U.S. Army Corps
of Engineers
Alaska District

Background Studies for Expedited Reconnaissance Study of Matanuska River Erosion

Matanuska-Susitna Borough, Alaska

August 2003

BACKGROUND STUDIES FOR EXPEDITED RECONNAISSANCE STUDY OF MATANUSKA RIVER EROSION

MATANUSKA-SUSITNA BOROUGH, ALASKA

prepared for:

Alaska District
U.S. Army Corps of Engineers

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BACKGROUND STUDY FOR EXPEDITED RECONNAISSANCE STUDY OF MATANUSKA RIVER EROSION, ALASKA

1. STUDY AUTHORITY

This study is in support of a partial response to the "Rivers and Harbors in Alaska" study resolution, adopted by the U.S. House of Representatives, Committee on Public Works, on December 2, 1970. The Congressional direction source is: Public Law 107-66, the Energy and Water Development Appropriations Act, 2002, was enacted on November 12, 2001 and authorized $100,000 for a reconnaissance level general investigation study called Matanuska River Erosion Control, Alaska.

2. STUDY PURPOSE

The purpose of this background study is to support an expedited reconnaissance study to document problems, needs, and opportunities related to erosion in the Matanuska River Valley. It supports whether there is a Federal interest in feasibility level erosion control studies in the Matanuska River Watershed.

3. LOCATION OF PROJECT/CONGRESSIONAL DISTRICT

3.1. Congressional District

The study area is in the Alaska Congressional District. The Alaska Congressional delegation is:

- Senator Ted Stevens (R)
- Senator Lisa Murkowski (R)
- Representative Don Young (R)

3.2. Location and Erosion Area Description

The Matanuska River flows from the Matanuska Glacier approximately 50 miles upstream of the Old Glenn Highway Bridge in Palmer, Alaska to its confluence with the Knik River approximately 10 miles downstream of the same bridge (Note: The East and South Forks extend an additional 20 miles past the Matanuska Glacier.). Downstream of the confluence the Knik River flows into the Knik Arm of Cook Inlet. For this reconnaissance study of erosion issues in the Matanuska River Valley, the initial study area included the river valley from the confluence with the Knik River upstream to the glacier. After an initial appraisal of erosion issues in the basin, the areas in the vicinity of Palmer and Sutton were identified as potential sources of erosion problems. The study area is identified in **Figure 1**.

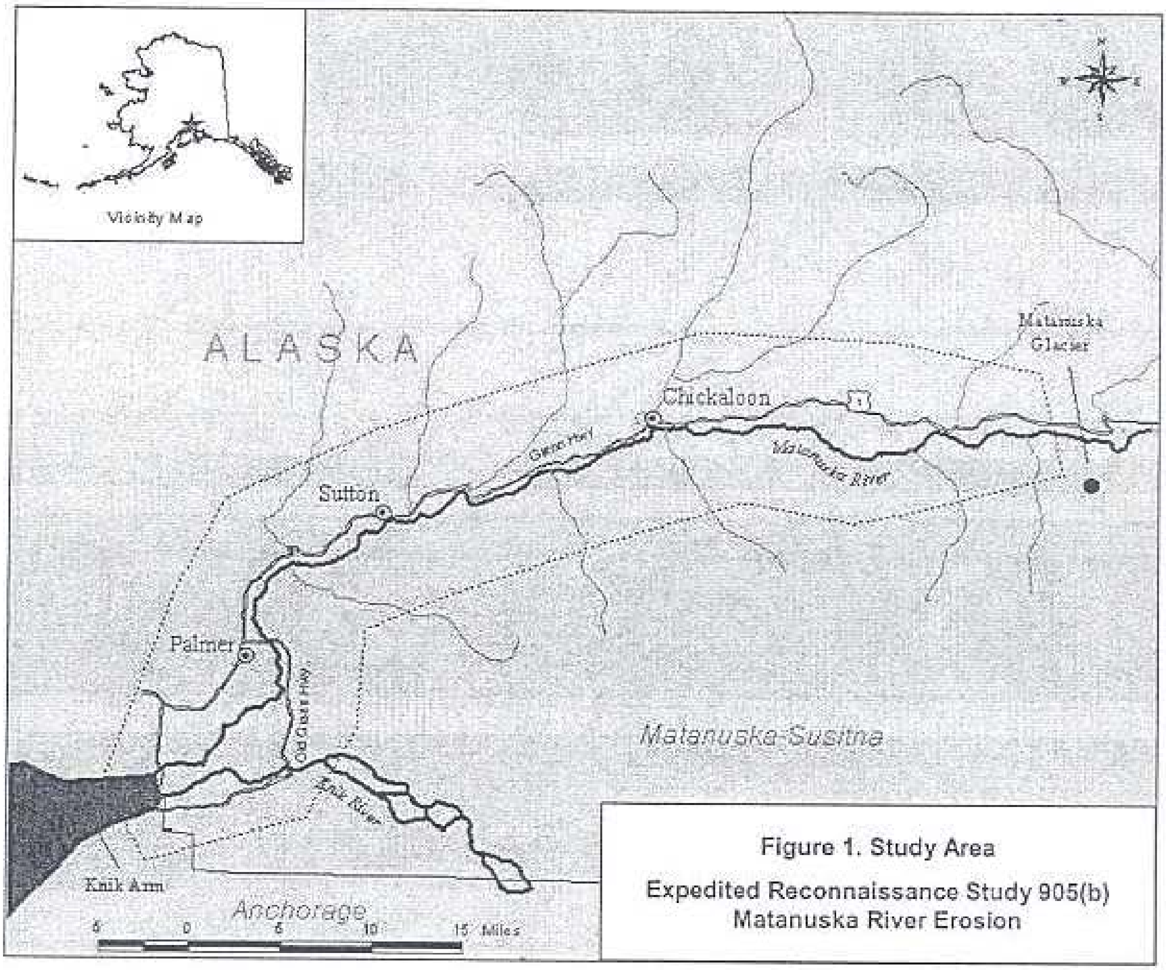

Figure 1. Study Area
Expedited Reconnaissance Study 905(b)
Matanuska River Erosion

4. DISCUSSION OF PRIOR STUDIES, REPORTS AND EXISTING WATER PROJECTS

4.1. Prior Reports and Studies

- February 1972. *Review of Reports on Matanuska River and Cook Inlet and Tributaries Alaska, Matanuska and Little Susitna Rivers Flood Control Alaska.* Alaska District, U.S. Army Corps of Engineers (USACE).

  Provides a summary of Matanuska and Little Susitna studies performed prior to 1972. Describes the economic development in the area. Climatology, runoff and streamflow data are given. Discusses various solutions for Matanuska River flood control and their feasibility from a federal point of view. Concludes that economic justification does not exist for structural solutions to flooding or bank erosion in the areas studied, and that local interests should avail themselves of technical information regarding nonstructural alternatives for wise management of the flood plain.

- September 10, 1987. *Sutton Erosion Control: A Report for the Matanuska-Susitna Borough Assembly.* G.N. McDonald & Associates.

    Report describes the state of erosion control at Sutton in 1987 and provides recommendation for future action. Describes the legislative history, the preconstruction administrative history, construction history, flood history, performance of the erosion control structures, and alternative rehabilitation schemes. Provides a record of correspondence of key parties, and a list of available aerial photos.

- September 8, 1989. *Emergency Flood Control Measures, State of Alaska, Plant Materials Center, Palmer, Alaska.* Alaska District, USACE.

    Report responds to a request from the State of Alaska Division of Emergency Services to provide technical assistance in alleviating flooding on agricultural land owned by the State Plant Materials Center in Palmer, Alaska. Recommends the use of gravel levees, and riprap and spur dikes for erosion control. Project life, cost estimates and environmental concerns are addressed. Includes engineering analysis as appendix.

- November 1991. *Matanuska River Erosion Control.* Prepared for Matanuska-Susitna Borough. Prepared by Peratrovich, Nottingham & Drage, Inc (PND).

    Report addresses the pre-feasibility of a proposed gravel extraction project on the Matanuska River. The extraction of gravel from the main channel of the river would serve as a control measure to keep the river from eroding its banks and destroying developed properties. The proposed gravel extraction project in this 1991 report is considered in this 2003 reconnaissance study.

- February 18, 1992. *Matanuska River Erosion Task Force Interim Report.* State of Alaska Division of Emergency Services.

    The Task Force was assigned to complete a written report to the Governor that assimilated the most up-to-date and objective information available about the capability of the State to react to erosion in the Matanuska River basin. The erosion information was to be used to develop policies and programs designed to reduce or eliminate damages from this erosion problem. Topics investigated were engineering solutions, relocation options, Federal Flood Insurance Program, and land management alternatives. The report included as an attachment, a general outline of the possible engineering solutions prepared by the Alaska Department of Transportation and Public Facilities and the Corps of Engineers.

- October 1992. *Matanuska River Erosion Control Recommendations.* Prepared for Mat-Su Borough Dept. of Public Works. Prepared by Peratrovich, Nottingham & Drage, Inc. (PND).

    The report consists of a review of the 1992 spur dike construction and performance, a discussion of maintenance alternatives, and a review of future erosion control alternatives and recommendations. Figures are included in the report that help to illustrate maintenance and future erosion control alternatives.

- June 1994. 1994 *Matanuska River Erosion Study: Field Trip Observations and General Erosion Control Recommendations*. Peratrovich, Nottingham & Drage, Inc. (PND).

  Report documents 1994 Matanuska flow character, performance of spur dikes near Circle View and erosion in the vicinity, Stampede Estates erosion, and general erosion comments and erosion control recommendations.

- 1996. *Planning Assistance to States: Matanuska River at Bodenburg Butte Erosion Study*. Alaska District, USACE.

  Documents the historical erosion patterns and the local erosion rates in the vicinity of Circle View Subdivision and Stampede Estates Subdivision. Available photographs and other data sources were compiled and analyzed to document the erosion patterns. Cross-sections of the river were also obtained to determine the difference in bed elevation between the north and south channels. The difference in bed elevation appears to have caused the channel shift to the southern channel, resulting in erosion.

- March 1999. *Matanuska River Watershed Reconnaissance Report, Alaska*. Alaska District, USACE.

  This watershed study reviewed prior studies, reports and water projects in the study area, identified water and related land resource problems and opportunities, documented existing and expected future conditions relevant to problems and opportunities and proposed that a feasibility level watershed study be conducted. Existing and expected future conditions were documented in the categories of:

  - Watershed hydrology/hydraulics, including bank erosion, flooding, sediment/bedload transport, hydrological changes in wetlands, and clearwater side-channels;
  - Environmental/ecosystem values, including ecosystem degradation, land use, and fish and wildlife habitat; and
  - Transportation and land use, including the Alaska Railroad, the Glenn Highway, material extraction, and recreation

  The proposed watershed feasibility study was to focus on specific hydrologic, hydraulic, erosion, habitat, and sedimentation issues relevant to local interests to put reliable information in the hands of planners and decision makers. The proposed feasibility study was not implemented.

4.2. Existing Water Projects

4.2.1. Glenn Highway Erosion Control (North of Palmer)

A series of projects were constructed in the late 80s through early 90s to address bank erosion problems along the Glenn Highway from Sutton to near Chickaloon. These projects were constructed by Alaska Department of Transportation and Public Facilities (ADOT/PF). They involved primarily bank armoring with riprap and flow deflecting structures. In general, these were constructed in areas where the river flows near the roadway, though several sites have components at least several hundred feet away from the highway, primarily to deflect flow upstream of locations where it could impinge on the highway (Kepler 2003 and Tetra Tech site visit observation, October 9, 2002).

4.2.2. *Dikes along Old Glenn Highway/Ye Old River Road*

A series of three dikes were constructed along the left bank of the Matanuska River near Ye Old River Road. The first of these dikes, which are armored with riprap, was constructed by the Borough in 1986. Two additional dikes, one upstream and one downstream, were constructed in 1989. All three dikes were constructed to control erosion. Erosion in this area could directly cause damage to several homes in the area as well as indirectly cause damage by connecting the main channel with low lying areas. The latter process would increase flooding. Funding for the 1989 dikes was from the Alaska Department of Emergency Services (Rulison 1989). See **Figure 2, Item (2)**.

4.2.3. *Bank Protection at Old Glenn Highway Bridge*

Riprap bank protection has been placed in the area of the Old Glenn Highway bridge, just north of Palmer, to protect the bridge approaches (Tetra Tech site visit observation, October 9, 2002). See **Figure 2, Item (1)**.

4.2.4. *Spur Dikes at Circle View Estates*

In April 1992, the Matanuska-Susitna Borough initiated the design, permitting, and construction of four finger dikes ranging from approximately 200 to 400 feet in length on the Matanuska's left bank in the vicinity of Circle View Estates. The dikes were designed to control erosion and protect property within the subdivision. These dikes were originally designed as a series of eight dikes but were cut back to four because of a lack of funding (Long, 1998). These dikes are still in place and have provided some protection to the properties in Circle View Estates. See **Figure 2, Item (4)**. Review of past reports indicates that some questions remain as to the upstream and downstream effects of the dikes. A permit application in 1995 shows a plan that would add 6 additional spur dikes, to bring the total to 10 spur dikes (Peratrovich Nottingham & Drage (PND), 1995).

4.2.5. *Old Glenn Highway Dike in the Bodenburg Butte Area*

In the late 1940s a dike was constructed to confine the Matanuska River from floodplain areas east of the newly constructed Old Glenn Highway near the Bodenburg Butte area. After the dike was broken during the 1971 flood, the dike was enlarged (U.S. Army Corps of Engineers (USACE), 1996).

4.2.6. *Alaska Railroad Sheet Pile Bank Protection*

This project consists of approximately 4,000 feet of dike constructed between 1947 and 1951 to divert flow away from the portion of the Alaska Railroad near the old Matanuska town site. The project has 2,500 feet of steel sheet pile dike and 1,500 feet of gravel and tree revetment. The project is located about 1 mile south of Mountain View Estates along the right bank of the river. The project was constructed across a portion of the old channel flow path and resulted in diverting flow to the south and east (Bradley et al 1972; USACE 1996). See **Figure 2, Item (7)**.

