variations documented by USGS in the active layer, has created a larger destabilized zone due to freeze/thaw action. The destabilization of this area has allowed for erosion due to planar/slab failure and slumping combined with wave action (mechanical erosion) to increase significantly.

Community Priorities

In our discussions with community members, primarily the Kotlik Village Council, four priorities were identified. In order of importance, these are as follows:

Priority 1: Relocate threatened homes. The community's main concern is the safety of its residents and the proximity of homes to the eroding shoreline.

Priority 2: Erosion protection. The community has requested assistance in pursuing a solution that could stop or decrease erosion rates.

Priority 3: Identify the safest site for long-term relocation. In response to concerns that Kotlik's current site may not be habitable in the future, the community seeks to determine a site for the long-term relocation of the entire community. Analysis of this priority is outside of the scope of this report. However, the Center for Environmentally Threatened Communities will continue to support the community of Kotlik with their efforts to gather information to support relocation decision-making.

Priority 4: Address erosion impacts to the community landfill. The community's fourth priority is to determine the impacts of erosion to the community's landfill and identify an appropriate way to protect the facility.

PRIORITY 1 OPTIONS—HOME RELOCATION

According to the 2003 MWH study and erosion data recently collected, approximately 120 structures (47 homes, seven commercial buildings, seven community buildings, and 59 outlying buildings) in the community of Kotlik, Alaska are expected to be catastrophically impacted by harmful environmental trends in the near future.

Of the 120 structures at risk, 21 homes are considered to be at a high level of risk—they lie ten feet or less from the shoreline. Four of those homes lie four feet or less from the shoreline and are considered to be imminently threatened. The imminently threatened homes are in danger of catastrophic foundation failure due to the bank erosion within zero to two years. One home is in immediate jeopardy, as the bank has already eroded approximately three feet back from the northwest corner of the foundation. This corner of the home is cantilevered over the river, and there is a high likelihood the home's foundation could become compromised to the point of failure during the next significant storm event.

The residents of all high-risk homes do not have the means to move their homes and are living in the homes despite immediate risk to life, safety, and health. The table below summarizes the threat to Kotlik homes:

Table 1: Kotlik Homes—Risk Categorization		
Housing Group (Number of Homes)	Risk Category	Details
Group A (4)	Imminently Threatened - Extremely High Risk	Catastrophic damage expected in 0-2 years
Group B (17)	High Risk	Catastrophic damage probable in 2-5 years
Group C (26)	At Risk	Structure located in erosion zone. Catastrophic damage possible in 5-10 years.

Home Relocation Option 1: Do Nothing

Scope of Work: One option is to do nothing. Under this option, no actions would be taken to move homes or stabilize the bank.

Cost: There is no capital or upfront cost associated with this option. However, this option may result in loss of life and loss of property for many community residents. The catastrophic loss of property that could result could drive a disaster declaration at the state or federal level.

Duration and Phasing: There is no duration or phasing required for this alternative.

Environmental Impacts: There are significant negative environmental impacts associated with this approach. If nothing is done, given the current rate of erosion being witnessed in the community, homes, sheds, and other property will end up in the river. This will result in fuel and other possibly hazardous material (used oil, paint, etc.), debris, human waste, woody material, white goods, snowmachines, ATVs, boats, and other material being released into the river. This uncontrolled release could jeopardize the drinking water intake, fish populations, and local bird populations. It could also irreversibly damage subsistence and bird-nesting areas. The financial cost associated with a cleanup of an environmental release of this kind is expected to be high.

Analysis: Though this option may be the most cost effective initially, it could potentially result in injuries, loss of life, loss of property, environmental contamination, and displaced residents. With

Kotlik's shortage of housing, there are no homes available for displaced residents. From a purely economic perspective, this option could result in significantly higher costs than any of the other options presented in this report. These costs would come from environmental cleanup, medical costs associated with injuries or even deaths, and costs of residents' relocation and/or the requirement for new homes for affected residents.

Conclusion: This option should not be considered. State and federal agencies have a responsibility to the communities they serve, and they should invest in the health and welfare of the residents of Kotlik.

Home Relocation Option 2: Relocate Homes to the Old Airport

Scope of Work: The scope of work for this alternative would include moving 47 homes to a new subdivision within the community. This requires developing the subdivision area to provide access, power, and a cost effective water and sewer system alternative. The most feasible relocation venue is the old airport south of the community. This area is higher in elevation than the surrounding community and would provide a stable base for the home relocation. The Kotlik Yupik Native Corporation has subdivided the site into 21 plots with room for additional future expansion. The corporation currently owns the land, and the site plan can be seen at Appendix A. Appendix B shows a site layout for this option's components.

Site Access—Boardwalk

Scope of Work: The site can be accessed at either end of the runway by river landing or by foot from town. Foot access is difficult from town, however, as the land between the townsite and the abandoned runway is a swamp/marsh. The area regularly holds water. While the site can be accessed by foot, significant improvements are needed for safe, efficient transportation to the center of the community.

The most efficient and cost effective means of providing site access would be to construct a boardwalk from the west end of town to the north end of the runway, a distance of approximately 1,200 feet. The boardwalk will be designed with a helical pile foundation and constructed with four-inch by twelve-inch decking for increased longevity of service. The boardwalk will be ten feet wide to allow for two-way traffic (most modern ATVs are 48 inches wide), and the design will allow room for structural support for pipes under the road. Handrails will be added to the boardwalk for any areas over 30 inches above the ground. Additionally, snow machine crossings should be included in the design for heavily trafficked areas in the winter. A typical section detail of a similar boardwalk can be seen at Appendix C.

Construction Duration: 4 Months

Cost: $672,750

Power Distribution System

Scope of Work: The site currently has no power. Power must be distributed from the power plant to the site then extended to the homes in the area. Kotlik is an Alaska Village Electric Cooperative (AVEC) community so design and construction work would likely be contracted to them. The north end of the old runway is approximately 1200 feet from the closest (west) end of town and approximately 1800 feet from the power plant. This power distribution system extension must be capable of providing adequate power for 47 homes.

Construction Duration: 3 Months

Cost—Main Power Extension: $120,000

Cost—Per Home Connection: $15,000

Total Cost:

Phase 1: Group A—4 Homes: $180,000

Phase 2: Group B—17 Homes: $255,000

Phase 3: Group C—26 Homes: $390,000

Civil Site Preparation
Scope of Work: The old runway site requires civil site preparation and final grading prior to providing an adequate location for a new subdivision. Geotechnical analysis of the area should be performed to ensure the area is stable and will provide adequate sub-grade stability for the homes being moved to the site. The area must be cleared, grubbed, re-graded, and properly sloped for site drainage. A civil site design including these elements should be completed for final preparation.

Duration: 2 Months

Cost—Civil Design, Geotechnical Engineering Analysis, and Site Preparation: $614,100

House Relocation
Scope of Work: It is highly recommended that all 47 homes be relocated to the new subdivision site in a phased approach based on risk.

Phase 1: Group A—4 Imminently Threatened Homes
The scope of work for this phase includes structurally analyzing each home, disconnecting the homes from all utilities, bracing the homes, jacking the homes, and moving the homes to a new site. This would most likely be performed during the winter months when the river ice could support a bulldozer-towed moving skid. Barges may be able to move the homes in the summer, but it could possibly be more efficient in the winter if the river ice could support the movement. Once moved to the new site, the homes would be set upon new post-and-pad foundations and the utilities reconnected. Due to the substantial capital cost of piped water and sewer infrastructure, it is recommended each home moved to the area be initially outfitted with ANTHC's Portable Alternative Sanitation System (PASS) for sanitation service. A typical section detail for the PASS can be seen in Appendix G. Under contract, AVEC would provide power for each home. Each affected homeowner/family would be temporarily housed in housing-unit trailers that would be set up at the new subdivision as temporary living facilities for displaced residents.

Duration: 12 Months

Cost: $100,000 (Structural Analysis), $855,750 (Home Relocation), $200,000 (PASS Installation)

Phase 2: Group B—17 High-Risk Homes

Duration: 24 Months

Cost: $1,875,500 (Relocation), $850,000 (PASS Installation)

Phase 3: Group C—26 At-Risk Homes

Duration: 36 Months

Cost: $2,909,000 (Relocation), $1,300,000 (PASS Installation)

Appendix D provides detailed cost estimates for this option's components.

Environmental Impacts: Environmental impacts for this project are minimal. There would be slight ground disturbance in the areas of the helical piles for the boardwalk and placement of power poles. Other than those minor areas, all construction would be performed above grade, and the primary site that would be disturbed is a formerly disturbed/constructed site (the abandoned runway itself). Each home site from which homes are taken will need to be cleared of debris prior to completion of the project to limit environmental risk after the homes are moved.

Analysis: The site can be prepared to provide housing for the threatened homes and will result in significantly improved access to services for those residents moving from the island locations. While most residents would prefer to have piped water and sewer extended to this area, this provision of resources is likely cost prohibitive (estimated at over $2 million for mains and services) and would significantly increase the water and sewer operational costs for the system. Some residents who would move to this area are currently on pipes, and some currently haul water and use honey buckets. The use of the PASS would provide adequate sanitation service for all residents of this area at a fraction of the capital and operational cost of a piped system. Appendix E is a schematic for the PASS. Once population density in the area supports a piped system, it can be pursued.

Conclusion: This alternative presents the most cost-effective and logistically probable method to protect threatened homes.

Home Relocation Option 3: Construct 21 New Homes at Old Runway

Scope of Work: The scope of work for this alternative is to develop a new subdivision in the community at the old airport site and construct new homes for all of the residents currently living in threatened homes. The old airport, detailed above, is the optimum site to locate new homes within the community. The same site preparation and power distribution expansion is required for this option as outlined in Option 3. After site prep, the construction of the boardwalk, and the extension of the power distribution system, new homes would need to be constructed on the site. Finally, all of the homes from which residents moved would need to be demolished, and the debris would need to be shipped out of the community for final disposal.

Cost:

Boardwalk, Civil Site Preparation, and Power Distribution: Approximately $1,500,000

Homes: $350,000 per home with PASS

Total Construction Cost: $16,450,000

Home Demolition, Site Clearing, and Back Haul: $50,000 per home

Total Demolition Cost: $2,350,000

Durations and Phasing:

Phase I: Boardwalk, Civil Site Preparation, Power Distribution and Five Homes – 1 year

Phase 2: 5 homes – 1 year

Phase 3: 5 homes – 1 year

Phase 4: 5 Homes – 1 year

Phase 5: 5 Homes – 1 year

Phase 6: 5 homes – 1 year

Phase 7: 5 Homes – 1 year

Phase 8: 5 Homes – 1 year

Phase 9: 7 Homes – 1 year

Phase 10: Demolition, Site Clearing, and Back Haul – 3 Years Throughout Duration of Project

Environmental Impacts: This project would result in a net positive impact to the environment by clearing old home sites and replacing those old homes with new homes. By clearing the old home sites, this alternative would prevent release of various chemicals and debris into the river through future bank erosion. Ground disturbance would only occur in the areas of the boardwalk helical pile anchors and the power poles.

Analysis: This would be, by far, the best thing for the community and the residents of the threatened homes. Providing new homes for these residents is expected to be preferable to relocating existing homes. Siting homes at the abandoned runway would provide these residents with convenient access to the community, while placing them out of the area most likely to be affected by bank erosion and floods. However, all of this comes at an extremely high cost likely prohibitive for this community and its residents.

Conclusion: While this alternative would be a wonderful option for the community, the $10 million price tag is likely prohibitive.

PRIORITY 2 OPTIONS – EROSION PROTECTION

Erosion Protection Option 1: Do Nothing

Scope of Work: For this option, no action would mitigate the community's shoreline erosion. This approach would entail allowing the erosion to follow its natural course while relocating infrastructure from affected areas.

Cost: There is no capital cost associated with this option. However, there are costs associated with relocating infrastructure from the shoreline as outlined in the section above.

Duration and Phasing: As this is the no action alternative, no duration or phasing is required.

Environmental Impacts: The primary environmental impact presented by this option is from the uncontrolled release of debris into the river as the bank erodes. This has been a problem for the community in the past, and it has driven the need for large-scale waste backhauls managed by the Kotlik Village Council's Environmental Protection Agency Indian General Assistance Program. If the shoreline is not cleared prior to erosion, this release of debris into the surrounding surface water will continue. In addition, any contaminated soil along the shoreline will be released into the surrounding surface water which could affect the drinking water intake, fish, and other marine life. Often, where homes are located with fuel oil tanks outside, there is localized soil contamination present from years of spills and/or leaks from the external tank. Ideally, all contaminated soils would be removed or remediated prior to erosion occurring, but the removal or remediation process is time consuming and likely cost prohibitive.

Analysis: As described previously, the causative factors driving the accelerated bank erosion are the combination of melting permafrost and mechanical bank erosion. If the permafrost were not deteriorating, there are viable options available to stabilize the bank. However, with the permafrost melting, the options are severely limited and wildly expensive. Any action taken to stabilize the bank will be temporary.

Table 2: Erosion Protection Option 1: Do Nothing Benefits and Drawbacks

Benefits (+)	Drawbacks (-)
No capital cost involved	Erosion will continue
	Could result in uncontrolled release of debris or contaminated soil
	Requires relocation of infrastructure

Conclusion: Doing nothing to the bank combined with relocating infrastructure may be the best option for the community. The combination of melting permafrost and severe mechanical erosion are quite difficult if not impossible to stop. Any attempts to arrest these conditions will be wildly expensive and temporary.

Erosion Protection Option 2: Seawall Construction

Scope of Work: For this option, the construction of a seawall, or revetment, is considered to protect the bank of the eroding areas and prevent further erosion. An effective seawall for this area would likely be constructed of Class III riprap or boulders on the exterior, geogrid-wrapped lifts with specified non-frost susceptible material, and gabion baskets for internal structural support. The seawall would have to cover an area of approximately 15,815 linear feet of bank to protect all of the eroding areas with threatened structures. Appendix F provides a map and typical seawall section detail.