4.2.7. *Palmer Sewage Lagoon Bank Protection*

Under Section 14 of the Flood Control Act of 1946, emergency bank protection consisting of three rock-fill groins was placed in 1969 along the right bank of the Matanuska River adjacent to the Palmer wastewater treatment lagoons. The project protects approximately 1,500 feet of bank.

At the time, the construction cost was $80,000 (Bradley et al 1972; USACE 1996; Hulbert 1989). See **Figure 2, Item (5)**.

4.2.8. Sutton Erosion Control

This project consists of five spur dikes constructed to protect homes and other property along the right bank of the Matanuska River just upstream of Sutton. The cost of the project was $470,000 and was funded by Senate Bill 364 in Fiscal Year (FY) 1985 which appropriated the money to the Mat-Su Borough as a grant. The project was constructed in 1986 (G.N. McDonald & Assoc. 1987).

4.2.9. Bank Protection at Sky Ranch

Approximately 3,000 feet of rock toe protection has been placed along the right bank of the Matanuska River in front of the Sky Ranch Subdivision. The dates of the rock placement are not known (Tetra Tech site visit observation, October 9, 2002). See **Figure 2, Item (6)**.

5. PLAN FORMULATION

5.1. Identified Problems

An understanding of current and historic bank erosion problems along the length of Matanuska River was developed based on review of pertinent documents, discussions with Corps of Engineers staff, meetings and interviews with local government and agency representatives, and site reconnaissance.

The Matanuska is a highly dynamic river system with the majority of its 80-mile length characterized as braided. The wide braided channel, representative of most reaches of the river not confined by bedrock, is typically indicative of a river that is unstable both vertically and laterally. The Matanuska is no exception, with significant areas of bank erosion, evidence of aggradation, and shifting channel braids occurring throughout much of its length. In areas, the active channel width exceeds 5000 feet.

The dynamic nature of the Matanuska River is not the result of human activities and disturbances but is due to natural physical processes occurring in the system dominated by active glaciers that cover 12 percent of the 2,070-square mile watershed. The glaciers supply large quantities of sediments that range from clay to boulders. In the lower portions of the Matanuska near Palmer, the USGS (1992) estimated the average suspended sediment load to be 5,000,000 tons per year and the bed load to be 500,000 tons per year. The former is comprised primarily of sands, silts and clays and the latter of gravel and cobble. In addition to the large sediment load, the bank erosion is partially attributable to the nature of the bank material, which is typically non-cohesive and easily eroded.

Bank erosion in some areas has averaged approximately 20 feet per year. This number is somewhat misleading in that bank erosion may not occur for many years or even decades at a given location, then in a matter of weeks over 100 feet of erosion may occur. This unpredictable, but dramatic nature of the bank erosion adds to the associated problems by increasing the difficulty of controlling it. This difficulty arises in designing erosion control structures that align properly with continuously shifting flow patterns as well as determining which locations to protect.

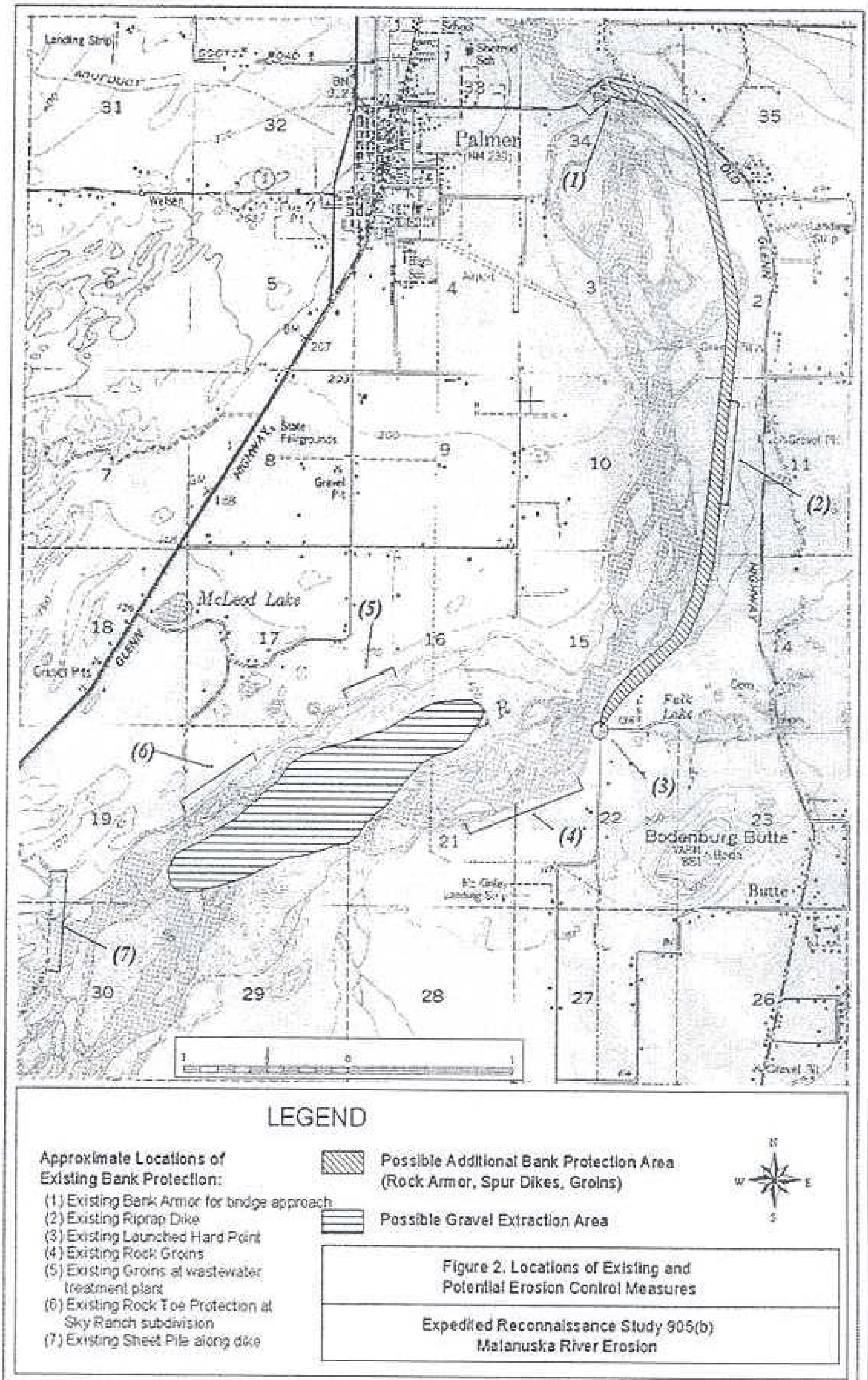

Figure 2. Locations of Existing and Potential Erosion Control Measures

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Matanuska River Erosion

Problems associated with bank erosion are documented as far back as 1956 and have generally increased over time as development of farmland, homes and infrastructure continues in the areas adjacent to the Matanuska River, increasing the potential for damage. The most dramatic examples of erosion damages were to homes that were undermined by erosion and fell in the river channel in the Bodenburg Butte area prior to construction of bank protection dikes in the area.

5.1.1. Erosion Damages to Land and Improvements

This category of damages has garnered the most attention and appears to represent the largest monetary loss associated with erosion. The most notable example of this occurred during 1991 when 7 houses were either directly lost, demolished or moved due to advancing bank erosion in the Circle View Estates subdivision. Little documentation of losses of farmland is available. The 1956 erosion account indicated that farmland losses had occurred prior to that time U.S. Army Corps of Engineers (USACE) 1996. More recently, at least several acres of farmland have been lost at the Alaska Plant Materials Center due to erosion of an overflow channel. However, by far, the loss of residential structures has been the most significant damage in this category. Although not a direct damage, the potential for erosion is believed by some to have impacted the value of homes located adjacent to the river (Karabelnikoff and Karabelnikoff 1991). Their memo postulates that the threat of erosion makes these properties less desirable, stating "about a dozen homes and many lots once worth more than a million dollars are now valueless and unmarketable because of recent public awareness of the Matanuska River." A preliminary bank erosion rate analysis was conducted to estimate expected erosion damages to land and improvements. This analysis is documented in **Section 5.2**.

5.1.2. Erosion Damages to Transportation and other Public Infrastructure

Erosion or the potential for erosion has impacted the transportation network in the Matanuska Valley. Portions of the Glenn Highway have been relocated due to erosion threats. Additionally, considerable bank protection has already been installed along the Glenn Highway from about milepost 61 (near Sutton) to milepost 78 (near Chickaloon). The Glenn Highway is the only ground transportation route for the upper portions of the Matanuska valley and also serves to connect the Anchorage area with much of Alaska.

Although no documentation was found, it is expected that damage to the Old Glenn Highway occurred in the 1971 flood, when portions of the Matanuska broke out and flowed over and along the highway. Currently, there is active erosion along the portion of the Matanuska paralleling the Old Glenn Highway from the Old Glenn Highway Bridge, over the Matanuska River, south to near Stampede Estates. In this area, the river is on the order of 100 to 1,600 feet from the highway. However, the low banks occurring throughout much of this area are susceptible to erosion as well as flooding. About 3,800 feet of levees with riprap armor have been constructed near the middle of this reach.

Potential for damage to the Alaska Railroad resulted in construction of a 4,000 foot long steel sheet pile wall and levee in the area of the Old Matanuska town site.

Other infrastructure adjacent to the Matanuska River has been threatened by erosion. The Corps constructed three rock-fill groins in 1969, as an emergency action, to protect the Palmer sewage lagoons from erosion. The power line crossings of the river near Bodenburg Butte utilize poles that are placed in the bed of the Matanuska. These have been eroded in the past.

A preliminary bank erosion rate analysis was conducted to estimate expected erosion damages to transportation infrastructure. This analysis is documented in **Section 5.2.** No other public infrastructure was identified by this reconnaissance study as at risk of expected erosion damage.

5.1.3. Flooding as a Result of Bank Erosion

Direct flooding from flows overtopping the channel banks is typically not a problem in the study area. The wide nature of the channel provides considerable capacity for the channel to convey large floods without the flows spreading out beyond the braided channel corridor. However, there are cases where erosion has intersected old channel scars and main channel flows have then been captured by these features. Historically, this has occurred primarily in the area bounded by the Matanuska River to the northwest, the Knik River to the south and the Old Glenn Highway to the east. Two significant examples of this were the flow breakout from the 1971 flood that followed the old Glenn Highway and Bodenburg Creek to the Knik River and the flooding that still occurs near the Alaska Plant Materials Center. Blockage of channel braids adjacent to the edges of the corridor by woody debris and deposited sediments can increase the likelihood of this type of flooding occurring.

A number of residents have expressed concerns over the last 30 years that the entire Matanuska could flow across the Bodenburg Butte area and be captured by the Knik River. This could result in damages to dozens of homes, several roads and losses of many acres of farmland. Representatives of the Corps and State have indicated that this is highly unlikely because of the topography between the two rivers and because relatively shallow depths can convey even the largest flood flows in the Matanuska River. The peak discharges associated with various return period events are provided below (Long 1998).

2-year	24,400 cfs
5-year	31,000 cfs
10-year	35,300 cfs
25-year	40,800 cfs
50-year	44,900 cfs
100-year	50,500 cfs

5.1.4. Fish and Wildlife Habitats

Erosion and sedimentation processes continuously alter fisheries habitat in the river corridor. Several ponds have been partially filled in by deposition. In other cases, existing groundwater-fed channels are destroyed when erosion shifts the active channels to new locations. However, at the same time, new groundwater fed channels are created as active braids become abandoned. Thus, there is a continuous process of these important habitat features evolving with new channels emerging and old channels disappearing. Fish and wildlife habitat conservation should be a goal and design criteria in feasibility level development of any erosion control alternatives. Any feasibility level study of erosion control alternatives should include a detailed analysis of resident and migratory fish and wildlife species in the study area and their habitat requirements.

5.1.5. Air Quality

Due to the wide braided channel and the large amount of silt deposited in the sediments of the Matanuska River, the strong winds blowing down the Matanuska Valley often cause particulate pollution during dry periods. This is a visual problem, but more importantly can be a health problem. It is also an economic problem resulting in accelerated wear of machinery and engines and sometimes disrupting small airplane traffic and recreational activities. It also affects water quality in lakes as far away as Wasilla.

The Borough Planning Department maintains two air quality monitoring stations and issues health warnings when levels exceed acceptable standards. It is expected that any erosion control measures would have insignificant impacts on air quality in the study area.

5.1.6. *Recurring Need for Emergency Bank Protection*

Review of past reports and correspondence indicates a recurring need for emergency bank stabilization efforts in the study area. Examples of past emergency bank erosion control activities include efforts at the Palmer Sewage Lagoons, Circle View Estates, Stampede Estates, the area west of the Old Glenn Highway near Ye Old River Road and the Glenn Highway from near Sutton to Chickaloon. Considering the historic behavior of the Matanuska River, it is expected that emergency bank stabilization actions will continue to be needed, though exact locations are difficult to predict. These emergency operations are both costly and may be environmentally harmful. For example, the construction of the four spur dikes in the area of Circle View Estates cost approximately $500,000 in 1992. Based on communications with the staff from the Alaska Department of Highways, $2,000,000 to $3,000,000 were spent between 1987 and 1996 on a combination of emergency and preventative erosion control measures along the Matanuska River from Sutton to Chickaloon. When emergency operations are required, it is often the case that properties/infrastructure are already lost or damaged. Opportunities for protection may also be limited by environmental conditions (e.g., high flows). At the time of this study, there were no imminent emergency bank protection projects identified or expected.