Cost: A similar project being constructed in the community of Fort Yukon was recently awarded for construction at $3,733.33 per linear foot at the lowest bid. Using this figure for unit cost analysis would result in a total cost for the Kotlik structure at $59,042,614. Another factor that would have to be considered outside of the scope of this report is the fact that rock material is much more difficult to procure in Kotlik than it is in Fort Yukon. This would drive the cost even higher. The Army Corps of Engineers has reported to our staff that some revetments can cost up to $10,000 per linear foot.

Duration/Phasing: The design phase of this project would extend one calendar year, and construction of a seawall of this magnitude would likely take three to five years.

Environmental Impacts: In order to construct this seawall, permits would have to be obtained to work within the rivers. Construction activities could affect fishing in the area, and silt residue runoff would have to be tightly controlled in order to not artificially increase river water turbidity; the river serves as the community's drinking water source. In addition, there may be the presence of historically significant artifacts on the bank, which may lead to the requirement for archaeological monitoring during the construction phase of the project.

Analysis: Initial analysis of this option shows it is cost prohibitive. Furthermore, the long-term impact of this option is unknown, as floods in the area could easily overtop the seawall. The construction of a seawall has the potential to exacerbate flood inundation impacts, as the seawall would create a "bathtub" effect if overtopped in a flood. This would trap the floodwater in the community for a longer period of time, increasing flood damage and time for recovery. Furthermore, as the permafrost in the area continues to melt, the land on which the seawall would sit may subside, thereby reducing the efficacy of the seawall.

Conclusion: This option is cost-prohibitive and should not be considered due to the extremely high cost, the uncertain efficacy, and potential to increase flood inundation impacts.

Erosion Protection Option 3: Sheet-pile and Vertically Drilled Thermosyphon Bank Stabilization

Scope of Work: Under this option, a vertical sheet-pile wall would be installed along each bank, and thermosyphons would be drilled vertically along the shoreline throughout the community to provide stabilization of the river bank. Thermosyphons would be vertically drilled behind the sheet-pile wall to provide a stable, frozen foundation resistive to erosion or differential settling. Thermosyphons would be installed approximately ten feet apart throughout the entire area of erosion.

Cost: $20,353,000

- Appendix G provides a cost estimate.

Duration/Phasing:

Design Phase: 6 Months

Construction Phase: 12 Months

Environmental Impacts: Environmental impacts of this option are minimal. There will be multiple drill points at the shoreline for the thermosyphons, but other than that, ground disturbance is minimal. Furthermore, this option would prevent the uncontrolled release of debris and contaminated soil.

Analysis: Thermosyphons are regularly used to stabilize soil foundations in arctic environments for structures ranging from homes to the Alyeska Pipeline. Thermosyphons use passive heat exchange based on natural convection to artificially cool their surroundings. This option would essentially freeze the bank to combat the subsidence of permafrost along the shoreline, resulting in a stabilized structure with the sheet-pile wall to resist mechanical erosion. This technique is designed to stabilize the bank, preventing or significantly slowing erosion.

According to Ed Yarmak, P.E., of Arctic Foundations, Inc. in Anchorage, "Thermosyphons are currently being used to harden the banks of the Colville River where the horizontally directional drilled pipelines are installed to bring the oil from Alpine/NPR-A over to the pipeline infrastructure that feeds Pump Station #1 near Deadhorse. In conjunction with sheet or pipe piles, thermosyphons have been used at Galena (early 1960's) and Bethel (mid 1980's) to minimize river erosion. Also, where pipelines from offshore drilling islands transition into the arctic ocean, thermosyphons are used to keep the right of way stable."

Thermosyphons are used with great success in many areas throughout the arctic in multiple applications. The application most similar to erosion control in Kotlik is the use of thermosyphons for dam building. Often thermosyphon-supported dams are used to contain tailing/waste ponds, clean water storage ponds, or flow control ponds.

Photo of thermosiphon dam at the Kubaka Gold Mine; Russia Far East

Photo Courtesy of Arctic Foundations, Inc.

Given that this technology has been utilized with success in these applications, there is data supporting the theory that this technique will stop the permafrost from melting in the area of the thermosyphon, thereby stabilizing the bank and preventing erosion.

Conclusion: Though this technology has a good track record and would provide bank stabilization, the number of thermosyphons required to stabilize Kotlik's entire shoreline makes this option cost prohibitive. It should, however, be considered for stabilizing small areas of the shoreline to protect high-value infrastructure.

PRIORITY 3 OPTIONS – IDENTIFICATION OF A SITE FOR LONG-TERM RELOCATION

Site identification for long-term relocation is outside the scope of this report. However, the Center for Environmentally Threatened Communities will continue to support the community of Kotlik with its efforts to gather information supporting relocation decision making.

PRIORITY 4 OPTIONS – ADDRESS EROSION IMPACTS TO THE COMMUNITY LANDFILL.

Landfill Erosion Protection Option 1: Do Nothing

Scope of Work: Under this option, no work would be done to protect the landfill from encroaching erosion.

Cost: There is no cost associated with this option. However, it should be noted that the costs associated with river cleanup of all of the solid waste released from the site due to erosion will be extremely high.

Duration/Phasing: This option does not have a duration or phasing.

Environmental Impacts: Doing nothing to the landfill will negatively impact the environment. The same permafrost subsidence and mechanical erosion seen in the community of Kotlik is impacting this site, and if action is not taken, the landfill will erode into the river. This situation will cause an uncontrolled release of solid waste, debris, and leachate in the soil. Due to the tidally influenced flow patterns of Apoon Pass and the Kotlik River, much of this debris will impact the residents of Kotlik, the potable water system intake, and fish and bird populations in the area.

Analysis: The landfill currently sits on Kotlik Yupik Native Corporation land and is operated by the City of Kotlik. Site control belongs solely to the corporation. This could create complications if public funds are expended for erosion control on for-profit, corporation-owned land. Site control and access are the first challenge in any work planned for this area. This issue will come up regardless of the erosion protection option chosen.

Doing nothing at the landfill creates an environmental crisis in the future. This area is eroding, and the refuse in the landfill should not be released into the environment in an uncontrolled manner.

Conclusion: The do nothing alternative for erosion protection at the landfill is not advised.

Landfill Erosion Protection Option 2: Relocate Landfill

Scope of Work: For this option, the landfill would be relocated to a predetermined location east of the community as a "managed retreat" option. The site was selected during a landfill study performed in 1998, and the location can be seen on the most current Alaska Department of Commerce, Community, and Economic Development (DCCED) DCRA maps as Parcel 8205-S in Block 81, which was deeded to the City of Kotlik from the corporation. The site can be seen on the DCCED map at Appendix H. The scope of work includes design services, site control, landfill facility construction, and boardwalk construction to access the new site. This option will require final capping and close-out of the existing landfill as well.

Cost: $5,375,000

Appendix I shows the cost estimate.

Duration/Phasing:

Design and Site Control: 12 Months

Construction: 18 Months

Environmental Impacts: Landfill relocation would result in a net positive environmental impact for the community. This option would allow residents of Kotlik easier access to the landfill and would allow for more efficient and effective landfill operations including waste volume minimization (incineration) and daily cover addition. Furthermore, this site can be located in an area protected from erosion that could serve the community for many years to come. A critical component of the environmental impact will be the proper closeout of the existing landfill. If this component of this option is not properly completed, it could result in a wide array of negative environmental impacts due to the uncontrolled release of the refuse in the existing landfill.

Analysis: The option of constructing a new landfill is attractive. However, the cost for the construction of the new facility is extremely high. The Alaska Department of Environmental Conservation requirement for separation from groundwater and the lack of locally available material suitable for the sub-grade foundation of this solid waste facility drive costs to a high level. To construct this facility, a large amount of material would have to be shipped to the community. Furthermore, in order to provide access to the facility, an extensive boardwalk would have to be constructed, further driving up the cost. The facility would be outfitted with two waste incineration burners, which, when properly utilized can provide significant volume minimization of the waste stream thus extending the service life of the facility.

Conclusion: The option of constructing a new landfill is preferred, but it is likely cost prohibitive. It would allow community residents much easier access to the landfill and would allow for more effective solid waste facility operations. However, due to the costs involved, funding for this option is not likely.

Landfill Erosion Protection Option 3: Seawall Construction

Scope of Work: The scope of work under this option would be to construct a seawall at the existing landfill location as a "defend in place" option. This seawall would be used as an erosion protection structure, providing increased structural support of the bank at the landfill. The structure would extend approximately 300 feet along the western edge of the landfill. The scope of this project would also include compaction and capping of the existing landfill, excavation of a new landfill cell, and perimeter fencing.

Cost: $2,331,000

Appendix J shows the cost estimate.

Duration/Phasing:

Design: 12 Months

Construction: 6 Months

Environmental Impacts: The construction of a seawall at the bank of the landfill would not result in any negative impacts to the environment. This option would prevent the erosion currently occurring at the site, protecting the site from uncontrolled release into the environment. Furthermore, fencing the landfill's perimeter and compacting and capping current refuse would result in the site being much more efficiently operated and maintained.

Analysis: The landfill currently sits on Kotlik Yupik Native Corporation land and is operated by the City of Kotlik. Site control belongs solely to the corporation. Expenditure of public funds for seawall construction on land owned by a for-profit corporation could create complications. Site control and access are the first challenge in any work planned for this area.

If site control can be obtained, a seawall could provide excellent bank protection at the landfill site. However, the permafrost degradation at the site could result in the seawall differentially settling, rendering the structure ineffective. The expected life span of this facility is unknown because of the permafrost degradation in this area.

Conclusion: Due to the high cost and potential for differential settling that could shorten the life span of the seawall, this option is not recommended for erosion protection at the landfill.

Landfill Erosion Protection Option 4: Sheet-pile and Thermosyphon Bank Stabilization

Scope of Work: Under this option, a synthetic sheet-pile wall would be constructed at the bank of the landfill to provide erosion protection. Vertically driven, solar-powered, active thermosyphons would freeze the bank at the landfill, providing foundation stabilization for the sheet-pile wall. Finally, the existing landfill would be compacted and capped, and perimeter fencing would be installed at the facility. Appendix K shows a schematic of the sheet-pile and thermoshyphon structure.

Cost: $1,605,400

- Appendix L provides a cost estimate for this option.

Duration/Phasing:

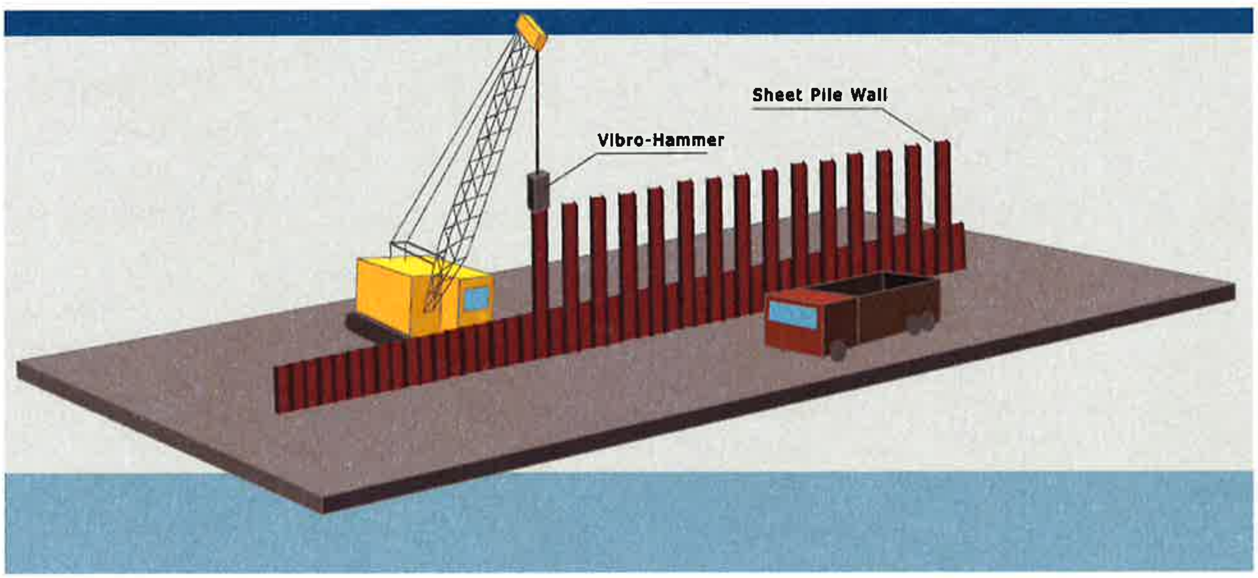
Design and Site Control: 12 Months

Construction: 4 months

Environmental Impacts: The construction of a stabilized sheet-pile wall at the bank of the landfill would not result in any negative impacts to the environment. This option would prevent the erosion currently occurring at the site, protecting the site from uncontrolled release into the environment. Furthermore, fencing the landfill's perimeter and compacting and capping current refuse would result in the site being much more efficiently operated and maintained.

Analysis: The landfill currently sits on Kotlik Yupik Native Corporation land and is operated by the City of Kotlik. Site control belongs solely to the corporation. Expenditure of public funds for seawall construction on land owned by a for-profit corporation could create complications. Site control and access are the first challenge in any work planned for this area.

The main advantage to this option is the fact that it addresses both of the bank erosion failure modes at play: mechanical erosion and permafrost degradation. The sheet-pile wall at the bank will provide enhanced, cost effective mechanical erosion protection, while the thermosyphons at the bank area will provide permafrost stabilization at the site. The stabilized permafrost will provide a solid foundation for the sheet-pile wall, thus preventing differential settling and premature system failure. The depiction below shows a typical sheet-pile wall installation.