5.2. Preliminary Bank Erosion Rate Analysis

An analysis of historic bank erosion rates was performed for the left bank of the Matanuska River from the Old Glenn Highway bridge downstream to just below Circle View Estates and for the right bank from about a mile upstream of the Palmer wastewater lagoons downstream to below Sky Ranch Subdivision. The lengths of these areas are approximately six miles for the left bank and three miles for the right bank. The analysis was performed to better understand the extent and magnitude of erosion and to project future erosion trends. This information was also used to support development of potential alternatives and economic analysis of benefits. These areas of the river were chosen because they represent the areas in which there appears to be the highest potential for benefits and are areas that have experienced erosion problems in the past.

The most significant recent problems have occurred in the Circle View Estates area on the left bank. The left bank of the river has the closest adjacent large-scale public infrastructure, the Old Glenn Highway, which parallels the Matanuska River within 100 to 1,600 feet of the current banks for about four miles. The right bank area chosen experienced erosion, prior to the main channel shifting to the left bank in the 1980s. Several subdivisions are located close to right bank, which would potentially be subject to erosion if the main channel shifted back to the right.

The aerial analysis was performed utilizing 1939 (black and white) and 1996 (color) aerial photographs provided by the Borough and the Corps, respectively. An extensive analysis of the aerial photography is beyond the scope of this reconnaissance study; however, this limited effort was performed since existing information only covers the left bank in the area of Circle View Estates and the right bank near the Palmer wastewater treatment lagoon.

INSERT FIGURE 3 HERE

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In order to compare the bank alignments a procedure was adopted that involved drawing a reference line between identifiable points on both images. Using distances measured between identifiable points on the USGS Anchorage C-6 quad map and the two aerials, a scale factor for this specific area of each photo was developed. Offset lines at even intervals were then drawn perpendicular to the reference lines. The offset distance from the reference line to the bank line was measured on the 1939 aerial. This distance was adjusted for scale differences and then transferred to the1996 aerial. Using this procedure, a series of points representing the 1939 bank alignment was transferred to the 1996 aerial. Approximately 80 points were transferred in this manner and the points connected, from the 1939 bank line. The resulting bank line and the 1996 bank line are shown in **Figure 3**.

5.2.1. Historic Results

The erosion distance during the 57 year period was measured at 118 locations on the left bank and 80 locations on the right bank. There were areas in which accretion, growth of the banks out into the former riverbed through deposition and establishment of vegetation, occurred. For identification purposes, erosion was indicated as positive values and accretion as negative. The maximum measured left bank erosion was 990 feet and occurred adjacent to Circle View Estates. The largest amount of right bank erosion was almost 400 feet near the Mountain View Subdivision. The maximum accretion over the period was 440 feet on the left bank and 360 feet on the right bank. The mean left bank erosion distance was 110 feet with a standard deviation of 270 feet while the mean right bank erosion rate was higher at 130 feet but the standard deviation was much lower at 160 feet.

The erosion areas on the left bank were further subdivided into the upper left bank and the lower left bank. The erosion rates have been higher in the lower left bank area, which includes Circle View Estates. The mean erosion distance in this portion of the left bank was 280 feet with a standard deviation of 340 feet. In contrast, the mean erosion distance for the upper left bank was 20 feet with a standard deviation of 170 feet. It is noted that there were no areas of significant accretion along the lower left bank; whereas, the amount of accretion along the upper left bank nearly equaled the amount of erosion. This latter factor contributed to the low average erosion distance in the upper left bank, since accretion was assigned a negative distance. **Figures 4A, 4B and 4C** provide histograms of the various erosion distances grouped into 50-foot intervals for the upper left, lower left and right bank, respectively. **Figure 4D** provides the erosion histograms for the left and right banks side by side.

The left bank area with the largest amount of erosion was the area along Circle View Estates. For approximately 5,000 feet the erosion ranged from 200 feet to 900 feet. The other area of extended significant left bank erosion occurred starting about half a mile downstream of Ye Old River Road and extends downstream for one mile. In this area, the largest amount of erosion was approximately 600 feet with 200 to 300 feet being more typical. In contrast, the left bank area near the upper end of the reach did not experience significant erosion for the first 6,500 feet below the Old Glenn Highway Bridge. This does not mean erosion has not occurred in this area, but because of the scale of the maps, the minimum detectable erosion distance was on the order of 50 feet. Some recent left bank erosion in this area is evident both near the bridge and behind a former restaurant 2,000 feet downstream of the bridge.

The average overall magnitude of the right bank erosion has been on the same order as the left bank with the mean distance over the 1939 to 1996 period being 130 feet and 110 feet, respectively. However, the maximum right bank erosion of approximately 400 feet is less than half of the maximum left bank erosion. The level of erosion along the right bank has been less variable as is evidenced by the standard deviation of right bank erosion measurements being 160 feet compared with the 270 feet for the left bank. The two most extensive areas of right bank erosion are adjacent to the Mountain View Estates and Sky Ranch Subdivisions. In both locations, there is a 2,000 foot length of bank with average erosion of approximately 250 feet.

In contrast to areas of erosion, accretion actually occurred in several locations. The two primary areas of left bank accretion were located in the upper third of the reach, starting just upstream of Ye Old River Road. At the first location, accretion of up to 440 feet with an average value of 300 feet occurred over a distance of 1,200 feet. At the second location, a maximum accretion of 350 feet occurred with an average accretion of 250 feet over a distance of 2,500 feet. There have been fewer areas of accretion on the right bank with the one primary area at the narrowest point in the river where up to 350 feet of accretion has occurred over a distance of 1,000 feet. This location is about one mile upstream of the Palmer wastewater treatment plant.

5.2.2. Future Erosion

Observations in the analysis area indicate erosion is still occurring. The four spur dikes appear to have controlled some of the worst erosion in the area of Circle View Estates. However, this protection is limited and does not extend over the original design length, which called for eight spur dikes instead of the four that were built. Erosion has continued downstream of these spur dikes. The 3,800 feet of left bank dike further upstream has controlled erosion along the bank that is immediately protected, however, site observations indicate erosion is threatening to flank or at least cause a severe angle of attack at the upstream end of the dike. Site observations also indicate erosion is active just downstream of the dike. There are numerous other areas where erosion has historically occurred and the banks are not protected. Considering these factors, and the general nature of braided rivers, bank erosion will continue sporadically along areas which have not been protected and the areas that are protected will require maintenance to ensure their effectiveness. Additionally, all of the existing erosion protection is limited in extent and not tied into stable areas. Thus, there is always the threat that existing erosion protection may be flanked.

Although it is inevitable that erosion will continue along this section of the Matanuska River in areas in which the banks are not protected, or in protected areas if the protection is not maintained or is flanked, it is impossible to identify exactly where this erosion will occur and to what extent. Because of the shifting nature of the braided channel, an area that is subjected to erosion for one period, may become stable for years as the channel either completely shifts away from that location or the angle of flow to the bank or amount of flow along the bank changes.

In a sinuous or meandering single threaded channel, erosion and accretion tend to follow trends, with erosion on the outside of bends, from concentration of forces and secondary currents, and accretion on the inside of the bend from the growth of point bars. Thus prediction of future erosion trends is often reasonably approximated by extending the rates of erosion into the future and projecting them along an extension of the historic paths. Although, erosion will not actually occur in such an idealized manner, due to factors such as differences in soils, changes in sediment supply, influence of vegetation, the sequence of flooding events, changes in flow patterns from upstream and downstream influences, blockage by debris and even channel avulsion (Note: channel avulsion is shift of the main channel alignment to a new location in a rapid process that does not involve erosion and migration of the land between the old and new location), this type of approach is often suitable for planning purposes.

Figure 4A. Distribution of Measured Erosion Rates - Upper Left Bank, 1939 - 1996

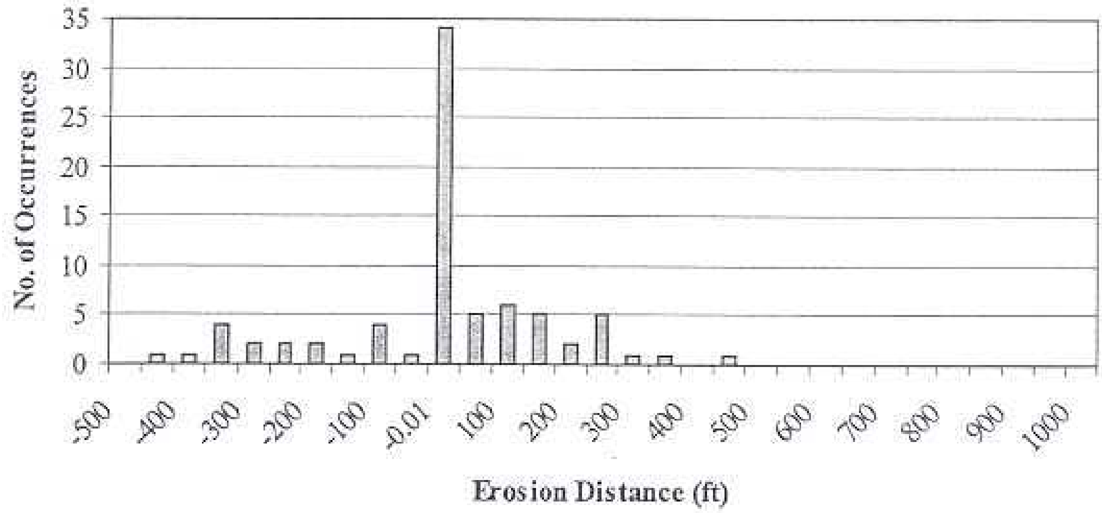


Figure 4B. Distribution of Measured Erosion Rates - Lower Left Bank, 1939 - 1996

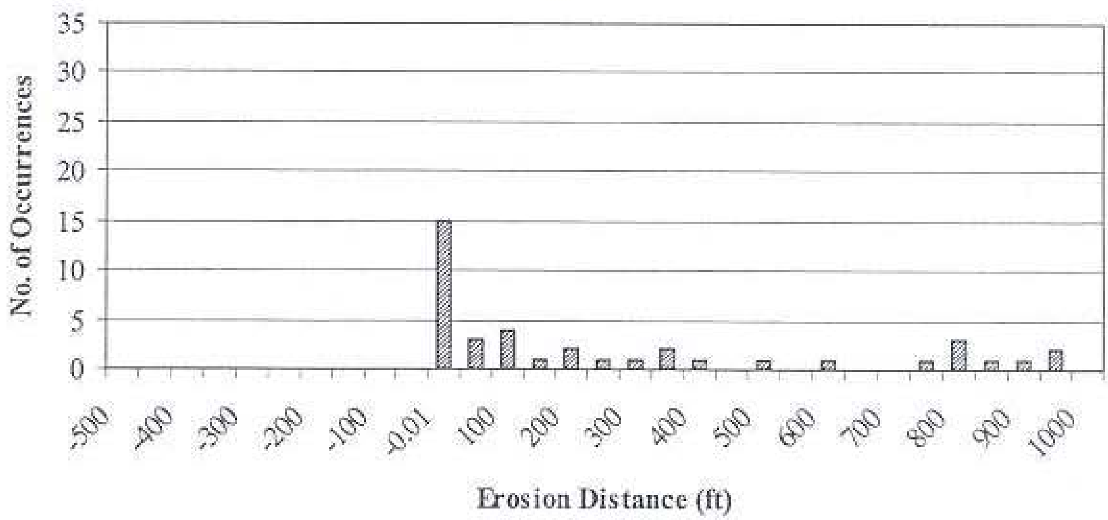


Figure 4C. Distribution of Measured Erosion Rates - Right Bank, 1939 - 1996

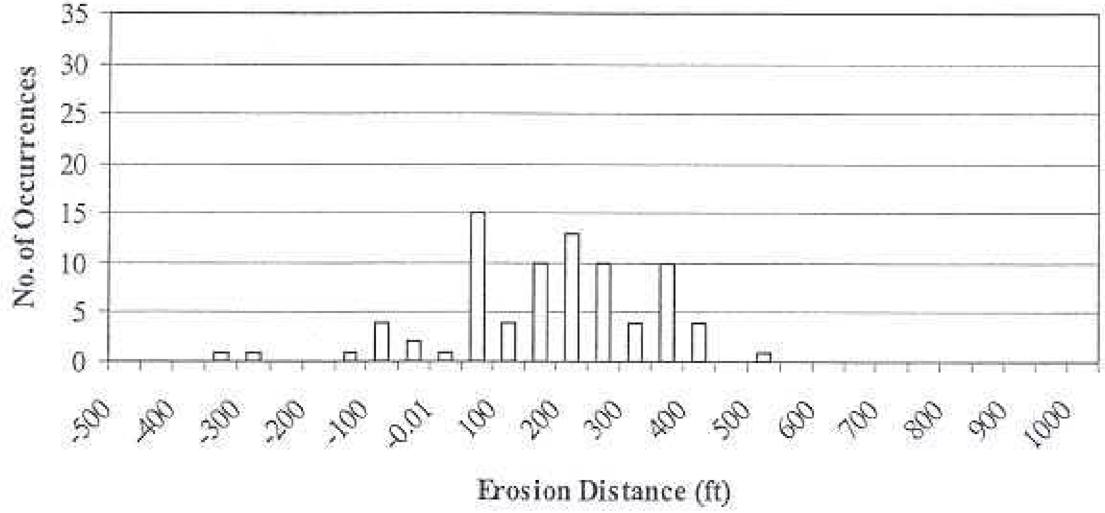
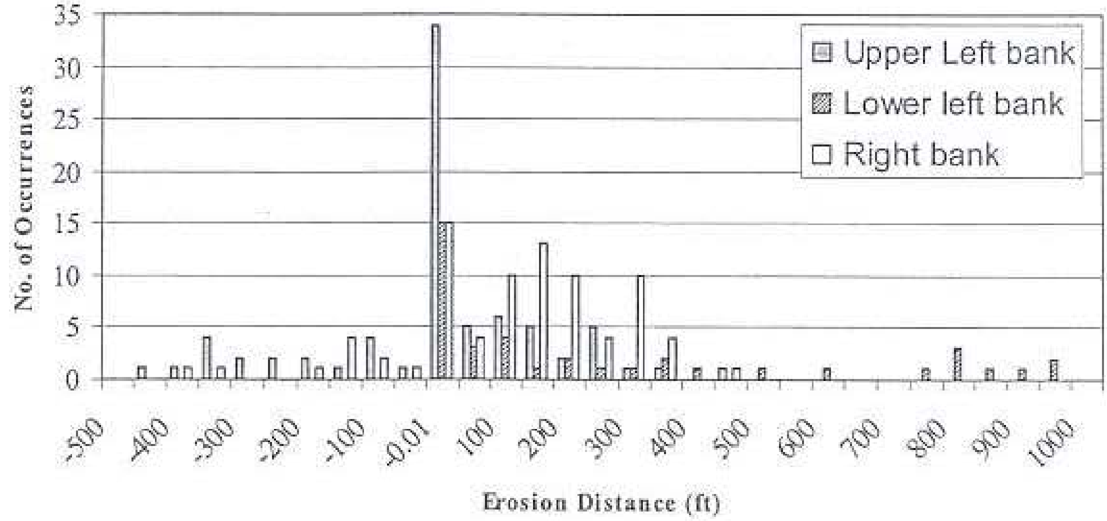


Figure 4D. Distribution of Measured Erosion Rates - Left and Right Banks, 1939 - 1996



In contrast to meandering channels, braided channels (like the Matanuska's) consist of multiple threads or braids that occupy a wide corridor. The braids are subject to rapid changes in alignment and the amount of flow they convey. In the case of a braided channel, future erosion and accretion cannot be quantitatively or qualitatively predicted by the same procedure as for a meandering channel. In a braided channel, an area of the bank may be attacked by erosion for several years, then the braid shifts entirely away from the bank. The point at which the braid impinges and attacks the bank may shift hundreds or thousands of feet upstream or downstream of the previous location or to the opposite side of the corridor. For example, the Matanuska has exhibited this behavior with the main area of bank erosion concern being along the right bank in the vicinity of the Palmer wastewater lagoons and Mountain View Estates for many years, then shifting 5,000 feet across the channel to the Circle View Estates area along the left bank in the late 1980s.

Because of the difficulty in predicting future locations of bank erosion on a braided channel, a statistical approach was utilized to estimate potential bank erosion in the future. Two methods were applied in this approach. In the first method, it was assumed that bank erosion rates were random and normally distributed. The mean and standard deviation of the computed 57-year record of erosion were adjusted to represent 50 years by multiplying by the ratio of 50 divided by 57. This ratio produces an adjusted 50 year mean and standard deviation for bank erosion of 96 feet and 248 feet for the left bank and 115 feet and 138 feet for the right bank. These values were then used to generate values of bank erosion distances associated with various ranges and their associated probability. In the second method, the actual sampled distribution was utilized after adjusting the distances by the ratio of 50 divided by 57. The results are presented in **Tables 1A** and **1B**.

One potential aspect of the erosion properties not accounted for by either approach (by assuming future erosion to be randomly distributed or by assuming that it follows the actual sampled distribution from historical data) is the possibility that flows concentrate on the left bank in some areas for an extended period. Historically, it appears that the area of erosion would switch back and forth between sides of the river on the order of every 10 to 20 years. This may have kept mature vegetation from developing in the braided corridor. The 1939 aerial shows very little vegetation evident in the main braided corridor. However, the 1996 aerial shows distinct islands, one just downstream of the Old Glenn Highway Bridge and a larger one adjacent to the Circle View Estate. Current field observations show substantial vegetation becoming established on the right (west) side of the larger island. As this vegetation becomes more established, it will be more difficult for the main channel to shift back to the right side. Thus, erosion may be concentrated on the left side for a longer period. This behavior is at least partially attributable to the capture of the Matanuska River main channel by the Knik River through the Ezi Slough, just downstream of Circle View Estates. This situation is likely to continue until deposition reduces the steeper gradient that exists along the current path to the Knik River. To assess the sensitivity of calculated expected erosion damages to this occurrence, an analysis was conducted that doubled the damages in the lower left bank erosion area for a worse case scenario. This sensitivity analysis is documented in Section 5.3

Table 1A. Probability Associated with Various Bank Erosion Distances for a 50 Year Period Based on Assumption of Normal Distribution – Right Bank of the Matanuska River near Palmer

50 Year Total Erosion Distance (ft)		Probability of Given Erosion Condition (%)		
Lower Limit	Upper Limit	Lower Limit	Upper Limit	Increment
Accretion	0	0	20	20
0	100	20	46	26
100	200	46	73	27
200	300	73	91	18
300	400	91	98	7
400	500	98	100	2

Table 1B. Probability Associated with Various Bank Erosion Distances for a 50 Year Period Based on Actual Sampled Distribution – Right Bank of the Matanuska River near Palmer

50 Year Total Erosion Distance (ft)		Probability of Given Erosion Condition (%)		
Lower Limit	Upper Limit	Lower Limit	Upper Limit	Increment
Accretion	0	0	12	12
0	100	12	38	26
100	200	38	69	31
200	300	69	98	29
300	400	98	100	2
400	500	100	100	0

Table 1C. Probability Associated with Various Bank Erosion Distances for a 50 Year Period Based on Assumption of Normal Distribution – Upper Left Bank of the Matanuska River near Palmer

50 Year Total Erosion Distance (ft)		Probability of Given Erosion Condition (%)		
Lower Limit	Upper Limit	Lower Limit	Upper Limit	Increment
Accretion	0	0	45	45
0	100	45	25	25
100	200	70	88	18
200	300	88	97	9
300	400	97	99.4	2.4
400	500	99.4	100	0.6

Table 1D. Probability Associated with Various Bank Erosion Distances for a 50 Year Period Based on Actual Sampled Distribution – Upper Left Bank of the Matanuska River near Palmer

50 Year Total Erosion Distance (ft)		Probability of Given Erosion Condition (%)		
Lower Limit	Upper Limit	Lower Limit	Upper Limit	Increment
Accretion	0	0	23	23
0	100	23	76	53
100	200	76	90	14
200	300	90	96	6
300	400	96	99	3
400	500	99	100	1

Table 1E. Probability Associated with Various Bank Erosion Distances for a 50 Year Period Based on Assumption of Normal Distribution – Lower Left Bank of the Matanuska River near Palmer

50 Year Total Erosion Distance (ft)		Probability of Given Erosion Condition (%)		
Lower Limit	Upper Limit	Lower Limit	Upper Limit	Increment
Accretion	0	0	20	20
0	100	20	31	11
100	200	31	44	13
200	300	44	57	13
300	400	57	70	13
400	500	70	80	10
500	700	80	93	13
700	1,000	93	100	7

Table 1F. Probability Associated with Various Bank Erosion Distances for a 50 Year Period Based on Actual Sampled Distribution – Lower Left Bank of the Matanuska River near Palmer

50 Year Total Erosion Distance (ft)		Probability of Given Erosion Condition (%)		
Lower Limit	Upper Limit	Lower Limit	Upper Limit	Increment
Accretion	0	0	0	0
0	100	0	50	50
100	200	50	62	12
200	300	62	65	3
300	400	65	75	10
400	500	75	78	3
500	700	78	85	7
700	1,000	85	100	15

5.3. Expected Erosion Damages

The expected value of losses from bank erosion that could occur over the next 50 years for the without project condition were determined by combining the value of the significant components of the area potentially subjected to erosion and the probability of erosion extending into an area. The significant features considered were the land, the structures (nearly all residential), and the Old Glenn Highway. The value of the Old Glenn Highway was estimated based on the cost of pavement, replacing approximately 6 feet of fill, and an allowance for miscellaneous features such as driveways and intersections. The land and structure values were obtained from the Borough's Assessor's records and the parcel locations from the Mat-Su Borough GIS files. Though not quantified for this reconnaissance study, additional economic costs would be associated with traffic delays and rerouting. Though not significant enough to impact the feasibility assessment of alternatives in this study, these impacts should be examined during any feasibility-level analysis.

The erosion study area was divided into three subareas to facilitate determination of potential benefits for alternative projects. These areas are: the left bank for 22,000 feet downstream of the Old Glenn Highway bridge, the left bank from 22,000 feet downstream of the Old Glenn Highway bridge to 32,000 feet downstream and the right bank from about 5,000 feet upstream of the Palmer wastewater lagoons to just downstream of Sky Ranch Subdivision. These three subareas are referred to as the upper left bank, lower left bank and right bank. The length of banks in each of these three subareas is 22,000 feet, 10,000 feet and 15,000 feet, respectively.

Expected annual damages for the without project condition in a scenario assuming no growth in the number of existing residential structures are presented in **Table 2A** through **2B**. In developing the damages, the areas that currently have some protection were not excluded from the potential erosion areas. These areas were included because the erosion control structures are isolated and could fail from erosion upstream or downstream. Additionally, the inclusion of these areas may offset some of the smaller damages that were omitted from this level of analysis such as utilities and residential roads. **Tables 3A** through **3B** present expected total losses of existing over the fifty-year period of analysis for land, existing structures (nearly all residential), and the Old Glenn Highway in terms of acres, number of structures, and feet of highway, respectively assuming no new residential structures are constructed in the study area.

As mentioned in section 5.2, there may be a current trend of flows concentrating along the lower left bank for a substantial period due to the capture of the Matanuska River by the Knik River just downstream. Historically, it appears that the erosion in the lower area has switched back and forth between the lower left and the right bank as the flows concentrated on one side of the channel or the other. Qualitatively, this has appeared to happen on the order of every 10 to 20 years. For a sensitivity analysis of this potential issue a scenario was analyzed where the flow was assumed to concentrate on the left side of the channel for the next fifty years. To account for this, the losses on the lower left bank were doubled. At the same time the right bank damages were reduced to zero, since it was assumed that the Matanuska stopped flowing on this side for the 50-year period. Losses along the upper left bank were not changed. The results showed that damages would increase marginally, with the added damages in the lower left bank being offset significantly by the reduction in damages on the right bank. The added damages were not significant enough to alter the BC analysis presented later in this report.

Table 2A. Estimated Expected Average Annual Losses from Matanuska River Bank Erosion by Subareas Based on Assumption of Normal Distribution

Subarea	Estimated Expected Annual Erosion Losses			
	Land	Structures (mostly residential)	Old Glenn Hwy	Total
Upper Left Bank	$1,976	$5,235	$9,347	$16,558
Lower Left Bank	$3,611	$23,644	-0-	$27,255
Right Bank	$5,358	$15,638	-0-	$20,996

Table 2B. Estimated Expected Average Annual Losses from Matanuska River Bank Erosion by Subareas Based on Actual Sampled Distribution

Subarea	Estimated Expected Annual Erosion Losses			
	Land	Structures (mostly residential)	Old Glenn Hwy	Total
Upper Left Bank	$2,095	$6,340	$7,893	$16,329
Lower Left Bank	$3,396	$21,551	-0-	$24,947
Right Bank	$5,642	$16,896	-0-	$22,538

Table 3A. Estimated Expected Total Losses over 50 Years from Matanuska River Bank Erosion by Subarea Based on Assumption of Normal Distribution

Subarea	Estimated Expected Total Losses		
	Land (Acres)	Structures (mostly residential)	Highway (Feet)
Upper Left Bank	36.9	2.2	1168.4
Lower Left Bank	65.5	5.8	-0-
Right Bank	45.5	4.2	-0-

Table 3B. Estimated Expected Total Losses over 50 Years from Matanuska River Bank Erosion by Subarea Based on Actual Sampled Distribution

Subarea	Estimated Expected Total Losses		
	Land (Acres)	Structures (mostly residential)	Highway (Feet)
Upper Left Bank	39.1	2.9	986.6
Lower Left Bank	61.6	6.0	-0-
Right Bank	47.9	4.7	-0-

5.4. Incorporation of Housing Growth Rate

The data presented in Tables 2A-2B and 3A-3B was based upon an assumption of no new development in the study area over the period of analysis. An additional analysis was conducted to see the effects of residential development in the study area. Because no specific data was available on growth rates in the study area, growth rates were studied for the Matanuska-Susitna Borough as a whole. This analysis was based upon U.S. Census Bureau data and identified a 40-year average annual population growth rate of 6.3%, a 30-year rate of 7.6%, a 20-year rate of 6.2% and a rate of 4.1% over the decade 1990-2000. The 4.1% annual growth rate was selected for estimating future development in the study area. A more conservative 2% rate was also applied as a sensitivity analysis. **Tables 2A-2B** are reproduced below as **Tables 4A-4B** to show the change in expected damages when incorporating the two growth factors for residential structures.