Typical Sheet-Pile Wall Installation

This technique has very promising potential to provide bank stabilization in warming regions of Alaska and the arctic. By addressing both primary failure modes creating the accelerated bank erosion, the sheet-pile/thermosyphon system can provide a cost-effective method of bank stabilization for small scale applications.

Conclusion: This option is the preferred alternative for erosion protection and bank stabilization at the Kotlik landfill. The site control issue will have to be addressed prior to any further action on this alternative. If funded, properly designed, and installed, this option could provide effective, long-term bank stabilization for this site.

Report Conclusions:

In conclusion, a number of actions should be taken to protect the life, health, well-being, and property of the residents of Kotlik. A combined strategy of managed retreat and defending in place is prudent for the community.

Managed Retreat:

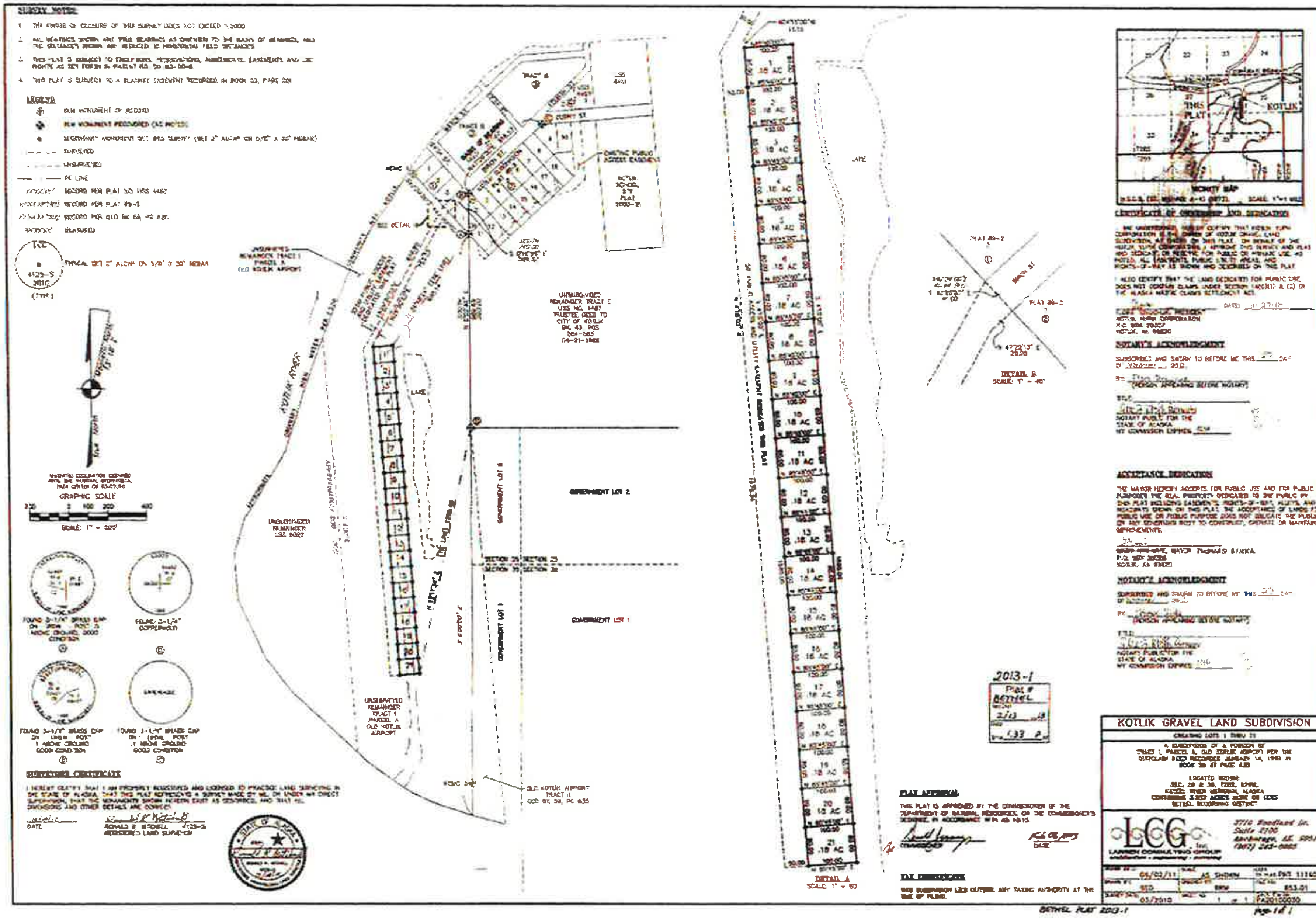
The managed retreat of homes is the most financially feasible and logistically viable option for protecting the community residences. A phased plan should be enacted to prepare the old runway site for relocated homes. This will require a new boardwalk, site preparation, and the extension of power utilities to the old runway site. Once these critical components are in place, homes should be relocated to this area prioritized by risk of catastrophic foundation failure due to bank erosion.

Defend in Place:

The defend-in-place strategy is the most financially feasible and logistically viable option for the community's landfill. Landfill relocation is likely cost prohibitive and would require extensive remediation of the existing landfill site. Construction of a stabilized sheet-pile wall at the bank would provide stable, long-term protection of the facility and prevent the uncontrolled release of refuse and leachate into the environment.

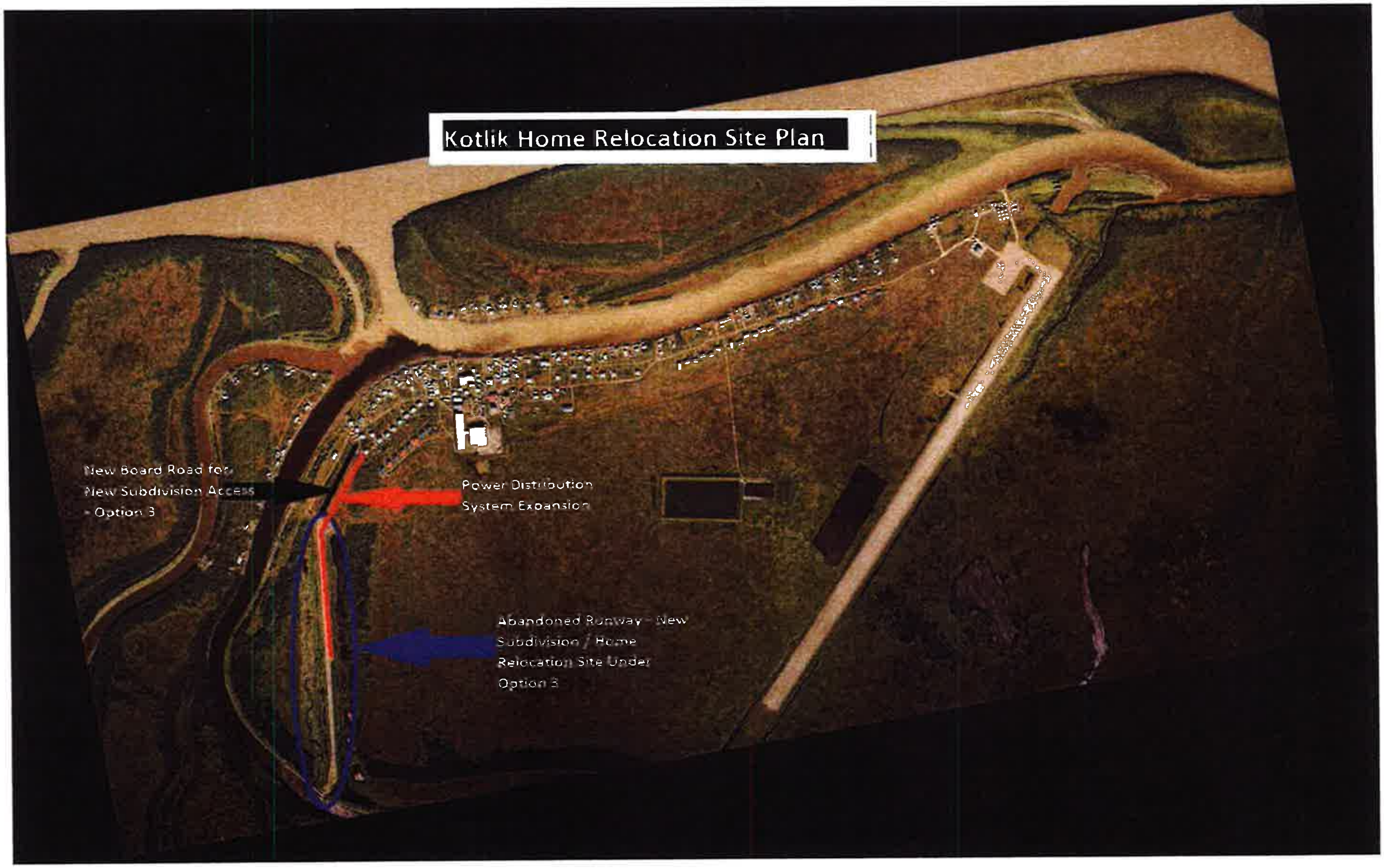
Finally, it is advisable for the community to begin the process of selecting a new townsite for full-scale relocation. The selection of such a site is outside of the scope of this report. However, it is likely that the community will need to relocate at some point due to the combination of continual permafrost degradation and rising sea levels.

Appendix A: Old Kotlik Runway Site Plan

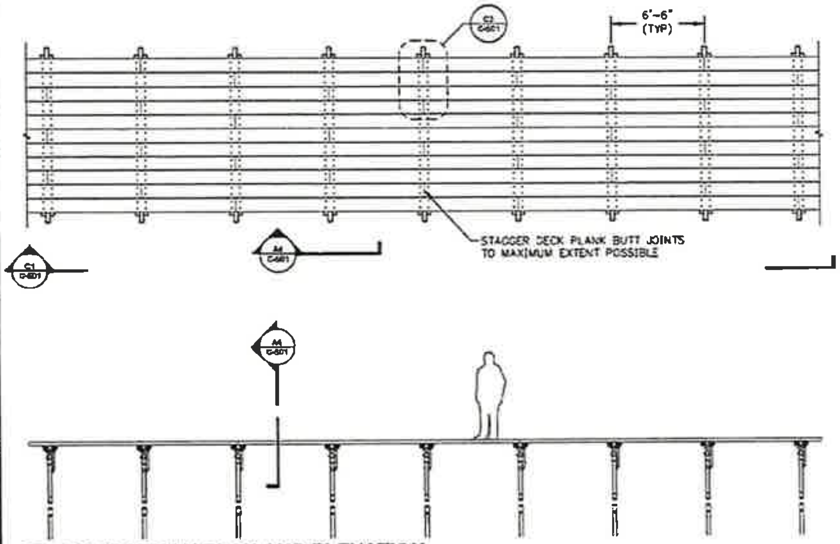


SURVEY NOTES:
LEGEND
VICINITY MAP
CERTIFICATE OF OWNERSHIP AND DEDICATION
NOTARY'S ACKNOWLEDGMENT
ACCEPTANCE DEDICATION
NOTARY'S ACKNOWLEDGMENT
SURVEYOR'S CERTIFICATE
PLAT APPROVAL
TAX CERTIFICATE
DETAIL A
DETAIL B
GRAPHIC SCALE
SCALE: 1" = 200'
GOVERNMENT LOT 2
GOVERNMENT LOT 1
LAKE
KOTLIK
THIS PLAT
KOTLIK GRAVEL LAND SUBDIVISION
CREATING LOTS 1 THRU 21
LCG
LARSEN CONSULTING GROUP
2013-1
BETHEL PLAT 2013-1
Pg 1 of 1

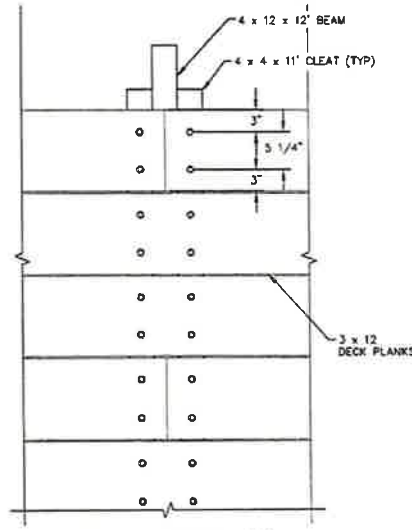
Appendix B: Kotlik – Home Relocation Option 1 Site Layout


Kotlik Home Relocation Site Plan
New Board Road for
New Subdivision Access
- Option 3
Power Distribution
System Expansion
Abandoned Runway - New
Subdivision / Home
Relocation Site Under
Option 3

Appendix C: Kotlik Old Runway Boardwalk Detail – Typical Section from ANTHC design prepared for Nunam Iqua, 2015



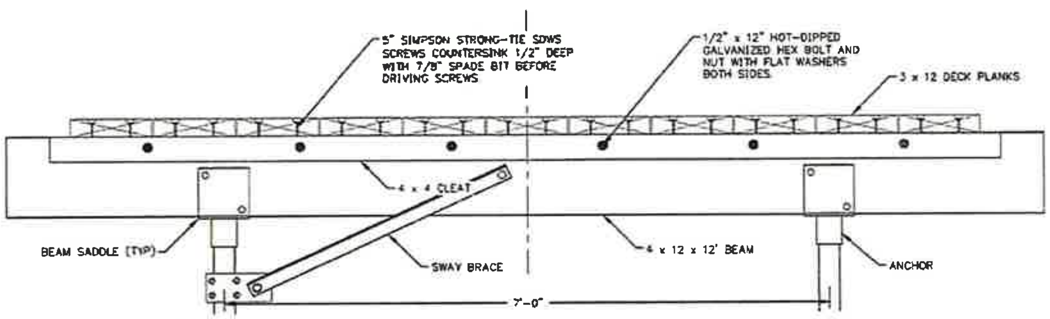
C1 BOARDWALK PLAN AND ELEVATION



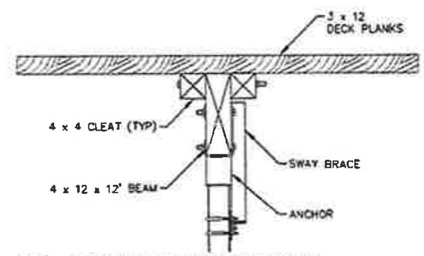
C3 BOARDWALK BEAM PLAN

NOTES:

1. ALL 3x AND 4x LUMBER, INCLUDING DECK PLANKS, BOARDS, CLEATS INCISED PRESSURE-TREATED 0.60 PCF.
2. SEE C-509 FOR DETAIL OF HELICAL ANCHOR, SWAY BRACE, AND BEAM SADDLES



A1 BOARDWALK SECTION



A4 BOARDWALK ELEVATION

Division of Environmental Health and Engineering

BAR IS ONE INCH ON ORIGINAL DRAWING, IF NOT ADJUST SCALES ACCORDINGLY

NUNAM IQUA, AK ACCESS ROAD AND BOARDWALK REPAIR ISSUED FOR CONSTRUCTION

PLAN SET:	SXP-15-010
PROJ MGR:	MR
PROJ ENG:	CB
DRWS ENG:	PC
DRAWN BY:	RN
SHEET TITLE	

BOARDWALK DETAILS

C-501

SHEET 8 OF 16

12 OF 20 TOTAL SHEETS

USER: SHOLLERING PRODUCT: Autodesk AutoCAD Civil 3D 2015 - English FILE: P:\Nunam_Iqua\SXP_Design\SXP-15-010\Civil\SXP-C-STBRD1.dwg LAYOUT: BRD_PLAN_FLAT PRINTED: 8/26/2015 7:33:10 AM

Appendix D: Home Relocation Option 1: Cost Estimates

Kotlik Boardwalk Extension - Old Airport
Native Village of Kotlik, Alaska
Cost Estimate - Parametric
Prepared by M. Roberts

Description	Code	Unit	Quantity	Unit Cost	Total Cost
Materials	M-BW	LF	1,200	275.00	330,000.00
Helical Pile Foundation (Chance Anchors or Equivalent Plus Extensions)	M-BW	EA	240	250.00	60,000.00
Heavy Equipment Rental	M-BW	LS	1	40,000.00	40,000.00
Mobilization/Freight and Shipping	M-BW	LS	80,000	1.00	80,000.00
Construction Drawings and Specifications	M-DS	EA	1	75,000.00	75,000.00
Subtotal					585,000.00
Contingency 15%					87,750.00
Total					**672,750.00**

Kotlik - Civil Site Preparation
Parametric Cost Estimate
Prepared by M. Roberts

Description	Code	Unit	Quantity	Unit Cost	Total Cost
Labor - 6 Man Crew, 30 days	M-CS	Man-Days	180	550.00	99,000.00
Heavy Equipment Rental	M-CS	Months	3	30,000.00	90,000.00
Gravel Material - FOB Kotlik	M-CS	CY	1,000	125.00	125,000.00
Mobilization/Demobilization	M-CS	LS	120,000	1.00	120,000.00
Construction Drawings and Specifications and Geotech	M-DS	EA	1	100,000.00	100,000.00
Subtotal					534,000.00
Contingency 15%					80,100.00
Total					**614,100.00**

Equipment Requirements: D6 Bulldozer, D4 Bulldozer, 320 Excavator, Roller Compactor, Loader, Dump Trucks, 2

Kotlik House Relocation - Phase 1, Group A
Native Village of Kotlik, Alaska
Cost Estimate - Parametric
Prepared by M. Roberts

Description	Code	Unit	Quantity	Unit Cost		Total Cost
Structural Assessment for 47 Homes	M-DS	LS	1	$100,000	$	100,000
House Relocation	M-HR	EA	4	75,000.00		300,000.00
Power Connection -Service Installation	M-HR	EA	4	10,000.00		40,000.00
Mobilization/Freight and Shipping	M-CB	LS	50,000	1.00		50,000.00
ATCO Housing Units and Setup	M-TH	EA	3	105,000.00		315,000.00
PASS Systems	M-WW	EA	4	50,000.00		200,000.00
Subtotal						1,005,000.00
Contingency 15%						150,750.00
Total						**1,155,750.00**

Kotlik House Relocation - Phase 2 - Group B
Native Village of Kotlik, Alaska
Cost Estimate - Parametric
Prepared by M. Roberts

Description	Code	Unit	Quantity	Unit Cost	Total Cost
House Relocation	M-HR	EA	17	75,000.00	1,275,000.00
Power Connection -Service Installation	M-HR	EA	17	10,000.00	170,000.00
Mobilization/Freight and Shipping	M-CB	LS	75,000	1.00	75,000.00
PASS Systems	W-WW	EA	17	50,000.00	850,000.00
Subtotal					2,370,000.00
Contingency 15%					355,500.00
Total					**2,725,500.00**

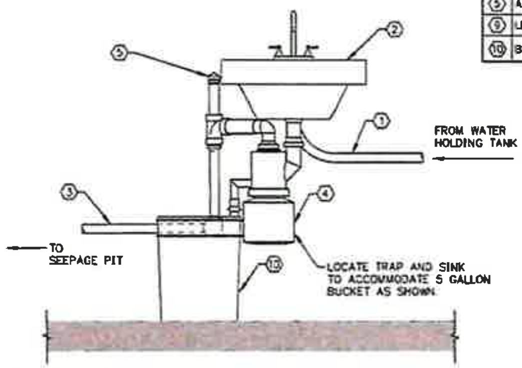
Kotlik House Relocation - Phase 3 - Group C
Native Village of Kotlik, Alaska
Cost Estimate - Parametric
Prepared by M. Roberts

Description	Code	Unit	Quantity	Unit Cost	Total Cost
House Relocation	M-HR	EA	26	75,000.00	1,950,000.00
Power Connection -Service Installation	M-HR	EA	26	10,000.00	260,000.00
Mobilization/Freight and Shipping	M-CB	LS	150,000	1.00	150,000.00
PASS Systems	W-WW	EA	26	50,000.00	1,300,000.00
Subtotal					3,660,000.00
Contingency 15%					549,000.00
Total					**4,209,000.00**

Appendix E: Portable Alternative Sanitation System (PASS) Schematic – Prepared by ANTHC for Allakaket, 2018

#	PART	REMARKS
	BATHROOM MATERIAL LIST	
1	POTABLE WATER PIPING	3/4" PEX
2	SINK AND FAUCET	AMERICAN STANDARD ROXALYN; BAR FAUCET 2 HANDLE SET & 0.5 GPM AERATOR
3	FAUCET DRAIN LINE	1 1/2" ABS PIPE
4	SINK TRAP	GLECCO 64OZ BOTTLE – SEE SHEET P-001
5	AIR ADMITTANCE VALVE	1 1/2" OATEY SURE-VENT
9	LEVEL SENSOR	SEE ELECTRICAL
10	BUCKET	5 GALLON BUCKET FOR OPTIONAL OPERATION

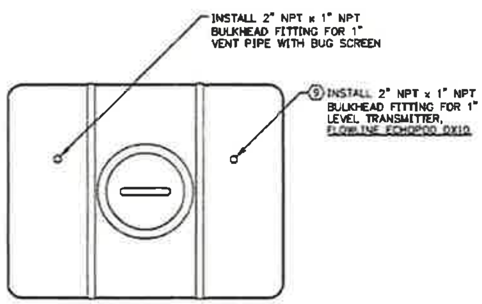
#	PART	REMARKS
	BATHROOM MATERIAL LIST	
11	TOILET	PRE-MANUFACTURED BY LIFEWATER ENGINEERING INC.
12	URINE JUG	PROVIDED WITH TOILET
13	URINAL	PROVIDED WITH TOILET (OPTIONAL)
14	URINE DRAIN PIPING	1" KURI ARCTIC TUNDRA TUBE
15	GREY WATER CLEANOUT	1 1/2" PVC WYE WITH PLUG
16	URINE CLEANOUT	1" x 1" x 1" TEE PVC WITH THREADED PLUG
17	WATER SYSTEM	PRE-MANUFACTURED BY CAMPWATER INDUSTRIES INC



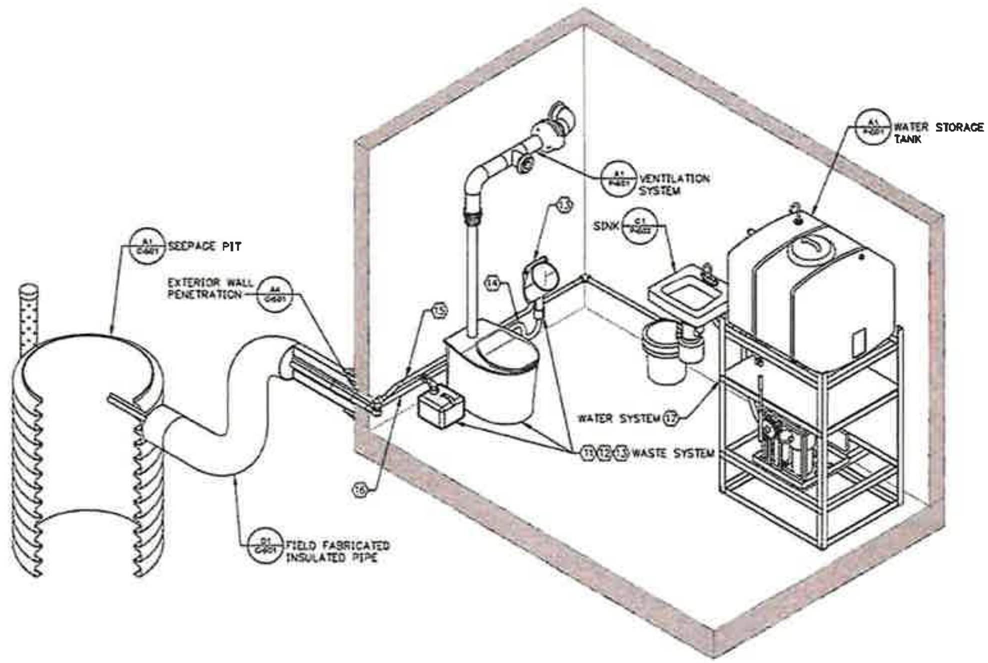
C1 SINK SECTION

NOTES:

1. CONNECT SENSOR TO DATA LOGGING PANEL IN FRED'S HOME. SEE ELECTRICAL.



A1 FRED NED SR WATER TANK



A2 NOTATIONAL SYSTEM ISOMETRIC

Division of Environmental Health and Engineering

BAR IS ONE INCH ON ORIGINAL DRAWING, IF NOT ADJUST SCALES ACCORDINGLY

ALLAKAKET, AK
PORTABLE ALTERNATIVE SANITATION SYSTEM (PASS) PROJECT
ISSUED FOR CONSTRUCTION

PLAN SET:	AET-18-004
PROJ MGR:	BS
PROJ ENG:	MH
DRWG ENG:	CM
DRAWN BY:	SSM
SHEET TITLE	

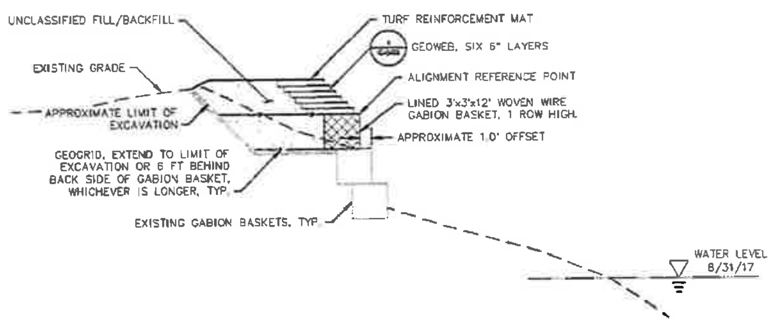
SINK SECTION AND SYSTEM ISOMETRIC

P-503

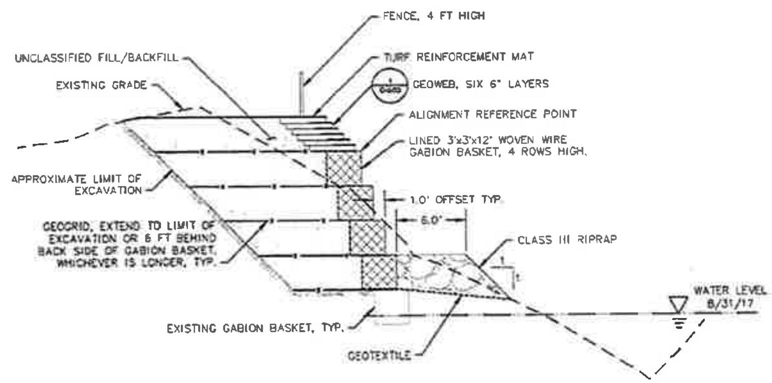
SHEET 6 OF 8

15 OF 18 TOTAL SHEETS

Appendix F: Typical Seawall Section Detail – Prepared by CRW for Fort Yukon, 2018