Table 4A. Estimated Expected Average Annual Losses from Matanuska River Bank Erosion by Subareas Based on Assumption of Normal Distribution

Subarea		Estimated Expected Annual Erosion Losses			
		Land	Structures (mostly residential)	Old Glenn Hwy	Total
No Growth	Upper Left Bank	$1,976	$5,235	$9,347	$16,558
	Lower Left Bank	$3,611	$23,644	-0-	$27,255
	Right Bank	$5,358	$15,638	-0-	$20,996
2% Growth	Upper Left Bank	$1,976	$7,258	$9,347	$18,581
	Lower Left Bank	$3,611	$32,785	-0-	$36,396
	Right Bank	$5,358	$21,683	-0-	$27,041
4.1% Growth	Upper Left Bank	$1,976	$10,926	$9,347	$22,249
	Lower Left Bank	$3,611	$49,351	-0-	$52,962
	Right Bank	$5,358	$32,640	-0-	$37,998

Table 4B. Estimated Expected Average Annual Losses from Matanuska River Bank Erosion by Subareas Based on Actual Sampled Distribution

Subarea		Estimated Expected Annual Erosion Losses			
		Land	Structures (mostly residential)	Old Glenn Hwy	Total
No Growth	Upper Left Bank	$2,095	$6,340	$7,893	$16,329
	Lower Left Bank	$3,396	$21,551	-0-	$24,947
	Right Bank	$5,642	$16,896	-0-	$22,538
2% Growth	Upper Left Bank	$2,095	$8,792	$7,893	$18,780
	Lower Left Bank	$3,396	$29,883	-0-	$33,279
	Right Bank	$5,642	$23,428	-0-	$29,070
4.1% Growth	Upper Left Bank	$2,095	$13,234	$7,893	$23,222
	Lower Left Bank	$3,396	$44,983	-0-	$48,379
	Right Bank	$5,642	$35,266	-0-	$40,908

5.5. General Erosion Control Measures

Opportunities exist for implementing solutions to address the erosion problems identified in **Sections 5.1 - 5.3**. The review of pertinent existing documents, discussions with Corps of Engineers staff, meetings and interviews with local government and agency representatives, and site reconnaissance confirmed that erosion has been a problem that has drawn attention along the Matanuska River for at least 50 years. Over that period, a variety of solutions have been proposed that fall into the general categories of:

- Flow Deflecting Structures
- Bank Armoring
- Gravel Extraction
- Non-Structural Measures

These measures are described below, including an assessment of the pros and cons for each:

5.5.1. Flow Deflecting Structures

Flow deflecting structures function to protect riverbanks by moving the erosive force of water away from the toe of the bank. Flow deflecting structures are typically utilized in a series to move the flow away from the bank over a significant length of the river; however, in some cases, they are used as a single unit to eliminate a single point of flow impingement on a bank. When spur dikes are used in a series, finer sediments tend to deposit in the slack water and eddies between the spur dikes. This further protects the banks and in some cases, allows for the establishment of vegetation.

Flow deflecting structures have been used at several locations along the Matanuska River and is one of the solutions proposed in several of the past reports. The flow deflecting structures proposed have been spur dikes, which protrude nearly perpendicular from the bank into the flow. Spur dikes have been used in the area of Circle View Estates and at several locations along the

Glenn Highway. Additionally, shorter spurs or groins have been utilized to protect the Palmer sewage lagoons.

Pros

- Have shown some success in controlling bank erosion on the Matanuska
- Moves high velocity flow away from eroding bank
- Creates channel thalweg at tip or nose of dikes due to channel deepening by scour, thus tending to stabilize the alignment
- Typically requires less rock to construct than armoring the banks with riprap
- Vegetation may become established on deposits between flow deflecting structures

Cons

- Earlier investigations indicated a low B/C ratio for the treatment
- Concern over shifting erosion problems upstream or downstream of structure
- Concern over potential for shifting erosion to opposite side of river (May not be warranted in areas where the channel is several thousand feet wide as is often the case in the study area)
- Changing river conditions, primarily shifting channel braids, could alter angle of attack and reduce effectiveness or cause failure
- Maintenance at tip is likely to be required due to large scour potential
- Concern over environmental impacts

5.5.2. Bank Armoring

This is the most common method of protecting banks from erosion. In this approach, a blanket of less erodible material is placed along the banks to prevent the flow from removing native bank material. Depending on the conditions, this may be accomplished using vegetation (biotechnical), rock (riprap), rock filled gabions or other manufactured revetments such as articulated concrete mattresses. Because of the hydraulic conditions, including velocities on the order of 10 feet per second and shear stresses exceeding 2 pounds per square foot, biotechnical approaches have not been considered on the Matanuska as a primary element for stabilization of main channel erosion sites. However, biotechnical means could be employed to protect upper banks and enhance the environmental aspects of bank armoring measures. Gabions and concrete mattresses are typically used when sources of suitable quality riprap are not readily available. Since riprap is available in the area, this would be the likely approach utilized for the bank armoring category of protection.

Bank armoring can either be applied directly to the banks by regrading the bank slopes and applying appropriate filters/bedding, or by construction of a training dike. The latter approach is utilized when the bank is irregular, has sharp bends or poor alignments that may create adverse hydraulic conditions. Additionally, the protection of a smooth training dike may require less riprap than an irregular shaped, eroded bank line. Both approaches to bank armoring have been proposed and applied to the Matanuska River.

Pros

- Has shown some success in controlling bank erosion on the Matanuska River

- Maintenance may be less than spur dikes because the severe scour conditions that occur at the tip of spur dikes is absent
- Less susceptible to changes in alignment of braids than spur dikes
- Less likely than spur dikes to transfer erosion problems to the opposite bank, upstream or downstream

Cons

- Earlier investigations indicated a low B/C ratio for the treatment
- Typically requires more riprap than spur dikes
- Thalweg tends to form at base of riprap, bringing main flow of channel along protected bank
- Concern over environmental impacts
- Extensive length would be required to prevent flanking of the protection – not suitable for protection of localized area

5.5.3. *Gravel Extraction*

It has been postulated in past studies that a significant factor causing bank erosion on the Matanuska River is the large supply of bed load that causes deposition and contributes to the dynamic nature of the braided channel. The gravel extraction approach to controlling bank erosion aims at removing a sufficient amount of bed load to eliminate the over supply and the associated deposition. Additionally, the proposed approach would attempt to relocate the channel to the center of the braided corridor rather than allowing it to impinge upon the outer banks or limits of the corridor. The approach would utilize an excavated channel to direct the flow into a large expansion or settling area where the bed load would be deposited. An excavated channel would convey the flow out of the settling area. The settling area would be used as the extraction point for the gravel and cobble. A fundamental requirement of this approach is that the economic value of the gravel extracted would fund the continued removal activities. It has not been established that this requirement can be met. A market analysis of gravel demand should be part of a more detailed feasibility study to further examine this issue.

There is considerable merit to attempt to solve the problem by attacking one of the causes of bank erosion (i.e., over supply of sediment) than by addressing the symptoms by protecting the banks. However, there are many questions that need to be answered prior to establishing the feasibility of such an approach.

Pros

- Attempts to address the cause of bank erosion rather than the symptoms
- Operation and maintenance may be self funding by the sale of the aggregate
- Would reduce the likelihood of a channel avulsion across the Bodenburg Butte area, should this possibility actually be a reality

Cons

- Addresses portion of erosion problem related to oversupply but banks' erosion may have other contributing factors such as nature of the banks, hydrologic conditions, and hydraulic conditions

- Management of gravel for reduction in oversupply to reduce or control bank erosion may conflict with management needed for operating a profitable gravel mining operation
    - Gravel supply by the river may vary considerably from year to year and has no correlation to variations in demand
    - If economics of gravel extraction change, cessation of extraction will terminate any bank erosion control afforded by the project
- It may be difficult to successfully control the gravel supply for very large events
- If not properly conducted, gravel extraction could adversely impact upstream and downstream areas
- Agency concerns over adverse environmental impacts
- Potential impacts to the groundwater fed channels that currently provide fish habitat through possible lowering of the groundwater level as a result of lowering the water level in the channel
- Stabilization of the channel could result in significant alterations in existing habitat functions and values

5.5.4. Non Structural Measures

Non-structural solutions aim to reduce expected future erosion damages by moving homes and infrastructure out of harms way and to discourage further development in erosion prone areas. Non-structural solutions could include some combination of acquisition and/or relocation of threatened properties and land management including land use controls and zoning regulations. These non-structural measures would reduce expected future erosion damages and would have less environmental impacts within the river corridor than structural solutions. However, some environmental impacts could be transferred to other areas as growth that would have occurred in the river corridor occurs in other areas.

Pros

- Non structural measures such as relocations and limitations of future development would reduce potential for future damages because fewer homes and other improvements would be in the path of future bank erosion episodes
- Likely to be most environmentally acceptable solution
- Less or no permitting relative to structural measures
- Would not alter the riverine environment

Cons

- Land Use controls alone (without relocation) do not protect current property from loss
- Relocation of existing properties alone (without land use controls) does not preclude future development in erosion prone areas
- Potential opposition by property owners within the corridor

5.6. Specific Erosion Damage Reduction Opportunities (Alternative Plans and Preliminary Evaluation of Alternatives)

To investigate the potential feasibility of controlling erosion on the Matanuska River, specific locations were identified that presented opportunities for implementation of erosion control measures. Locations were selected based on two primary criteria: 1) locations where valued resources are at risk of damage from erosion, and 2) where implementation of erosion control measures appears feasible.

The primary opportunities identified to address erosion problems in the study areas extend from approximately four miles upstream of the Glenn Highway crossing of the Matanuska at the Knik Arm to just above Chickaloon (Mile Post 77). Two primary erosion reaches were initially identified along this length of the river. The first erosion reach identified is in the more populated area near Palmer, from the Old Glenn Highway crossing downstream for approximately seven miles. The second erosion reach identified includes intermittent erosion areas along the Glenn Highway from Mile Post 61 (near Sutton) to Mile Post 78 (near Chickaloon). In the lower reach, the most significant problems have centered around bank erosion threatening and in some cases actually destroying homes. In the upper reach the problem has to a large part been associated with bank erosion threatening and damaging the highway, although, there have been several homes threatened by erosion near Sutton.

Discussions with Mr. Chris Kepler of the Alaska Department of Transportation and Public Facilities indicated that past efforts have resulted in controlling erosion of the upstream reaches of the Matanuska River along the Glenn Highway to the extent that erosion is now primarily a maintenance issue. He did not feel that there was a need for a significant effort to implement new bank protection measures along the Glenn Highway. The site visit conducted as part of this effort confirmed this opinion.

In contrast to the upstream reaches of the Matanuska River, the bank erosion problems in the Palmer area, below the Old Glenn Highway Bridge are still a major concern. Currently, attention is focused on the left side (left defined facing downstream) of the river, though erosion of the right bank in the area of the Palmer wastewater lagoons and the Mountain View Estates were both problems prior to the Matanuska shifting to the south in the period following the 1986 high flows. Based on the evaluation of active bank erosion, the highest opportunities for control of bank erosion exist along the reach of the Matanuska River in the Palmer area, below the Old Glenn Highway Bridge.

For a viable bank erosion control project to exist, not only do eroding banks need to be present, but also there must be threatened land and improvements that are of sufficient value to justify the expense associated with providing significant bank erosion protection. In the Palmer area below the Old Glenn Highway Bridge, it was determined that both these conditions existed at a level to warrant their further consideration in this study.

To further investigate the feasibility of implementing bank protection along the Matanuska River in this area, the general erosion damage reduction measures described in **Section 5.3** were formulated into specific erosion damage reduction plans at specific locations in the study area. The first alterative plan involves implementing a program of gravel extraction to stabilize the river system. The second alternative plan involves providing bank armoring to prevent erosion. Various groups and individuals have expressed interest in both of these alternatives over the past decades as documented by previous reports and input provided by local agencies. Additionally, a non-structural erosion damage reduction alternative was evaluated.

The gravel extraction alternative was formulated by Peratrovich, Nottingham and Drage (PND, 1991) under contract with the Borough and is primarily intended to protect homes from about half a mile north of North Bodenburg Butte Loop Road on downstream for approximately three miles on both sides of the river. It should be noted that the PND plan is very conceptual and numerous important questions and issues, both in terms of engineering and economics, need to be further investigated before a determination of whether the plan will actually work can be made. The bank armoring alternative would protect the Old Glenn Highway and buildings on the left bank from the bridge on downstream to near the Triple Crown Estates subdivision. The general locations of the alternatives are presented as **Figure 2** and are described in the following paragraphs. The non-structural alternative would involve acquisition of erosion-prone lands and improvements for conversion to open space or other beneficial uses.

As a reconnaissance study, the development and evaluation of the alternatives is at a conceptual level. The purpose is not to identify a definitive project, but to determine if there is a possibility that a technically and economically feasible project may exist that warrants further consideration. The specific alternatives were chosen since they appear to have the highest potential for protecting features of economic value. The gravel extraction alternative and the non-structural alternative concentrate on reducing erosion damages to homes, while the bank protection alternative reduces potential damages to both infrastructure (Old Glenn Highway) and homes. Collectively, the alternatives offer an assessment of the potential range of benefits from bank erosion damage reduction projects in the study area.

5.6.1. Alternative 1 – Gravel Extraction

Description: Much of the bank erosion problem within the Matanuska River in the Palmer area is the result of the channel exhibiting a highly braided planform. The braided channel is characterized by multiple and shifting channels within the overall river corridor. This behavior results in areas of high bank erosion when one of the channel braids shifts against a bank along the edge of the corridor, as was the case at Circle View Estates a decade ago. A primary factor contributing to the braided channel condition is a high rate of bed load supply in excess of the flow's capacity to transport the material. The gravel extraction alternative would remove the oversupply of bed load with the intent of controlling the channel's tendency to braid, and therefore greatly reduce bank erosion.

Peratrovich, Nottingham and Drage, Inc. (PND) prepared a report for the Matanuska-Susitna Borough presenting the conceptual design and basis for a gravel extraction scheme to control erosion along a portion of the Matanuska River. In addition to eliminating the over supply of bed load to reduce erosion, the plan also incorporates excavation and channel training associated with the gravel extraction plan to intitially move the flow of the river towards the center of the corridor and away from the banks. The alternative presented in this section is a summary of the alternative presented in the PND report. It is cautioned that the actual ability of this alternative to control the erosion problems has not been addressed to the extent that it is considered technically feasible. This section also presents some of the questions and concerns related to the gravel extraction plan to fully evaluate its feasibility.

Alternative 1 would be located in the Matanuska River from about three miles downstream (south) of the Old Glenn Highway Bridge to below the Sky Ranch subdivision. The downstream location would be approximately one mile upstream of the Matanuska Dike constructed to protect the Alaska Railroad. The length of the project would be about three miles. In this configuration, the project would be intended to provide erosion protection for both sides of the river within this three-mile reach. Refer to **Figure 2** above for location of potential gravel extraction site.