(1) GABION RETAINING WALL STATION 1+25
NTS



(2) GABION RETAINING WALL STATION 1+50
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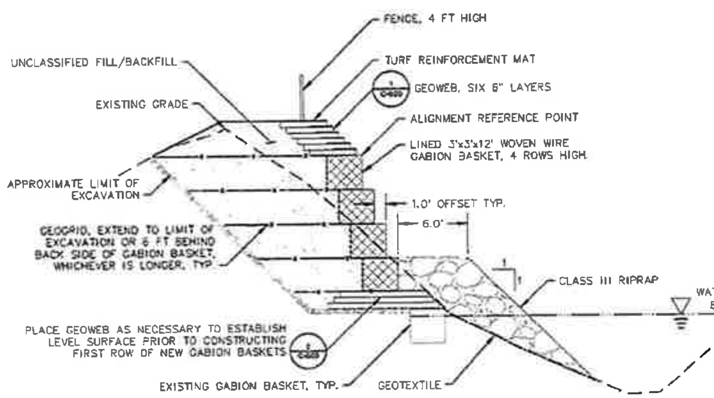
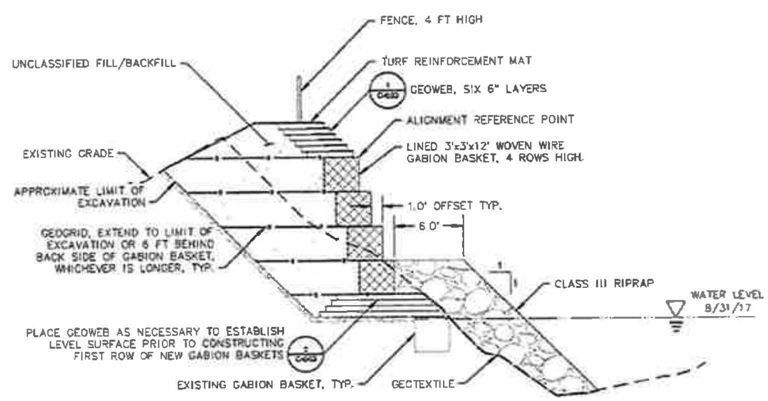


(3) GABION RETAINING WALL STATION 1+75
NTS



(4) GABION RETAINING WALL STATION 2+00
NTS

Division of Environmental Health and Engineering
4500 Diplomacy Drive
Anchorage, Alaska 99508
(907) 729-3600

3940 ARCTIC BLVD SUITE 300
ANCHORAGE, ALASKA 99503
PHONE: (907) 562-3252
#AECL882-AK

BAR IS ONE INCH ON ORIGINAL DRAWING. IF NOT ADJUST SCALES ACCORDINGLY

FORT YUKON, AK
SEAWALL / LEVEE REPAIR

REV	DATE	DESCRIPTION	INIT
0	5-9-18	ISSUED FOR CONSTRUCTION	JVS

PLAN SET: FYU-D21-1330
PROJ MGR: JVS
PROJ ENG: CWS
DRAINS ENG: ----
DRAWN BY: CWS
SHEET TITLE

RETAINING WALL SECTIONS

C-501
SHEET **5** OF **9**

10 OF 14 TOTAL SHEETS

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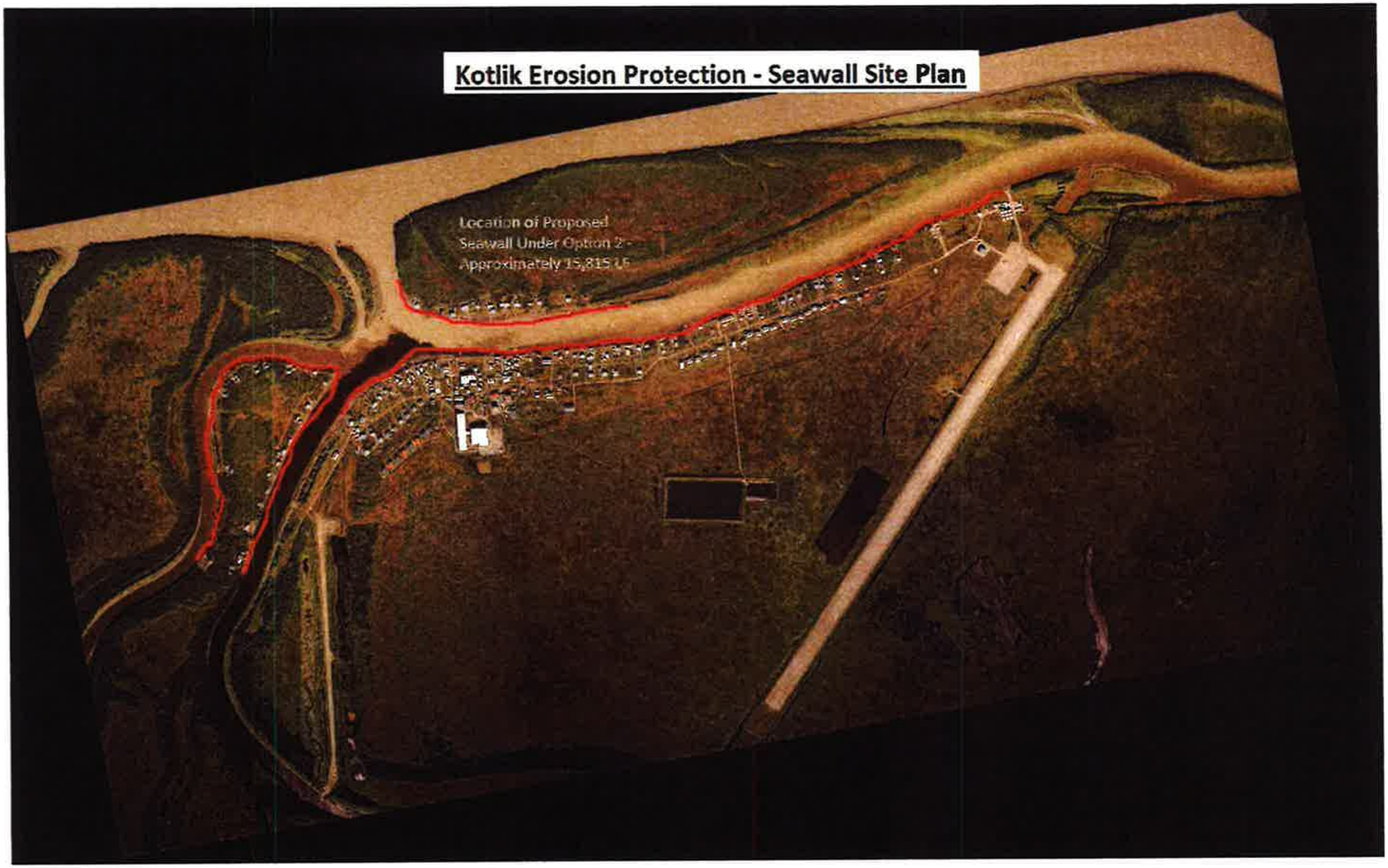
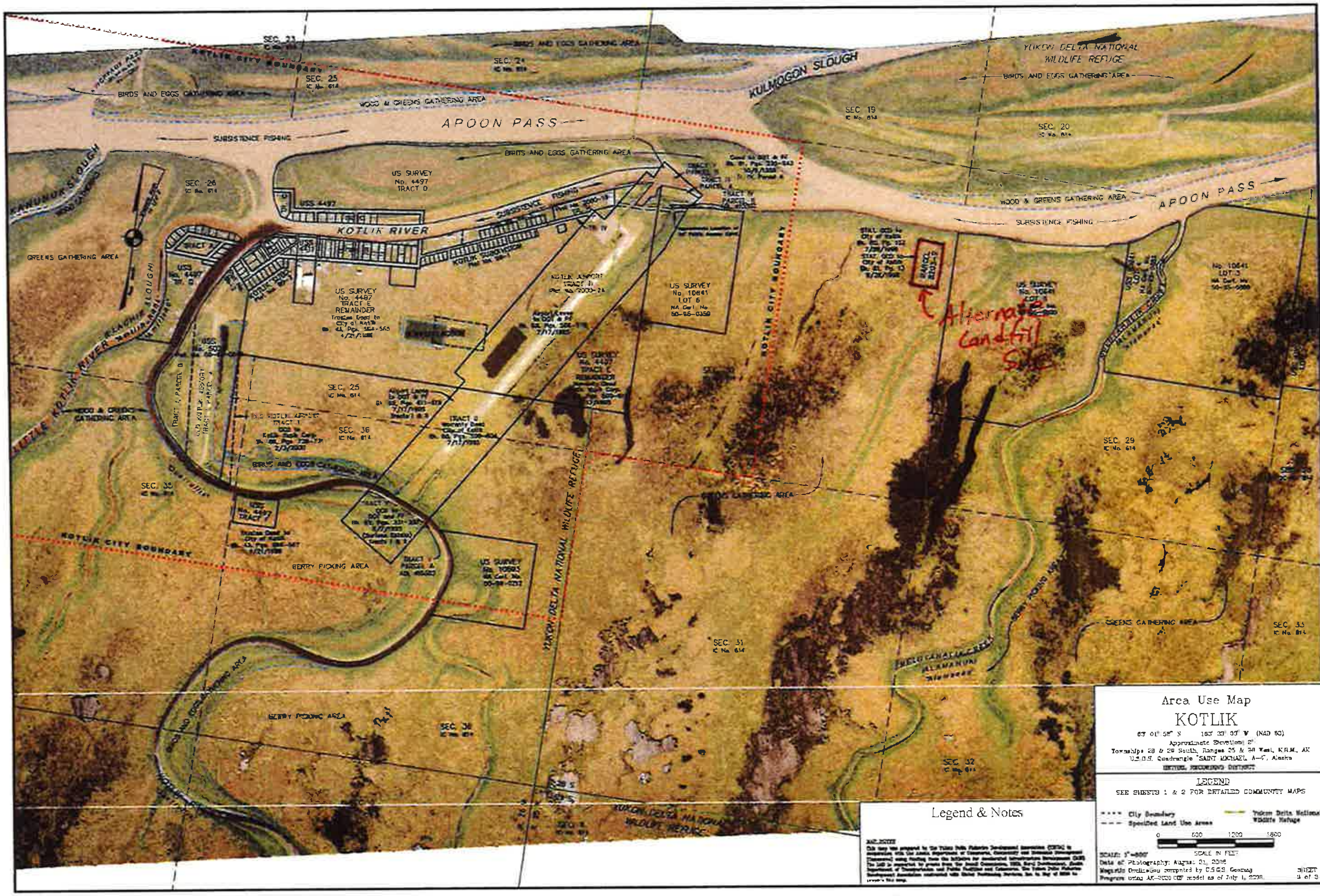

Kotlik Erosion Protection - Seawall Site Plan
Location of Proposed
Seawall Under Option 2 -
Approximately 15,815 LF

Appendix G: Community Sheet-Pile Bank Stabilization System Cost Estimate

Kotlik Community Sheet Pile Bank Stabilization Cost Estimate
Native Village of Kotlik, Alaska
Cost Estimate - Parametric
Prepared by M. Roberts

Description	Code	Unit	Quantity	Unit Cost	Total Cost
Materials	M-TS	EA	1,200	7,500.00	9,000,000.00
Labor	M-TS	Man-Days	480	400.00	192,000.00
Drill Rig - Contract	M-TS	LS	1	150,000.00	150,000.00
Heavy Equipment Rental	M-TS	LS	1	100,000.00	100,000.00
Sheet Pile Wall Installation	M-TS	LF	15,815	500.00	7,907,500.00
Mobilization/Freight and Shipping	M-BW	LS	200,000	1.50	300,000.00
Construction Drawings and Specifications	M-DS	EA	1	75,000.00	75,000.00
Subtotal					17,724,500.00
Contingency 15%					2,658,675.00
Total					**20,383,175.00**

Appendix H: New Landfill Site – DCCED Map 2006



APOON PASS
KULMOGON SLOUGH
YUKON DELTA NATIONAL WILDLIFE REFUGE
BIRDS AND EGGS GATHERING AREA
WOOD & GREENS GATHERING AREA
SUBSISTENCE FISHING
KOTLIK CITY BOUNDARY
KOTLIK RIVER
US SURVEY No. 4497 TRACT D
US SURVEY No. 10641 LOT 6
SEC. 19
SEC. 20
SEC. 24
SEC. 25
SEC. 26
SEC. 29
SEC. 31
SEC. 32
SEC. 33
SEC. 35
SEC. 36
GREENS GATHERING AREA
BERRY PICKING AREA
LITTLE KOTLIK RIVER
KOTLIK AIRPORT
Alternate Landfill Site
Legend & Notes
Area Use Map
KOTLIK
LEGEND
SEE SHEETS 1 & 2 FOR DETAILED COMMUNITY MAPS
City Boundary
Specified Land Use Areas
Yukon Delta National Wildlife Refuge
SCALE IN FEET
0
600
1200
1800
Date of Photography: August 31, 2006
SHEET 3 of 3

Appendix I: New (Relocated) Landfill Cost Estimate

Kotlik Solid Waste Facility
Native Village of Kotlik, Alaska
Cost Estimate - Parametric
Prepared by Mike Roberts, PE

Description	Code	Unit	Quantity	Unit Cost		Total Cost
Site Clearing and Grubbing	L-LO	AC	3	$25,000	$	75,000.00
Site Grading	L-LO	AC	3	$35,000	$	105,000.00
Imported NFS Material - Sub Grade	L-LO	CY	15000	$125	$	1,875,000.00
Disposal Cell Excavation	L-LO	AC	3	$50,000	$	150,000.00
Stockpile Daily Cover Material	L-LO	CY	2000	$30	$	60,000.00
Perimeter Fencing	L-LO	FT	1500	$125	$	187,500.00
Signage	L-LO	EA	3	$5,000	$	15,000.00
Boardwalk - With Helical Pier Foundation	L-LO	LF	2000	$560	$	1,120,000.00
Burn Box Trailer-Mounted Unit	L-LO	EA	2	$30,000	$	60,000.00
Old Landfill Capping/Close Out	L-LO	LS	1	$250,000	$	250,000.00
Freight	L-LO	LB	100000	$1.00	$	100,000.00
O&M Manual and Training	L-LO	LS	1	$7,500	$	7,500.00
O&M Tools	L-LO	EA	5	$500	$	2,500.00

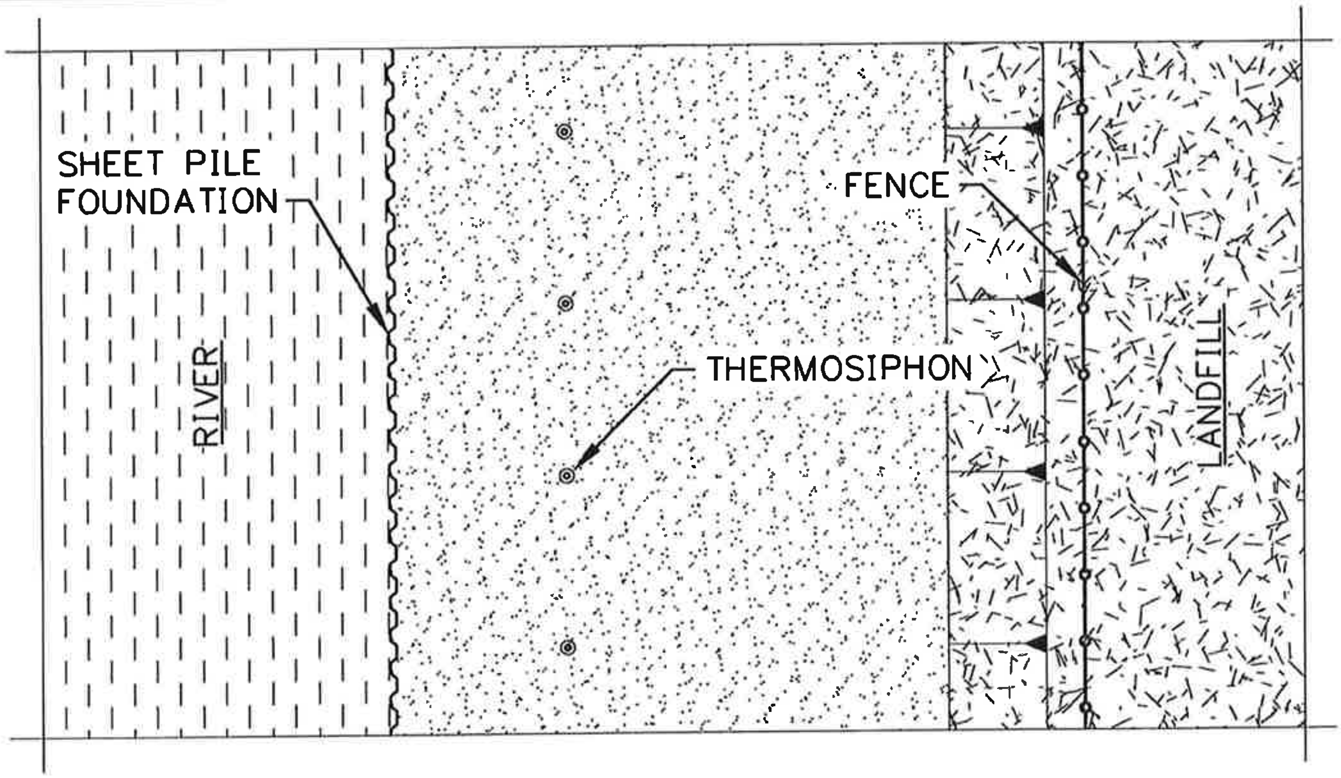
Construction Cost		$	4,007,500.00
Contingencies	15%	$	601,125.00
Total Construction Cost		$	4,608,625.00
Project Technical Support	15%	$	690,798.51
Specialty Engineering (Geotech)		$	75,000.00
Total Project Cost		**$**	**5,374,424**

Appendix J: Landfill Seawall Conceptual Cost Estimate

Kotlik Solid Waste Facility - Seawall Construction Estimate
Native Village of Kotlik, Alaska
Cost Estimate - Parametric
Prepared by Mike Roberts, PE

Description	Code	Unit	Quantity	Unit Cost		Total Cost
Shoreline Excavation and Prep	L-LO	LF	300	$250	$	75,000.00
Seawall Construction	L-LO	LF	300	$4,500	$	1,350,000.00
Perimeter Fencing	L-LO	FT	1500	$125	$	187,500.00
Compaction and Capping	L-LO	LS	1	$50,000	$	50,000.00
Freight	L-LO	LB	100000	$1.00	$	100,000.00
	Construction Cost				$	1,762,500.00
	Contingencies			15%	$	264,375.00
	Total Construction Cost				$	2,026,875.00
	Project Technical Support			15%	$	303,813.44
				Total Project Cost	**$**	**2,330,688**

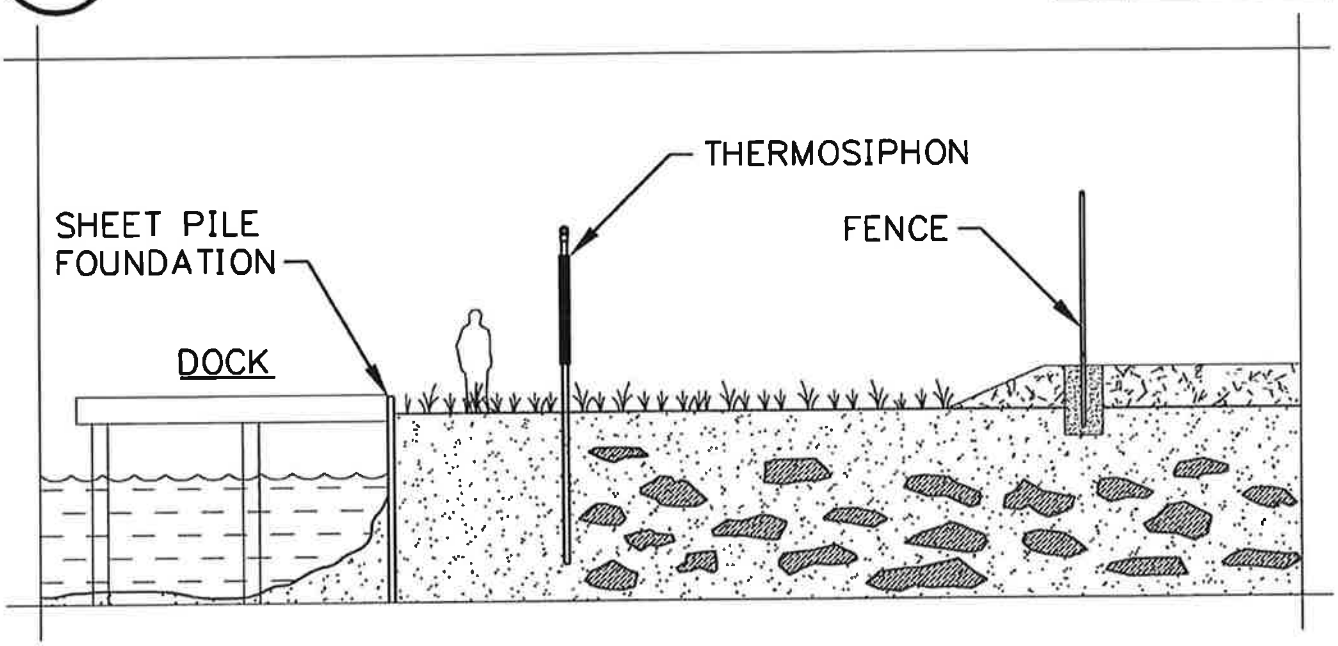
Appendix K: Sheet-Pile and Thermosyphon Structure Schematic



A1 PLAN VIEW

3/32" = 1'-0"

0 4' 8' 16'



A2 SECTION

3/32" = 1'-0"

0 4' 8' 16'

Division of Environmental Health and Engineering
4500 Diplomacy Drive
Anchorage, Alaska 99508
(907) 729-3600

KOTLIK, AK
LANDFILL SHEET PILE FOUNDATION DETAIL

PRINTED DATE: 10/5/18 | SHEET 1 OF 1

USER: THOELLERING PRODUCT: AutoCAD 2018 - English FILE: O:\Projects\Kotlik_Sheet_Pile_Foundation\KOT-C-STPLAN.dwg LAYOUT: SHEET_PILE

Appendix L: Landfill Sheet-Pile and Thermosyphon Bank Stabilization Conceptual Cost Estimate

Thermosyphon Landfill Bank Stabilization Cost Estimate
Native Village of Kotlik, Alaska
Cost Estimate - Parametric
Prepared by M. Roberts

Description	Code	Unit	Quantity	Unit Cost	Total Cost
Materials	M-TS	EA	30	7,500.00	225,000.00
Labor	M-TS	Man-Days	240	400.00	96,000.00
Drill Rig - Contract	M-TS	LS	1	150,000.00	150,000.00
Heavy Equipment Rental	M-TS	LS	1	100,000.00	100,000.00
Sheet Pile Wall Installation	M-TS	LF	300	1,500.00	450,000.00
Mobilization/Freight and Shipping	M-BW	LS	200,000	1.50	300,000.00
Construction Drawings and Specifications	M-DS	EA	1	75,000.00	75,000.00
Subtotal					1,396,000.00
Contingency 15%					209,400.00
Total					**1,605,400.00**

Appendix M: Results of Ground Temperature Monitoring Study, USGS

2015

KOTLIK

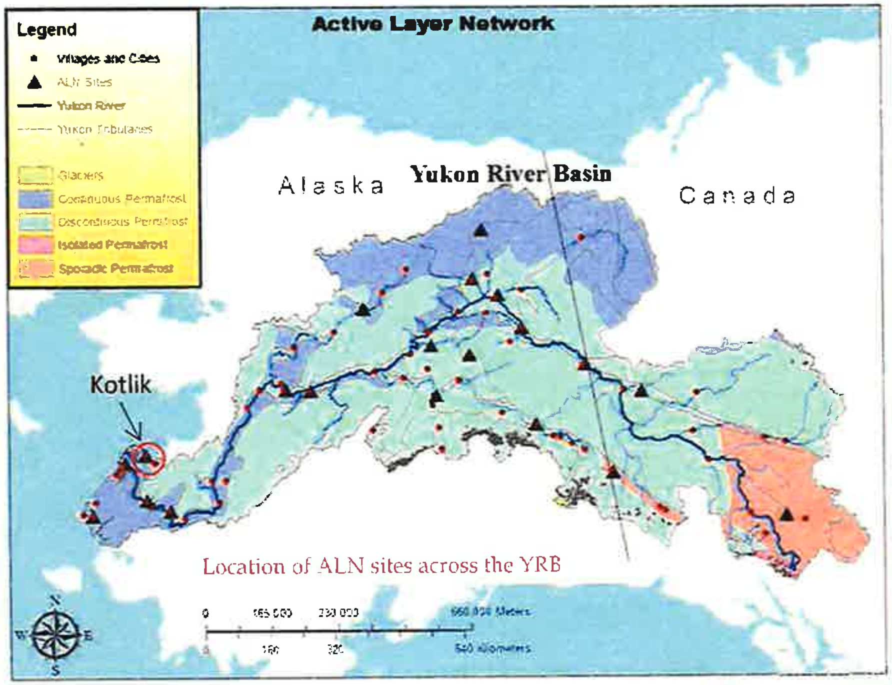
THE ACTIVE LAYER NETWORK: A COLLABORATIVE PROJECT BETWEEN THE US GEOLOGICAL SURVEY, YUKON RIVER INTER-TRIBAL WATERSHED COUNCIL, AND YUKON RIVER BASIN COMMUNITIES. A FIVE YEAR SUMMARY REPORT FOR KOTLIK

USGS science for a changing world

ONE PEOPLE-ONE RIVER
Yukon River Inter-Tribal Watershed Council
www.yritwc.org

Introduction

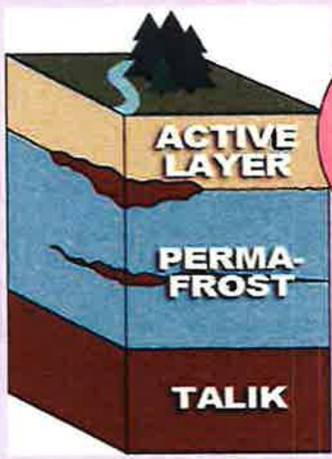
The Active Layer Network (ALN) was launched in 2009 as a cooperative project between the United States Geological Survey (USGS), the Yukon River Inter-Tribal Watershed Council (YRITWC) and Yukon River Basin (YRB) communities. The active layer is the soil above the permanently frozen ground that thaws during the summer months and freezes again in the autumn. By measuring the depth of the active layer in late summer, at the time of maximum thaw over several years, we are able to better understand the effects of a warming climate on permafrost. Over the 2009 and 2010 field seasons twenty ALN sites were installed across the YRB.



Location of ALN sites across the YRB

Problem and Need

Numerous studies indicate that permafrost is thawing and the active layer is deepening. Permafrost thaw will likely lead to changes in groundwater flows and the quantity and quality of the rivers, streams, and lakes in the YRB. Additionally, changes in the thickness of the active layer may have profound effects on human infrastructure such as houses, sewage lagoons, and water systems.



Active Layer: layer of soil above the permafrost that freezes and thaws with the seasons.

Talik: year round unfrozen ground in permafrost areas.

Permafrost: soil that has been frozen for two or more years.


"Drunken Houses" that are falling over due to permafrost thaw

Previous Work

Faculty at the University of Alaska – Fairbanks (UAF) pioneered permafrost and active layer network studies in Alaska through the development of the global Circumpolar Active Layer Monitoring Program (CALM). The primary goal of CALM is to observe the response of the active layer and near surface permafrost to climate change of long (multi-decadal) time scales. The data collected as part of the ALN is submitted to the CALM program and available online at http://www.gwu.edu/~calm/.