As presented by PND (1991) the project would consist of five major components:

1. The first component would be a gravel extraction pit constructed in the center of the channel corridor adjacent to Mountain View Estates. The pit is proposed to be 20 feet deep and 1,200 feet in diameter with a volume of 600,000 cubic yards.

2. The second component would be an 8,000 foot long upstream supply channel extending from the extraction pit upstream to the narrow area in the channel corridor just upstream of North Bodenburg Loop Road and adjacent to the Triple Crown Subdivision.

3. The third component would be a similar channel extending downstream of the extraction pit for 3,000 feet. The channels are proposed to have widths of 300 feet and require 400,000 cubic yards of excavation. The channels are designed to be a total of ten feet deep with five feet of depth created by excavation and the remaining five feet created by pushing up berms along the channel from the channel excavation material. This size channel in this configuration is designed to convey the two-year flood. The design depends on the channel incising to create sufficient capacity to carry larger floods.

4. The fourth component would be a 1,000 foot wide flared transition into the 8,000 foot long upstream channel.

5. The fifth component of the system would be the gravel transportation facilities. This would consist of a 6,500 foot long railroad spur constructed to haul gravel from the site and connect with the existing Alaska Railroad tracks, gravel loading facility, haul road from the pit, and a gravel stockpile pad.

The facility described above would be utilized to extract an average of 250,000 cubic yards per year of gravel. PND indicates the intention of this volume roughly equaling the estimated annual bed load supply. Separate estimates of the average annual bed load supply in the Matanuska River resulted in values of 267,000 cubic yards (USGS) and 300,000 cubic yards (AHS).

Engineering Considerations: It is not possible to determine the engineering feasibility of gravel extraction as a means to control bank erosion along the Matanuska River based only on existing information. Thus, this alternative cannot be considered technically feasible until further investigations have been conducted (technical feasibility has not been ruled out at this time). The following paragraphs identify specific issues that need to be addressed to determine engineering feasibility.

1. An extremely important question to answer is the expected amount of the gravel to be extracted. Uncertainty in this area arises from two aspects of the plan. First, the proposed plan calls for extraction of the entire estimated bed load supply; however, this may not be a wise approach. Extracting the entire bed load supply will leave the channel downstream of the project starved of coarse material and could adversely impact the downstream channel. Typically instream gravel mining is conducted under the concept

of "safe yield," where safe yield is the difference between the bed load sediment supply into the reach and the bed load sediment transport capacity within the reach. The safe yield may be much smaller than the actual supply. The second level of uncertainty involves the actual estimate of bed load. The predictions of 267,000 to 300,000 cubic yards are based on only 9 measurements for the first value and an approximate relationship from other Southcentral Alaska streams for the second value.

2. Another important question to answer is what will be the upstream impact of the proposed gravel extraction project? The method assumes that a headcut will occur, but there is not an analysis indicating that the headcut will be confined to the intended area. If the headcut proceeded upstream of the controlled channel, it could result in damages to other locations. Similarly, downstream impacts to the channel morphology must also be assessed.

3. The nature and variability of the sediment supplied to the extraction area must also be better understood. In low flow years, the bed load supply would likely be much smaller than the predicted average annual yield. Conversely, in high flow years the yield would be significantly larger. In the former case, it could create a hardship for any entity that was expecting to remove 250,000 cubic yards to make the gravel extraction economically viable. In the second case, the extraction area or upstream supply channel might be overwhelmed with sediment, resulting in a massive amount of deposition and shifting of the channel in the same manner as the project was intended to arrest. A better understanding of these two possibilities can only be obtained by analyzing the variability of sediment supply over a period of record and simulating the trapping characteristics of the gravel extraction pit.

4. The sediment trapping characteristics of the extraction pit under varying flow conditions must also be understood to identify the sizes of sediment trapped and their volumes. Though the plan is written as if the only material being trapped is gravel, it is inevitable that appreciable sand and some silt will be trapped. To estimate their volumes, the incoming supply must be estimated and the trapping characteristics of the proposed pit simulated over a range of flows. It is expected that the percentage of sands and silts in the sediments trapped in the extraction pit will be greater than that typically found in the channel deposits. This is due to the fact that the sediments trapped in the extraction pit will be deposited under a much lower energy environment than currently or historically existed, on the average, in the main channel of the Matanuska River.

5. Potential impacts to the stability of the system upstream and downstream, including existing bank protection structures needs to be addressed. This would relate to the potential for upstream headcuts, downstream channel degradation and migration or filling of the upstream supply channel.

6. Reduction in sediment supply would change the expected channel form from braided to single thread, but the single threaded channel may ultimately adopt a meandering form. This in turn would cause erosion of gravel and supply additional sediments. Thus, additional study is required to assess how much maintenance or bank protection might be needed to maintain the straight approach and exit channels from the settling area.

<u>Preliminary Cost:</u> The PND report did not provide a detailed cost breakdown of Alternative 1, but provided an estimated initial construction cost for the entire project of $3,000,000 in 1989

dollars. Applying a cost escalation factor of 1.5 (based on Engineering News Record's historic construction cost index to bring the estimate to the current price level) to this value results in an estimated cost of $4,500,000 in 2003 dollars. The PND report does not indicate the costs associated with extracting the gravel nor the value of the extracted gravel.

In addition to the initial construction cost, there would be costs associated with the annual extraction of gravel as well as maintenance of the facilities such as conveyor belts, roadways and the channels. For this analysis, the cost of extracting the gravel and stockpiling in the project area is estimated to be $3.00 per cubic yard. The annual cost of extracting 250,000 cubic yards of gravel is then $750,000. If it is assumed that maintenance costs of the other project components averages 2 percent of the initial construction cost, this is an additional annual expense of $90,000 per year. The estimated annual O&M cost is then $840,000. Calculated over a fifty-year period at the current Federal interest rate of 5.875%, this O&M has a present value of $13,474,500. The average annual equivalent cost is $1,120,530. A separate analysis was conducted assuming that the O&M costs were self-liquidating (that is, they pay for themselves by the sale of the extracted gravel). In this self liquidating scenario, the total present value of the gravel extraction alternative is $4,500,000, with an average annual equivalent value of $280,530. Adding the O&M and Construction costs results in a cost (present value) of $17,974,500 (average annual equivalent value of $1,120,530).

<u>*Economic Considerations:*</u> Implementation of the gravel extraction project would affect the study subareas delineated as Lower Left Bank and Right Bank. The erosion zones defined in **Section 5.2** of this report were compared with GIS-based county assessors data to determine the value of lands and improvements (see **Section 5.3** and **Tables 2A – 2B**). Land in the lower left bank was determined to have an average value of $2,755 per acre. Structures (all residential) within 1,000 feet of the current left bank totaled 28 with an average value of $119,170, and an average replacement value of $156,170. In the right bank, the land was valued at $5,894 per acre and there were 13 residential structures within 500 feet of the current bank with an average value of $182,585 and an average replacement value of $224,680. (Note: Section 5.2.2 provides a discussion of potential erosion distances for each bank.) Total expected erosion losses averted by this plan range from approximately 110 to 131 acres of land and 10 to 12 residential structures (see **Section 5.3** and **Tables 3A – 3B**). The calculated present value of prevented damages in these subareas ranged from approximately $762,000 to $774,000 (average annual equivalent value of $47,500 to $48,250). The range is based upon the different analysis methodologies employed (assumptions of normal vs. actual distribution). The estimated costs of this alternative exceed the expected benefits by a factor of approximately 23.2 to 1. Therefore this gravel extraction alternative does not appear to be economically justified. In the case where O&M costs are assumed to be self-liquidating, the value of prevented damages remains the same but the cost decreases. As a result, the estimated costs of this version of the alternative exceed the expected benefits by a factor of approximately 5.8 to 1.

If the two growth factors are applied to approximate development in the study area, expected damages and the value of prevented damages increase while the costs of the alternative remains constant. With the assumed 2% annual growth rate, expected damages prevented range from $1,000,100 to $1,018,000. Costs exceed benefits by a factor of approximately 17.7 to 1. In the self-liquidating O&M scenario, the ratio of costs to benefits is approximately 4.4 to 1.

Going to the assumed 4.1% growth rate, expected damages prevented range from $1,432,300 to $1,459,100. Costs exceed benefits by a factor of approximately 12.3 to 1. In the self-liquidating O&M scenario, the ratio of costs to benefits is approximately 3.1 to 1.

If this alternative were studied further, economic questions related to demand for gravel and gravel extraction/processing requirements and costs must be answered to determine if long term demand would exist for the gravel and if annual operation and maintenance of the project would be self liquidating. Demand for gravel varies based on regional construction trends, which are subject to changes in the local economy and government funding levels for large infrastructure projects. Additional demand for gravel may be possible through export out of the region. Even without considering any operation and maintenance costs, the project does not appear to be economically justified (that is, its annual costs far exceed its annual benefits).

Environmental Considerations: Applicable regulatory agencies expressed concern that gravel extraction within the river channel could adversely impact migrating adult and juvenile salmon and might actually result in channel destabilization. Agencies recommended a comprehensive watershed management study to document fisheries use and potential impacts of any proposed in-channel gravel extraction project. See **Section 13** for specific agency views and comments on these issues.

5.6.2. Alternative 2 – Bank Armoring by Riprap

Description: Alternative 2 consists of a riprap bank armoring extending along the left bank (east side) of the Matanuska River from the Old Glenn Highway Bridge downstream for 3.5 miles to near the Triple Crown Subdivision. Refer to **Figure 2** for the general extents of the bank armoring. The purpose of the bank armoring would be to control erosion in order to protect homes and the Old Glenn Highway. In this area, the Matanuska River ranges from less than 100 feet to approximately 1,600 feet from the Old Glenn Highway. Approximately 3,800 feet of the river currently has a combination of riprapped bank and dike installed. The rirpap armoring may also help to protect the area from flooding that can result as the channel erodes into low lying overbank areas and abandoned channels, such as occurred in 1971.

A detailed site-specific design of bank protection for this reach would utilize a combination of riprap armoring applied directly to the banks that have been cut back to an appropriate slope, rip-rap armoring applied to fill or a berm where the current bank alignment is not suitable for applying armor and possibly some flow deflecting structures such as spur dikes and groins. Armored banks would be used in areas where the existing bank has a suitable alignment for protecting as is sufficiently high to prevent flood flows from flanking the protection. Armored dikes could be used in other areas where the bank is low or an irregular bank line makes the job of protecting the existing bank difficult and expensive.

Engineering Considerations: Use of a riprap bank armoring to control erosion and also reduce possible flooding is a feasible engineering approach in the area proposed. This type of structure has already been successfully utilized in a 4,000 foot long section of river in the area of Ye Old River Road. On a larger scale, the ability to control erosion using similar measures has been proven by ADOT/PF on the reach of the Matanuska River from Sutton to Chickaloon. Further site-specific design efforts may result in including flow-deflecting structures, which have also been shown to be effective in controlling erosion in the Sutton to Chickaloon reach as well as within portions of the Matanuska in the Palmer area.

Although feasible, the use of the riprap bank armoring or any other bank protection measure, in a river as dynamic as the Matanuska will require that there be a commitment for significant long-term maintenance. All of the previous measures given as examples of current applications have required maintenance over the years. Finally, the alternative has been formulated with the intent of controlling bank erosion along the entire reach, rather than just applying protection to areas identified as currently eroding, because the dynamic nature of the Matanuska River could quickly shift erosion to new locations. Thus, in the long run, protection would be applied along the entire reach, assuming a strategy to control erosion by structural measures was adopted. By formulating a single project, the risk of smaller individual projects failing is eliminated and an integrated approach is implemented.

Preliminary Cost: It is estimated that riprap bank armoring would cost approximately $400 per foot or roughly $2,000,000 per mile. Of the 3.5-mile reach, approximately 2.7 miles are not currently diked. The resulting 14,000 feet of dike is estimated to cost on the order of $5,600,000. In addition, the current dike is in need of repair in several places. Allowing $100 per foot for repairs on the 4,000 feet of existing dike adds $400,000 to the cost of the project. The total first cost would be $6,000,000. Maintenance would be required to ensure long-term performance of the project. It is assumed that annual maintenance would average two percent of the initial construction cost. Based on this the estimated annual maintenance is $120,000 per year. The present value of first costs and O&M costs over the 50-year period of analysis amounts to $7,924,930 (average annual equivalent cost of $494,000).

The cost of protecting approximately 2,000 feet of bank along Circle View Estates in 1992 with spur dikes was $500,000. Escalating the price to current dollars by a factor of 1.33 (Engineering News Record's historic construction cost index) results in a cost of $666,000 for 2,000 feet ($1,800,000 per mile), which is in the same range of cost as constructing the armored bank protection. Therefore, whether armored bank protection or spur dikes are used, the cost of continuously protecting a significant length of the Matanuska will be similar with either option or a combination of the two.

Economic Considerations: Implementation of the bank armoring by riprap alternative would affect the study subarea delineated as Upper Left Bank. The erosion zones defined in **Section 5.2** of this report were joined with county assessors data to determine the value of lands and improvements within each zone. Additionally, expected damages to the Old Glenn Highway in the Upper Left Bank subarea were calculated (see **Section 5.3** and **Tables 2A – 2B**). The average per acre value of land in the upper left bank was found to be $2,676 per acre. The estimated value of the Old Glenn Highway was $400 per foot. The average value of the 7 residential structures in the estimated potential erosion zone of 500 feet width was $119,170, with an average estimated replacement cost of $156,168. Assuming no new development, total expected erosion losses averted by this plan range from approximately 37 to 39 acres of land, 2 to 3 residential structures, and 987 to 1168 feet of Old Glenn Highway (see **Section 5.3** and **Tables 3A – 3B**). In the no new development scenario, the combined present value of prevented damages in the Upper Left Bank subarea ranged from approximately $262,000 to $266,000 (average annual equivalent value of $16,330 to $16,580). The range is based upon the different analysis methodologies employed (assumptions of normal vs. actual distribution). The estimated costs of this alternative exceed the expected benefits by a factor of approximately 29.8 to 1. Therefore this bank armoring alternative does not appear to be economically justified.

If the two growth factors are applied to approximate development in the study area, expected damages and the value of prevented damages increase while the costs of the alternative remains constant. With the assumed 2% annual growth rate, expected damages prevented range from $298,100 to $301,200. Costs exceed benefits by a factor of approximately 26.6 to 1. Going to the assumed 4.1% growth rate, expected damages prevented range from $357,000 to $373,000. Costs exceed benefits by a factor of approximately 22.2 to 1.

Environmental Considerations: Applicable environmental agencies expressed concern that any kind of hard structural and protruding bank protection measures would create nearshore velocity barriers to upstream migrating juvenile salmon species. Any proposal for implementing these controls will need to evaluate and minimize these potential velocity barriers. Agencies recommended a comprehensive watershed management study to document fisheries use and potential impacts of any proposed bank protection project. See **Section 13** for specific agency views and comments on this issue.

5.6.3. *Alternative 3 – Non Structural Measures Plan*

Description: A non-structural plan would aim to reduce expected future erosion damages by moving homes and infrastructure out of harms way and to discourage further development in erosion prone areas. A non-structural measures plan could include a combination of nonstructural features, including land acquisition in erosion hazard areas, control of future development in erosion hazard areas, and public education to foster awareness of erosion risks along the river corridor. These non-structural measures would reduce expected future erosion damages and would have less environmental impacts within the river corridor than the structural solutions identified in this report. Conversion of developed areas in erosion hazard zones to open space could provide environmental benefits for wildlife in the study area. Additional opportunities would exist for utilization of converted lands for low-impact recreational activities such as camping and walking/cross county ski trails or for conversion of lands to agricultural production.

Several previous studies of erosion in the Matanuska River valley have concluded that non-structural erosion control measures should be implemented in the study area:

The Alaska District conducted a study resulting in the 1972 report Matanuska and Little Susitna Rivers, Flood Control, Alaska. Study findings stated "the District Engineer concludes that economic justification does not exist for structural solutions to flooding or bank erosion in either area studied; and that local interests should avail themselves of technical information regarding non-structural alternatives for wise management of the floodplain." The report further recommends "additional clearing and development within the established floodplain should be discouraged by institution of borough planning and zoning controls.

Alaska Governor, Walter Hickel, in 1991 convened the Alaska Task Force on Erosion in the Matanuska River Basin. The task force considered several alternatives for addressing erosion problems, including housing relocations and land use management options. Task Force recommendations published in their February 1992 report included the following non-structural measures:

- House relocations where appropriate, including land swaps and in some cases demolition
- Operate an "education campaign" to inform local officials, developers, and other interested parties of the state's policy regarding erosion hazard area management and the severity of the erosion risk along the Matanuska River.

- Identify Erosion Hazard areas and erosion rates in developed areas and areas of high development potential. The State and Borough should adopt minimum standards and definitions for riverine hazards and when delineating shorelines subject to erosion. These should include areas subject to imminent erosion hazards (within 10 years, E-10 zone), intermediate hazard (within 30 years, E-30 zone), and long-term hazard (within 60 years, E-60 Zone)
- Require the adoption of appropriate land use ordinances for communities adjacent to erosion hazard areas.
- Create building standards for buildings on or near erosion prone areas. Also, an analysis of erosion control measures should be made when plans for development in erosion prone areas are proposed. Erosion control should be required by the local government when needed for proper development.

These recommendations are still relevant at this time and should be considered for implementation by local governments.

A nonstructural alternative to erosion control was identified for evaluation in this reconnaissance study that includes items similar to those listed in the 1992 Task Force report:

- Identification of riverine erosion hazard areas.
- Developing a land acquisition program for privately owned land within erosion hazard areas
- Establishing set back distances from the river banks for all future development
- Educating riverfront property owners about riverine erosion and the potential for damage to land and residential structures built within erosion hazard areas

5.6.3.1. Identification of Riverine Erosion Hazard Areas

An initial step in the river management plan would be to identify the riverine erosion hazard areas (REHA). This is done by evaluating historic changes in channel behavior and projecting areas where the river may migrate or erode its banks in the future. The preliminary geomorphic assessment prepared in the structural alternatives section of this reconnaissance study can be used as a model and starting point for a more in-depth engineering assessment.

A more detailed identification of REHA's based upon findings of engineering studies would provide a more defensible basis to define erosion hazard areas on maps, establish set back distances and delineate buffer zones. A buffer is the region immediately beyond the banks of the river. It acts as a "right-of-way" for the river and allows for lateral movement of the channel. Added benefits of such buffers are that they can provide a foundation for present or future greenways. The linear nature of the buffer can provide connected corridors for the migration of plant and animal populations and allows recreational visitors to move more efficiently through the recreation zone.

5.6.3.2. Land Acquisition (Buyout) Program

Property acquisition, often times referred to as a buyout, is the most permanent step to reduce the risks of land failure in erosion hazard areas. Usually residences on the acquired property will be demolished. However, relocating the structure outside the hazard area may be an alternative in some cases. Of course, the structural condition of the house and the feasibility of transporting it are considerations for moving residences to safer ground. As a simplifying assumption for this reconnaissance level analysis, property demolition is assumed for all residences.

Property acquisition works like other real estate transactions. Property owners are given the opportunity to sell their property at a fair price. The value placed on the property is based on common real estate practices, including appraisals and market analysis of comparable housing. Besides minimizing erosion damages to specific parcels, land acquisition yields a number of other important benefits. One immediate advantage is that purchasing undeveloped erosion-prone property eliminates the need for structural improvements (such as bank stabilization, levees, etc.) that would otherwise be needed to protect those parcels. In the case of land failure, the cost of insurance or emergency management of affected residences is mitigated. Land acquisition also helps create recreational opportunities, maintaining public open space along the riverbanks, and protecting wildlife habitat. Once the property is acquired, residential structures are removed and the property must then remain open space land, suitable for wildlife refuges, campgrounds, other public recreational uses, or agriculture.

5.6.3.3. Establish Setback Distances for Future Development in Erosion Hazard Zones

An integral component to the nonstructural plan is the institution of land use controls to curb future development in identified erosion hazard areas. This serves to protect against future erosion damages. The analysis of expected erosion damages to structures (all residential) in the study area evaluated two growth scenarios, a 2% annual development rate and a 4.1% annual development rate (the 4.1% rate is based upon the average annual population growth rate of the Matanuska-Susitna Borough from 1990-2000). The present value of expected damages to residential structures over the 50-year period of analysis increased from a value of $756,040 assuming no growth in development, to $1,010,220 with the 2% annual growth rate and a value of $1,461,440 with the 4.1% annual growth rate. These added damages expected with development could be averted by steering development outside of erosion hazard areas.

5.6.3.4. Erosion Hazard Education

An important part of a nonstructural plan would be a planned proactive program of Erosion Hazard Education. Educating developers and riverfront property owners about riverine erosion and the potential for damage to land and residential structures built within erosion hazard areas would help to build pubic awareness of the erosion hazards in the study area and could serve to preclude some future development in erosion hazards zones and reduce future damages.

Engineering Considerations: Implementation of the above described non-structural measures involving acquisition of threatened land, relocation of homes where appropriate, and implementation of land use regulations is engineeringly feasible.

Preliminary Cost: Costs of the non-structural plan have three major components: 1) costs of land acquisition in erosion hazard areas, 2) removal of existing improvements from erosion hazard areas, and 3) labor costs for a local administrator of a erosion hazard mitigation program that would include erosion education and administration of the land acquisition and land use control functions of the non-structural alternative.

The costs of acquisition and removal of land and improvements would vary depending on the areas planned for acquisition. For this reconnaissance level planning study, costs were developed for each erosion zone and for each study breakout area (upper left bank, lower left bank, right bank). This data is presented in **Table 5**. The costs in Table 5 do not include costs for relocation assistance payments that may be required under Public Law 91-646 (the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970) for any persons, farms, or businesses that are displaced due to the acquisition of their land and improvements. These costs should be assessed and accounted for in any feasibility level investigations.

Table 5. Cost of Land Acquisition and Removal of Improvements (Present Values)

	Zone 1 (0-100 from bank)	Zone 2 (100-200 from bank)	Zone 3 (200-300 from bank)	Zone 4 (300-400 from bank)	Zone 5 (400-500 from bank)	Zone 6 (500-1000 from bank)	All Zones
	PV	PV	PV	PV	PV	PV	PV
Total Right Bank Cost	$202,957	$1,116,157	$796,457	$396,357	$599,056	NA	$3,110,982
Total Upper Left Bank Cost	$332,060	$167,960	$195,886	$146,585	$235,860	NA	$1,078,353
Total Lower Left Bank Cost	$63,241	$112,540	$90,241	$146,140	$199,041	$1,009,407	$1,620,609

Labor costs for a local erosion hazard mitigation program administrator were based upon 20% of a FTE earning a $50,000 salary and a 3.0 overhead multiplier, resulting in an annual cost of $30,000. The present value of this annual labor cost over a fifty-year period of analysis is $481,230.

<u>*Economic Considerations:*</u> A benefit cost analysis of a range of alternative non-structural plans was performed as part of this study. The range of alternatives was based upon various different combinations of land acquisition in specific study breakout areas combined with specific erosion zones. All combinations include the labor cost for a program administrator and assume that land use controls are put in place to eliminate any future development in those zones that are included in the combination. For each erosion zone in each study breakout area that is included in a combination, it is assumed that all parcels are acquired within that zone/breakout area combination.

The results of this benefit-cost analysis are presented in **Table 6** for the no development, the 2% annual growth, and the 4.1% annual growth scenarios based on assumption of a normal distribution. The data is sorted in the order of descending BC Ratio associated with the 4.1% growth scenario. The non-structural alternative with the highest BC Ratio is the plan for acquisition of all zones in the lower left study area, zoning to preclude future development in that area, and establishment of a erosion hazard mitigation program administrator. With a .4 BC Ratio, the costs of this alternative exceed the benefits by a factor of approximately 2.5 to 1. The analysis was also conducted for the erosion rates based upon the actual observed distribution with similar results.

Table 6. Benefit Cost Analysis of Non-Structural Alternatives (Normal Distribution)

Alternatives:		No Growth		Annual Growth of 2%		Annual Growth of 4.1%	
	Cost (PV)	Benefit (PV)	BC Ratio	Benefit (PV)	BC Ratio	Benefit (PV)	BC Ratio
Nonstructural Alternatives:							
All Zones - Lower Left	$2,101,841	$437,197	0.208	$583,823	0.278	$849,566	0.404
Zones 1, 2, 3, 4, and 5 - Lower Left	$1,092,434	$194,362	0.178	$257,894	0.236	$373,037	0.341
All Zones - Left + Right	$6,291,176	$1,039,592	0.165	$1,315,658	0.209	$1,815,995	0.289
All Zones - Lower Left + Right	$5,212,823	$773,991	0.148	$1,017,594	0.195	$1,459,095	0.280
Zones 1, 2, 3, and 4 - Left + Right	$4,247,812	$695,821	0.164	$857,490	0.202	$1,150,496	0.271
Zones 1, 2, and 3 - Upper Left	$1,177,139	$233,125	0.198	$261,985	0.223	$314,291	0.267
Zones 1, 2, 3, and 4 - Lower Left	$893,393	$125,110	0.140	$165,398	0.185	$238,416	0.267
Zones 1, 2, 3, and 4 - Upper Left	$1,323,724	$258,519	0.195	$290,168	0.219	$347,529	0.263
Zones 1, 2, 3, 4, and 5 - Left + Right	$5,281,768	$796,758	0.151	$989,729	0.187	$1,339,466	0.254
Zones 1, 2, and 3 - Left + Right	$3,558,730	$542,679	0.152	$661,908	0.186	$877,997	0.247
Zones 1, 2, 3, and 4 - Lower Left + Right	$3,405,319	$437,302	0.128	$567,322	0.167	$802,967	0.236
Zones 1, 2, 3, 4, and 5 - Lower Left + Right	$4,203,416	$531,156	0.126	$691,664	0.165	$982,566	0.234
Zones 1, 2, 3, 4, and 5 - Upper Left	$1,559,585	$265,601	0.170	$298,064	0.191	$356,900	0.229
All Zones - Upper Left	$1,559,585	$265,601	0.170	$298,064	0.191	$356,900	0.229
Zones 1 and 2 - Upper Left	$981,253	$152,083	0.155	$172,227	0.176	$208,736	0.213
Zones 1, 2, and 3 - Lower Left + Right	$2,862,823	$309,555	0.108	$399,923	0.140	$563,706	0.197
Zones 1, 2, 3, and 4 - Right	$2,993,158	$312,193	0.104	$401,924	0.134	$564,551	0.189
Zones 1 and 2 - Left + Right	$2,476,146	$289,379	0.117	$347,173	0.140	$451,919	0.183
Zones 1, 2, and 3 - Right	$2,596,802	$245,783	0.095	$316,007	0.122	$443,280	0.171
Zones 1, 2, 3, 4, and 5- Right	$3,592,214	$336,794	0.094	$433,770	0.121	$609,529	0.170
All Zones - Right	$3,592,214	$336,794	0.094	$433,770	0.121	$609,529	0.170
Zones 1, 2, and 3 - Lower Left	$747,253	$63,772	0.085	$83,916	0.112	$120,425	0.161
Zones 1 and 2 - Lower Left + Right	$1,976,126	$137,296	0.069	$174,946	0.089	$243,183	0.123
Zones 1 and 2 - Right	$1,800,345	$112,684	0.063	$142,780	0.079	$197,326	0.110
Zone 1 - Upper Left	$813,292	$30,471	0.037	$40,156	0.049	$57,708	0.071
Zones 1 and 2 - Lower Left	$657,013	$24,612	0.037	$32,166	0.049	$45,857	0.070
Zone 1 - Left + Right	$1,079,490	$40,052	0.037	$49,737	0.046	$67,289	0.062
Zone 1 - Lower Left + Right	$747,429	$9,581	0.013	$9,581	0.013	$9,581	0.013
Zone 1 - Right	$684,188	$8,465	0.012	$8,465	0.012	$8,465	0.012
Zone 1 - Lower Left	$544,473	$1,116	0.002	$1,116	0.002	$1,116	0.002

Environmental Considerations: During coordination with applicable environmental agencies, a number of agencies advocated that a nonstructural approach be given equal consideration to hard structural or gravel extraction alternatives as a means for reducing erosion damages in the study area. See **Section 13** for specific agency views and comments on this issue.