Methods

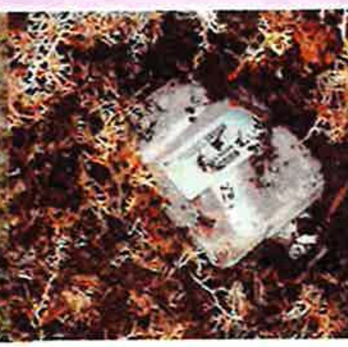
Site Locations

The location of ALN site was based on several factors. First, locations were chosen based on the presence of generally continuous permafrost at a depth that can be measured manually with a calibrated rod. Second, distribution of sites within the YRB must represent the wide range of regions and land cover such us upland, lowland, un-forested, and forested areas. Third, the site must be available for community involvement. The specific location of each site within the chosen regions was selected through community participation using community member's location knowledge of permafrost distribution and depth.

Design

The general project design for the ALN follows the design of other CALM projects. All sites consist of 50 meter by 50 meter grids. The depth of the active layer is measured each year at these grid locations. Measurements are taken every 5 meters for a total of 100 measurements. Measurements are made with a calibrated 1.1 meter steel metal rod with a blunt tip and a T-handle grip. The rod is pushed into the active layer until it makes contact with the permafrost. The depth is then measured and recorded on a field sheet. The results of these measurements from your community are provided on the following pages. In addition to manual active layer measurements soil temperature, soil moisture, and air temperature data are all recorded at the ALN site in the center of the grid. Each site is equipped with two soil temperature and two soil moisture sensors. One soil temperature sensor and one soil moisture sensor is placed just above the permafrost and the others are placed just below the soil surface. The sensors collect data every 30 minutes. The air temperature sensor is placed on a tree or a wooden stake and also collects data every 30 minutes. Each year this data is downloaded onto a laptop computer from the data logger box which is also placed at the ALN grid.

Air Temperature Sensor



Data Logger

Soil Temperature & Moisture Sensors

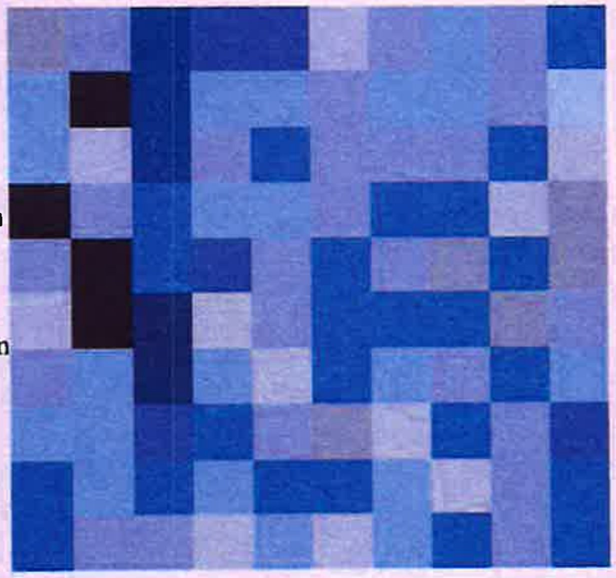
Results from manual measurements. The colors in each square represent how far from the surface the permafrost is, which is also the depth of the active layer. The darker the color the deeper the active layer.

2009

Average depth: 51.4 cm

Minimum depth: 34 cm

Maximum depth: 1 meter



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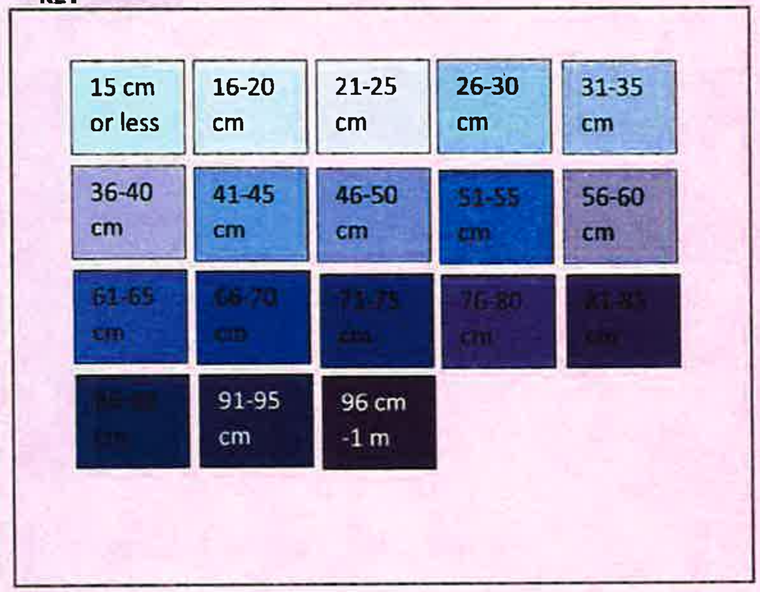
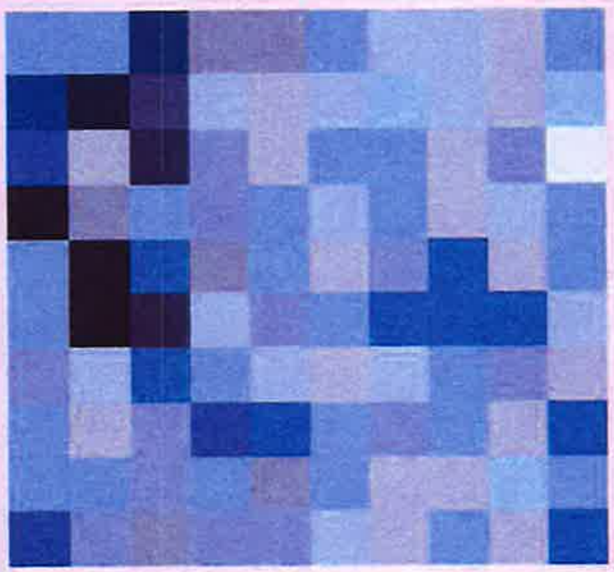


2010

Average depth: 47.3 cm

Minimum depth: 27 cm

Maximum depth: 1 meter

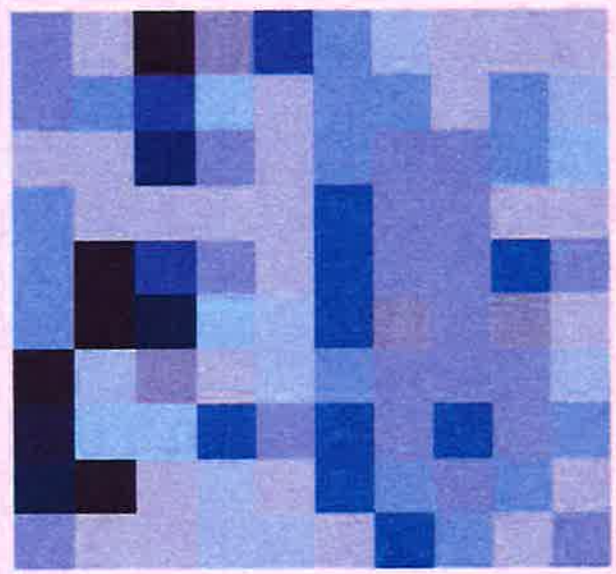


2011

Average depth: 47.9 cm

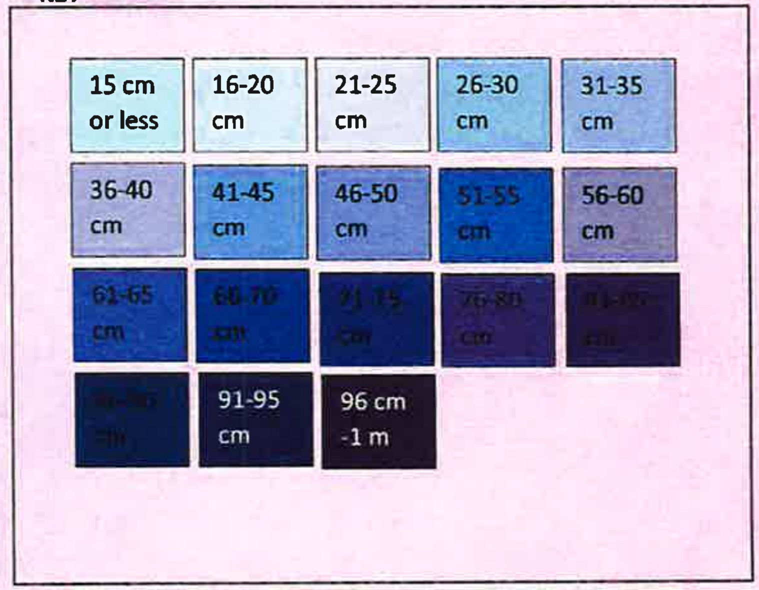
Minimum depth: 27 cm

Maximum depth: 1 meter



Results from manual measurements. The colors in each square represent how far from the surface the permafrost is, which is also the depth of the active layer. The darker the color the deeper the active layer.