5.7. Additional Potential Benefits with Non-Structural Plan

While the estimated benefits for the alternatives of the nonstructural plan did not equal their costs, added benefits associated with new and beneficial land uses might provide the difference needed to justify implementation of a nonstructural plan. These new land uses could be incorporated with the non-structural plan by converting acquired lands to other beneficial uses. These potential added benefits could include environmental benefits associated with restoration of wildlife habitats in acquired lands and economic benefits associated with the provision of recreational opportunities on acquired properties, or economic benefits associated with conversion of lands to agricultural production.

An analysis was conducted to illustrate the potential for recreational benefits on acquired lands. This hypothetical analysis assumed that acquired land was converted to natural space with recreational rustic camping facilities and trails for use in the summer season and wintertime activities such as cross country skiing, dog sledding, and/or snow machining. Corps Economic Guidance Memorandum 03-04 was referenced to obtain unit day values that serve to estimate recreationist's willingness to pay for a recreational site visit. The memorandum defines current FY03 values for general recreational activities to range between $2.94 and $8.82 per day. This analysis assumed the midpoint, or $5.88/user day. Yearly visitation was estimated at 7,560 user days (approximately 20 users per day). Applying the user day value of $5.88 to the 7,650 user days resulted in an estimated annual NED benefit of approximately $45,000. The present value of this annual benefit over the 50-year period of analysis equates to approximately $721,600 in NED recreation benefits.

Combining this level of economic benefit to the erosion damage reduction benefits brings some of the non-structural alternatives closer to economic justification (closer to a BC ratio of 1) as presented in **Table 7.** Non-structural plans focusing on land acquisition in the lower left bank study area had the highest benefit to cost ratio (.819 - .960 to 1). No costs of constructing the recreational features were incorporated into this equation but the analysis does demonstrate the potential for adding other National Economic Development (NED) benefits by beneficial land uses for acquired lands with the non-structural plan. A more detailed recreation study could be performed as part of a feasibility level study to better assess the potential for recreation benefits. A similar approach could be applied during feasibility level studies to assess the economic benefits of agricultural uses of acquired lands. Similarly, lands could be used for fish and wildlife habitat restoration to provide National Ecosystem Restoration Benefits (NER Benefits). These non-monetary benefits can be combined with economic (NED) benefits to jointly contribute to economic justification.

Table 7. Adjusted BC Ratios for Nonstructural Plans with Addition of Hypothetical Recreation Benefits (Normal Distribution)

Alternatives:		No Growth			Annual Growth of 2%			Annual Growth of 4.1%		
	Cost (PV)	Benefit (PV) w/o Rec	Benefit (PV) with Rec*	BC Ratio	Benefit (PV) w/o Rec	Benefit (PV) with Rec*	BC Ratio	Benefit (PV) w/o Rec	Benefit (PV) with Rec*	BC Ratio
Nonstructural Alternatives					$0			$0		
Zone 1 - Lower Left	$544,473	$1,116	$522,675	0.960	$1,116	$522,675	0.960	$1,116	$522,675	0.960
Zones 1 and 2 - Lower Left	$657,013	$24,612	$546,171	0.831	$32,166	$553,725	0.843	$45,857	$567,416	0.864
Zones 1, 2, and 3 - Lower Left	$747,253	$63,772	$585,331	0.783	$83,916	$605,475	0.810	$120,425	$641,984	0.859
Zones 1, 2, 3, and 4 - Lower Left	$893,393	$125,110	$646,669	0.724	$165,398	$686,957	0.769	$238,416	$759,975	0.851
Zones 1, 2, 3, 4, and 5 - Lower Left	$1,092,434	$194,362	$715,921	0.655	$257,894	$779,453	0.714	$373,037	$894,596	0.819
Zone 1 - Right	$684,188	$8,465	$530,024	0.775	$8,465	$530,024	0.775	$8,465	$530,024	0.775
Zones 1 and 2 - Upper Left	$981,253	$152,083	$673,642	0.687	$172,227	$693,786	0.707	$208,736	$730,295	0.744
Zone 1 - Upper Left	$813,292	$30,471	$552,030	0.679	$40,156	$561,715	0.691	$57,708	$579,267	0.712
Zone 1 - Lower Left + Right	$747,429	$9,581	$531,140	0.711	$9,581	$531,140	0.711	$9,581	$531,140	0.711
Zones 1, 2, and 3 - Upper Left	$1,177,139	$233,125	$754,684	0.641	$261,985	$783,544	0.666	$314,291	$835,850	0.710
Zones 1, 2, 3, and 4 - Upper Left	$1,323,724	$258,519	$780,078	0.589	$290,168	$811,727	0.613	$347,529	$869,089	0.657
All Zones - Lower Left	$2,101,841	$437,197	$958,756	0.456	$583,823	$1,105,382	0.526	$849,566	$1,371,125	0.652
Zones 1, 2, 3, 4, and 5 - Upper Left	$1,559,585	$265,601	$787,160	0.505	$298,064	$819,624	0.526	$356,900	$878,459	0.563
All Zones - Upper Left	$1,559,585	$265,601	$787,160	0.505	$298,064	$819,624	0.526	$356,900	$878,459	0.563
Zone 1 - Left + Right	$1,079,490	$40,052	$561,611	0.520	$49,737	$571,296	0.529	$67,289	$588,848	0.545
Zones 1 and 2 - Right	$1,800,345	$112,684	$634,243	0.352	$142,780	$664,339	0.369	$197,326	$718,885	0.399
Zones 1, 2, 3, and 4 - Left + Right	$4,247,812	$695,821	$1,217,380	0.287	$857,490	$1,379,049	0.325	$1,150,496	$1,672,055	0.394
Zones 1, 2, and 3 - Left + Right	$3,558,730	$542,679	$1,064,238	0.299	$661,908	$1,183,467	0.333	$877,997	$1,399,556	0.393
Zones 1 and 2 - Left + Right	$2,476,346	$289,379	$810,938	0.328	$347,173	$868,732	0.351	$451,919	$973,478	0.393
Zones 1, 2, 3, and 4 - Lower Left + Right	$3,405,319	$437,302	$958,861	0.282	$567,322	$1,088,881	0.320	$802,967	$1,324,526	0.389
Zones 1 and 2 - Lower Left + Right	$1,976,126	$137,296	$658,855	0.333	$174,946	$696,505	0.352	$243,183	$764,742	0.387
All Zones - Lower Left + Right	$5,212,823	$773,991	$1,295,550	0.249	$1,017,594	$1,539,153	0.295	$1,459,095	$1,980,654	0.380
Zones 1, 2, and 3 - Lower Left + Right	$2,862,823	$309,555	$831,114	0.290	$399,923	$921,482	0.322	$563,706	$1,085,265	0.379
All Zones - Left + Right	$6,291,176	$1,039,592	$1,561,151	0.248	$1,315,658	$1,837,217	0.292	$1,815,995	$2,337,554	0.372
Zones 1, 2, and 3 - Right	$2,596,802	$245,783	$767,342	0.295	$316,007	$837,566	0.323	$443,280	$964,839	0.372
Zones 1, 2, 3, and 4 - Right	$2,993,158	$312,193	$833,752	0.279	$401,924	$923,483	0.309	$564,551	$1,086,110	0.363
Zones 1, 2, 3, 4, and 5 - Lower Left + Right	$4,203,416	$531,156	$1,052,715	0.250	$691,664	$1,213,223	0.289	$982,566	$1,504,125	0.358
Zones 1, 2, 3, 4, and 5 - Left + Right	$5,281,768	$796,758	$1,318,317	0.250	$989,729	$1,511,288	0.286	$1,339,466	$1,861,025	0.352
Zones 1, 2, 3, 4, and 5- Right	$3,592,214	$336,794	$858,353	0.239	$433,770	$955,330	0.266	$609,529	$1,131,088	0.315
All Zones - Right	$3,592,214	$336,794	$858,353	0.239	$433,770	$955,330	0.266	$609,529	$1,131,088	0.315

5.8. Comparison of Alternatives

Table 8 present the costs, benefits, and BC Ratios of the structural and nonstructural alternatives evaluated in this study. The data presented in the table are based upon the assumption of the normally distributed erosion rates. An analysis based upon actual observed rates was also performed with similar results (actual observed rates resulted in slightly less damages reduced than normally distributed rates). The data is presented for the no-growth, 2% annual growth, and 4.1% annual growth scenarios. Non-structural plans focusing on land acquisition in the lower left bank study area had the highest benefit to cost ratio (.404 to 1). While no alternatives were estimated to have net benefits, potential recreational, agricultural, and/or habitat benefits could result in some of the nonstructural options having net NED and NER benefits that justify their cost (see Section 5.7).

Table 8. Comparison of Benefits, Costs, and BC Ratios for All structural and Nonstructural Alternatives (Based on Normal Distribution)

Alternatives:		No Growth		Annual Growth of 2%		Annual Growth of 4.1%	
	Cost (PV)	Benefit (PV)	BC Ratio	Benefit (PV)	BC Ratio	Benefit (PV)	BC Ratio
Nonstructural Alternatives:							
All Zones - Lower Left	$2,101,841	$437,197	0.208	$583,823	0.278	$849,566	0.404
Zones 1, 2, 3, 4, and 5 - Lower Left	$1,092,434	$194,362	0.178	$257,894	0.236	$373,037	0.341
All Zones - Left + Right	$6,291,176	$1,039,592	0.165	$1,315,658	0.209	$1,815,995	0.289
All Zones - Lower Left + Right	$5,212,823	$773,991	0.148	$1,017,594	0.195	$1,459,095	0.280
Zones 1, 2, 3, and 4 - Left + Right	$4,247,812	$695,821	0.164	$857,490	0.202	$1,150,496	0.271
Zones 1, 2, and 3 - Upper Left	$1,177,139	$233,125	0.198	$261,985	0.223	$314,291	0.267
Zones 1, 2, 3, and 4 - Lower Left	$893,393	$125,110	0.140	$165,398	0.185	$238,416	0.267
Zones 1, 2, 3, and 4 - Upper Left	$1,323,724	$258,519	0.195	$290,168	0.219	$347,529	0.263
Zones 1, 2, 3, 4, and 5 - Left + Right	$5,281,768	$796,758	0.151	$989,729	0.187	$1,339,466	0.254
Zones 1, 2, and 3 - Left + Right	$3,558,730	$542,679	0.152	$661,908	0.186	$877,997	0.247
Zones 1, 2, 3, and 4 - Lower Left + Right	$3,405,319	$437,302	0.128	$567,322	0.167	$802,967	0.236
Zones 1, 2, 3, 4, and 5 - Lower Left + Right	$4,203,416	$531,156	0.126	$691,664	0.165	$982,566	0.234
Zones 1, 2, 3, 4, and 5 - Upper Left	$1,559,585	$265,601	0.170	$298,064	0.191	$356,900	0.229
All Zones - Upper Left	$1,559,585	$265,601	0.170	$298,064	0.191	$356,900	0.229
Zones 1 and 2 - Upper Left	$981,253	$152,083	0.155	$172,227	0.176	$208,736	0.213
Zones 1, 2, and 3 - Lower Left + Right	$2,862,823	$309,555	0.108	$399,923	0.140	$563,706	0.197
Zones 1, 2, 3, and 4 - Right	$2,993,158	$312,193	0.104	$401,924	0.134	$564,551	0.189
Zones 1 and 2 - Left + Right	$2,476,146	$289,379	0.117	$347,173	0.140	$451,919	0.183
Zones 1, 2, and 3 - Right	$2,596,802	$245,783	0.095	$316,007	0.122	$443,280	0.171
Zones 1, 2, 3, 4, and 5- Right	$3,592,214	$336,794	0.094	$433,770	0.121	$609,529	0.170
All Zones - Right	$3,592,214	$336,794	0.094	$433,770	0.121	$609,529	0.170
Zones 1, 2, and 3 - Lower Left	$747,253	$63,772	0.085	$83,916	0.112	$120,425	0.161
Zones 1 and 2 - Lower Left + Right	$1,976,126	$137,296	0.069	$174,946	0.089	$243,183	0.123
Zones 1 and 2 - Right	$1,800,345	$112,684	0.063	$142,780	0.079	$197,326	0.110
Zone 1 - Upper Left	$813,292	$30,471	0.037	$40,156	0.049	$57,708	0.071
Zones 1 and 2 - Lower Left	$657,013	$24,612	0.037	$32,166	0.049	$45,857	0.070
Zone 1 - Left + Right	$1,079,490	$40,052	0.037	$49,737	0.046	$67,289	0.062
Zone 1 - Lower Left + Right	$747,429	$9,581	0.013	$9,581	0.013	$9,581	0.013
Zone 1 - Right	$684,188	$8,465	0.012	$8,465	0.012	$8,465	0.012
Zone 1 - Lower Left	$544,473	$1,116	0.002	$1,116	0.002	$1,116	0.002

6. PROJECT AREA MAP

See **Figure 1** for a vicinity/study area map and **Figure 2** for approximate locations of potential erosion control features.

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