KEY

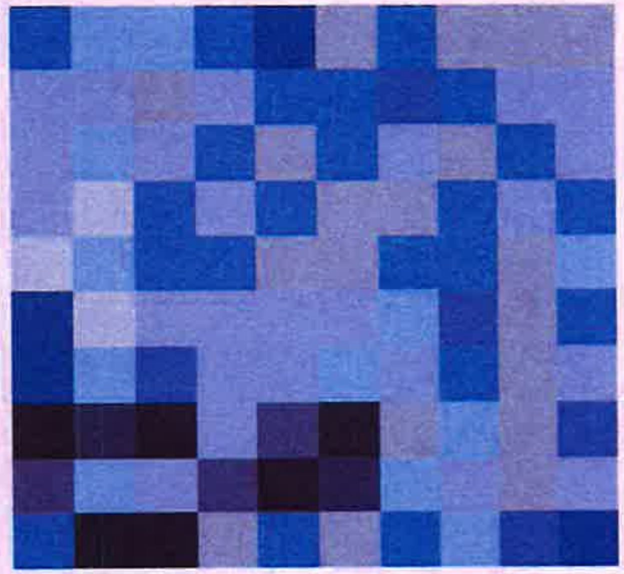


2012

Average depth: 56.4 cm

Minimum depth: 39 cm

Maximum depth: 1 meter

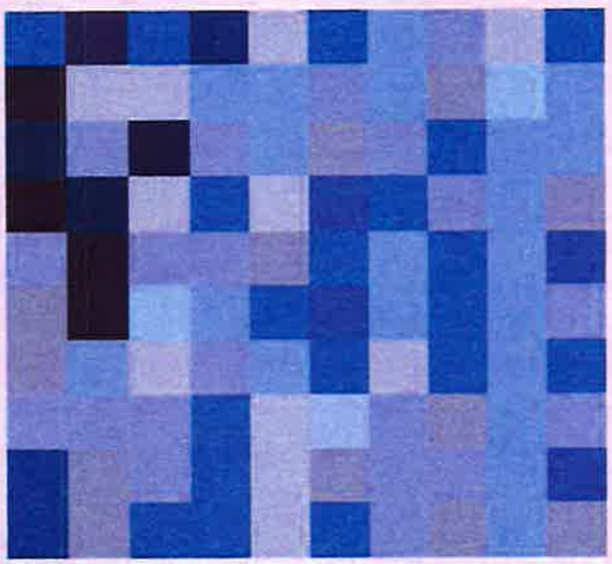


2013

Average depth: 52.5 cm

Minimum depth: 28 cm

Maximum depth: 1 meter

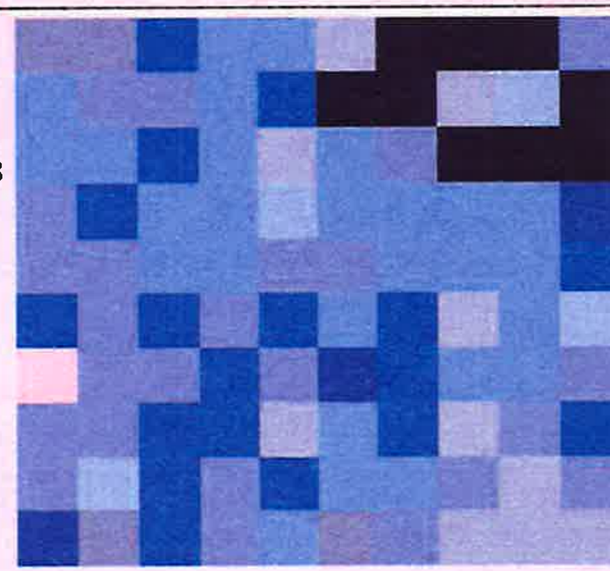


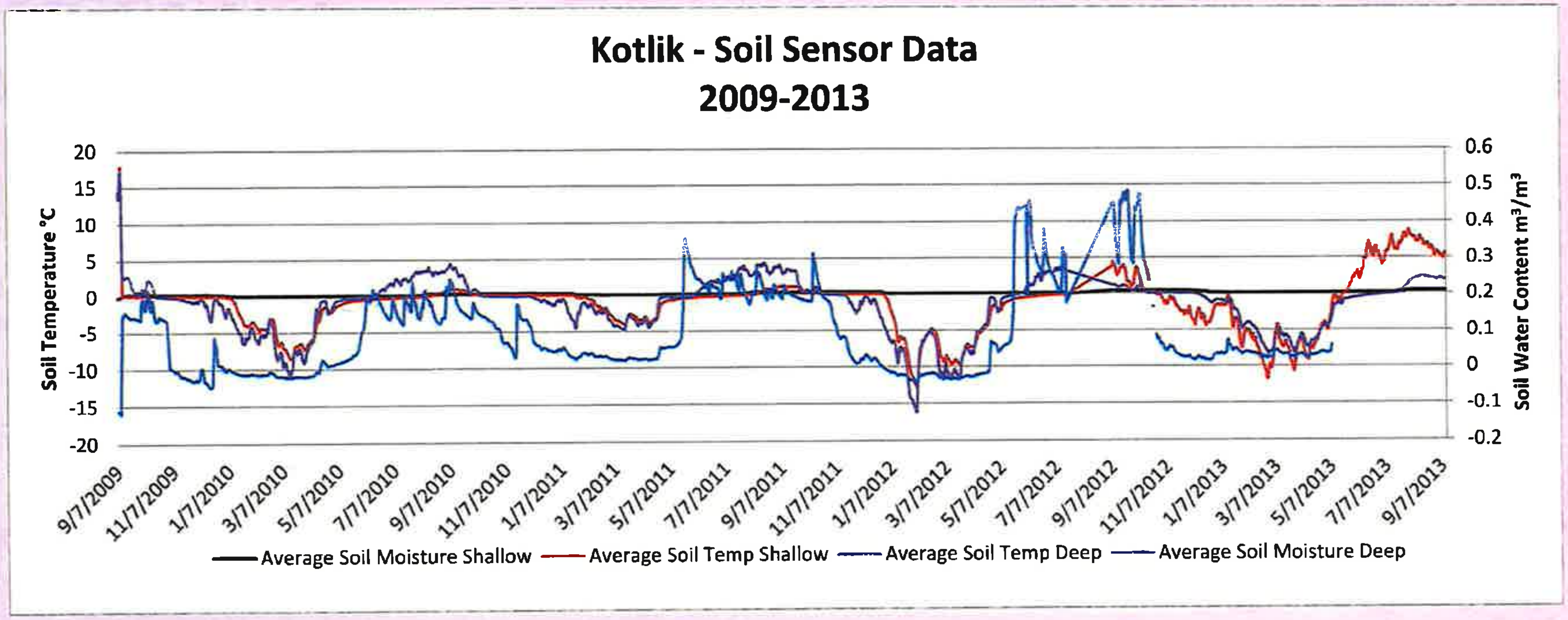
2014

Average depth: 51.8

Minimum depth: 33 cm

Maximum depth: 1 meter





Annual soil moisture and temperature °C Averages 2009-2010

Soil measurements	September	October	November	December	January	February	March	April	May	June	July	August
shallow soil moisture	0.180	0.264	Frozen	Frozen	Frozen	Frozen	Frozen	Frozen	Frozen	0.077	0.089	0.231
deep soil moisture	0.096	0.158	Frozen	Frozen	Frozen	Frozen	Frozen	Frozen	Frozen	0.170	0.165	0.159
Shallow soil temperature	3.231	0.184	0.051	0.050	-1.770	-4.040	-7.171	-3.826	-0.881	-0.343	-0.159	0.140
Deep soil temperature	4.457	0.734	-0.310	-0.008	-4.043	-5.130	-8.767	-3.436	-0.392	0.260	2.164	3.392

Freeze Back	Frozen Ground	Thawing	Thaw peak

Annual soil moisture and temperature °C Averages 2010-2011

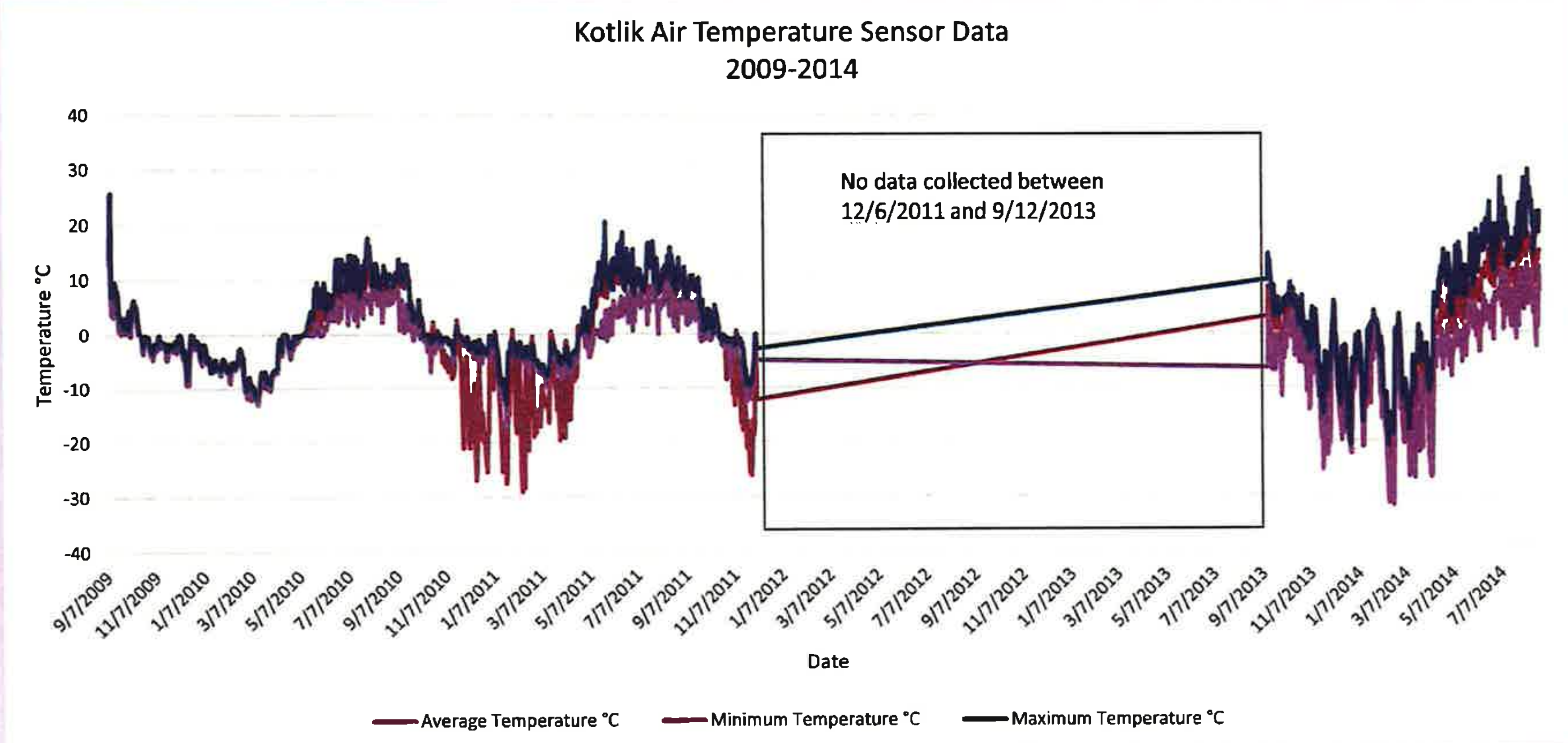
Soil measurements	September	October	November	December	January	February	March	April	May	June	July	August
shallow soil moisture	0.291	0.287	Frozen	Frozen	Frozen	Frozen	Frozen	Frozen	Frozen	0.087	0.107	0.310
deep soil moisture	0.181	0.140	Frozen	Frozen	Frozen	Frozen	Frozen	Frozen	Frozen	0.235	0.233	0.211
Shallow soil temperature	0.715	0.135	0.053	0.051	-0.033	-1.103	-3.184	-2.969	-0.552	-0.228	-0.088	0.392
Deep soil temperature	2.948	0.229	-0.046	-0.594	-1.865	-1.871	-3.749	-3.059	-0.181	1.057	2.650	3.473
	Freeze Back		Frozen Ground							Thawing		Thaw peak

Annual soil moisture and temperature °C Averages 2011-2012

Soil measurements	September	October	November	December	January	February	March	April	May	June	July	August
shallow soil moisture	0.308	0.306	Frozen	Frozen	Frozen	Frozen	Frozen	Frozen	Frozen	0.077	0.091	No data
deep soil moisture	0.201	0.208	Frozen	Frozen	Frozen	Frozen	Frozen	Frozen	Frozen	0.341	0.248	No data
Shallow soil temperature	0.946	0.174	0.051	0.039	-5.690	-7.256	-8.908	-5.062	-1.186	-0.328	-0.157	No data
Deep soil temperature	3.056	0.309	-0.608	-1.635	-8.915	-8.061	-10.22	-4.735	-0.644	1.877	3.318	No data
	Freeze Back		Frozen Ground							Thawing		Thaw peak

Annual soil moisture and temperature °C Averages 2012-2013

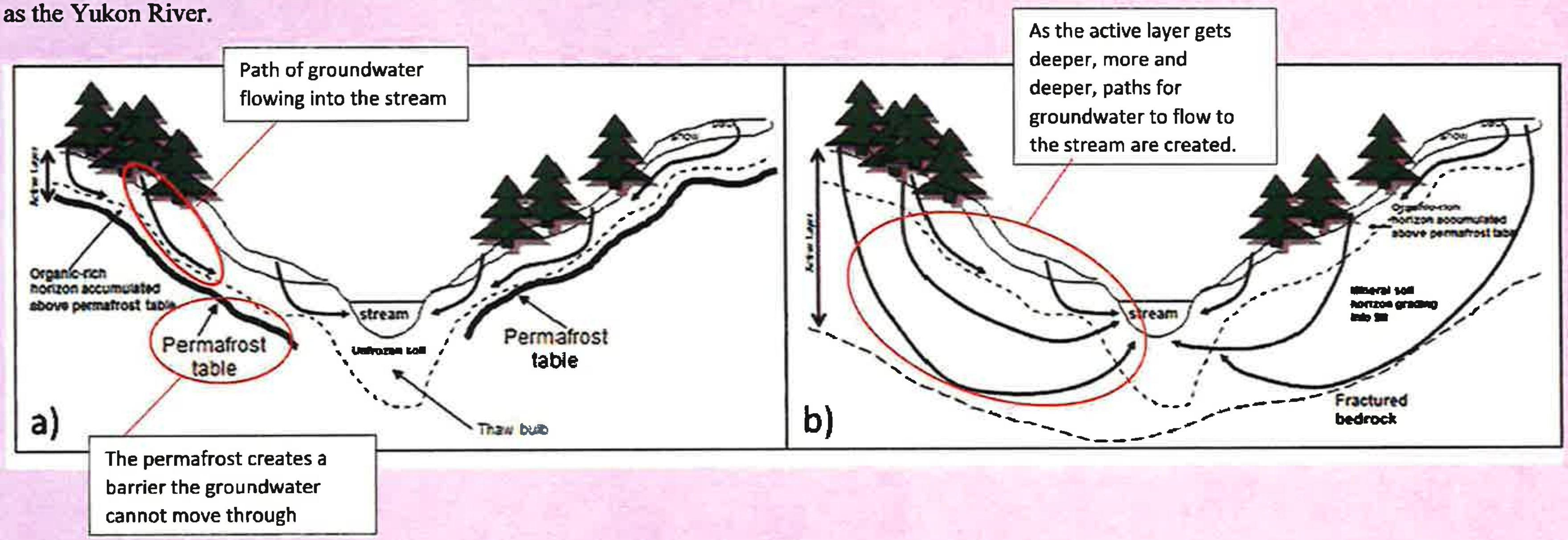
Soil measurements	September	October	November	December	January	February	March	April	May	June	July	August
shallow soil moisture	0.386	0.380	Frozen	Frozen	Frozen	Frozen	Frozen	Frozen	Frozen	0.082	0.147	0.376
deep soil moisture	0.408	0.277	Frozen	Frozen	Frozen	Frozen	Frozen	Frozen	Frozen	no data	no data	no data
Shallow soil temperature	2.893	0.876	-1.565	-3.119	-3.048	-7.683	-7.717	-6.672	-1.041	4.470	6.411	7.048
Deep soil temperature	0.903	0.311	0.051	-0.499	-1.884	-5.742	-6.551	-6.112	-1.929	-0.384	0.113	1.980
	Freeze Back		Frozen Ground							Thawing		Thaw peak



Annual Averages	September	October	November	December	January	February	March	April	May	June	July	August
2009-2010	6.18	0.95	-2.21	-2.68	-5.04	-5.82	-9.64	-3.49	0.97	5.29	8.40	8.69
2010-2011	8.15	0.25	-5.51	-16.05	-10.58	-13.67	-10.99	-7.16	4.12	10.94	10.55	9.69
2011-2012	7.68	-0.33	-13.12	no data	no data	no data	no data	no data	no data	no data	no data	no data
2012-2013	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
2013-2014	3.12	2.24	-6.45	-9.00	-4.99	-12.02	-12.53	-3.05	4.33	9.66	12.19	14.60
Average Temperature 5 years	6.28	0.78	-6.82	-9.24	-6.87	-10.51	-11.05	-4.57	3.14	8.63	10.38	10.99

Next Steps

The ALN project is designed to continue for decades as it can take years to see a definitive change in the depth to the active layer and permafrost degradation. However, early analysis of the ALN and water-quality data suggests that we are seeing a relationship between a thawing active layer and ground water. As the diagram below shows as the active layer deepens new paths for groundwater to flow through are created. This means that more elements in the soil may be dissolved by the water traveling through new paths and these elements may be carried into the nearby streams such as the Yukon River.



As the figure above shows in figure a) the permafrost creates a barrier that groundwater cannot move through, this forces the groundwater to move through shallow paths into the stream; in figure b) the active layer is deeper, which means the permafrost is further down and the groundwater can move through more paths and deeper paths than before. New and deeper paths of groundwater flow can change the chemical composition of the stream this groundwater is flowing into. The results of preliminary analysis at key ALN locations across the YRB suggest that we are seeing a seasonal change in the chemical composition of the river due to seasonal changes in the depth of the active layer. In order to confirm these findings the ALN and Water-quality monitoring must continue in the future at key locations so that we can collect more data to see if this trend continues into the future.

Appendix N: Bank Erosion Projection from MWH Report "Kotlik Bank Protection Feasibility Study", June 2003

AERIAL PHOTO- AEROMAP USA, 6/12/02

MWH
Anchorage Alaska

pg 7

FIGURE 4

CITY OF KOTLIK
KOTLIK BANK STABILIZATION FEASIBILITY STUDY

2002 BANK CONDITIONS