MWH

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| **To:** | File | **Date:** | September 29, 2004 |
| **From:** | Nick Smith | **Reference:** | 1851040.010107 |

**Subject:** **Matanuska River Erosion Project – Matanuska Survey Data Summary**

# Matanuska Survey Data Summary

## Introduction

Homes, land and utilities are being endangered due to riverbank erosion on the Matanuska River near the city of Palmer, Alaska. NRCS has retained MWH to evaluate methods to protect the river bank from further erosion. Protection methods under consideration include bank stabilization, excavation in order to reroute the river and use the gravel as a revenue source to offset the costs, and/or conservation efforts, which alter public land use practices. Relatively accurate survey information was needed to analyze these options. The survey data was used for development of river transport models and evaluation of historical information to draw practical conclusions.

Two sources of survey data have been obtained. First, Aeromap collected aerial photography and gather aerial photographs and Light Detection And Ranging (LiDAR) data. Secondly, DOWL Engineering has surveyed two cross sections of the Matanuska River. These surveys were conducted in response to a request from the USACE for updated information regarding erosion to compare to the September 19, 1991 Erosion Control of the Matanuska River near Bodenburg Butte report. This survey information has been compiled to use with various modeling techniques.

## LIDAR Data

LiDAR uses the same principle as RADAR. The LiDAR instrument transmits laser light out to a target. Laser transmitters are used that fire thousands of pulses per second. By scanning the laser pulses across the terrain using a rotating mirror, a dense set of distances to the surface is measured along a narrow corridor. Some of this is reflected / scattered back to the instrument where it is analyzed. The distance measurement are converted to map coordinates and elevations for each laser pulse by combining the distance data with information on the position of the airplane (using GPS) at the time the laser pulse was fired and the direction in which the pulse was fired. The change in the properties of the beam enables some property of the target to be determined. The time for the beams to travel out to the target and back to the LiDAR is used to determine the range to the target.

There are three basic generic types of LiDAR:

- Differential Absorbtion LiDAR (DIAL)
- Doppler LiDAR
- Range Finders (used in the Matanuska River analysis)

**DIAL** is used to measure chemical concentrations (such as ozone, water vapor, and pollutants) in the atmosphere. This method of data collection was not used for the Matanuska River project.

**Doppler LiDAR** is used to measure the velocity of a target. When the light transmitted from the LiDAR hits a target moving towards or away from the LiDAR, the wavelength of the light reflected/scattered off the target will be changed slightly. This is known as a Doppler shift - hence Doppler LiDAR. This method of data collection was not used for the Matanuska River project.

**Range finder LiDAR** is what was used on the Matanuska River in our analysis. Range finder LiDAR are used to measure the distance from the LiDAR instrument to a solid or hard target. It was the method used on the Matanuska as we only needed topographical information.

### LIMITATIONS TO LIDAR

There are several limitations to LiDAR data. These limitations include:

- **Vegetation** - When the laser beam is pointing straight down, a hole in the canopy the system will receive a return a signal from the ground surface. In a forested area, there is a wider angle of scan. The further the beam is off vertical the greater the chance of hitting other objects (tree trunks and branches) besides the surface. In densely forested areas the laser tends to hit more tree trunks, and this produces a scattering effect making a noisy return. It is then more difficult to determine what is giving returns: some foliage, some branches and tree trunks and some ground returns. (http://www.lasermap.com/laserM/english/lidarRadar.asp). This appears to be only a minor concern on the Matanuska River as most of the area of concerns is sparsely vegetated.
- **Accuracy –** Although more accurate than Radar, LiDAR has limitations to its inherent accuracy typically from the inertial system and the GPS due to plane movement, equipment inaccuracies or other imperfections.
- **Water Surfaces –** When the laser light beam hits a column of water, part of the energy is reflected off the surface and the rest travels through the water column and reflects off the water body bottom. The water surface reflects energy from the infrared pulse, while the blue-green pulse is the one that penetrates the water column and is reflected off the seafloor. The system records the time it takes for the reflected signals from the surface (infrared) and seafloor (blue-green) to return to the aircraft. The water depth is calculated from the time difference between the return pulses. LiDAR was chosen, despite these limitations since water depth is relatively shallow.

  Hydrographic LiDAR is extremely useful for regional coastal mapping. LiDAR systems can provide uniform and dense data in extremely shallow water. It is a good complement to acoustical surveys, which are less effective in depths less than about 5 meters. The biggest limitation of LiDAR, as with other airborne techniques, is its dependency on water clarity. In clear waters it can be used to depths of over 50 meters (over 150 feet), but in turbid water it is only successful to depths of two to three times the visible depth. LiDAR is cost effective for surveying large, shallow areas with generally good water clarity (http://www.csc.noaa.gov/benthic/mapping/techniques/sensors/lidar.htm). Unfortunately, the Matanuska River has high silt content and low clarity.

## Cross Section Survey

DOWL Engineering performed a cross section survey in 2003 on the Matanuska River in two locations A and B. The older cross section data did not match well with the LiDAR data in terms of elevations reported.

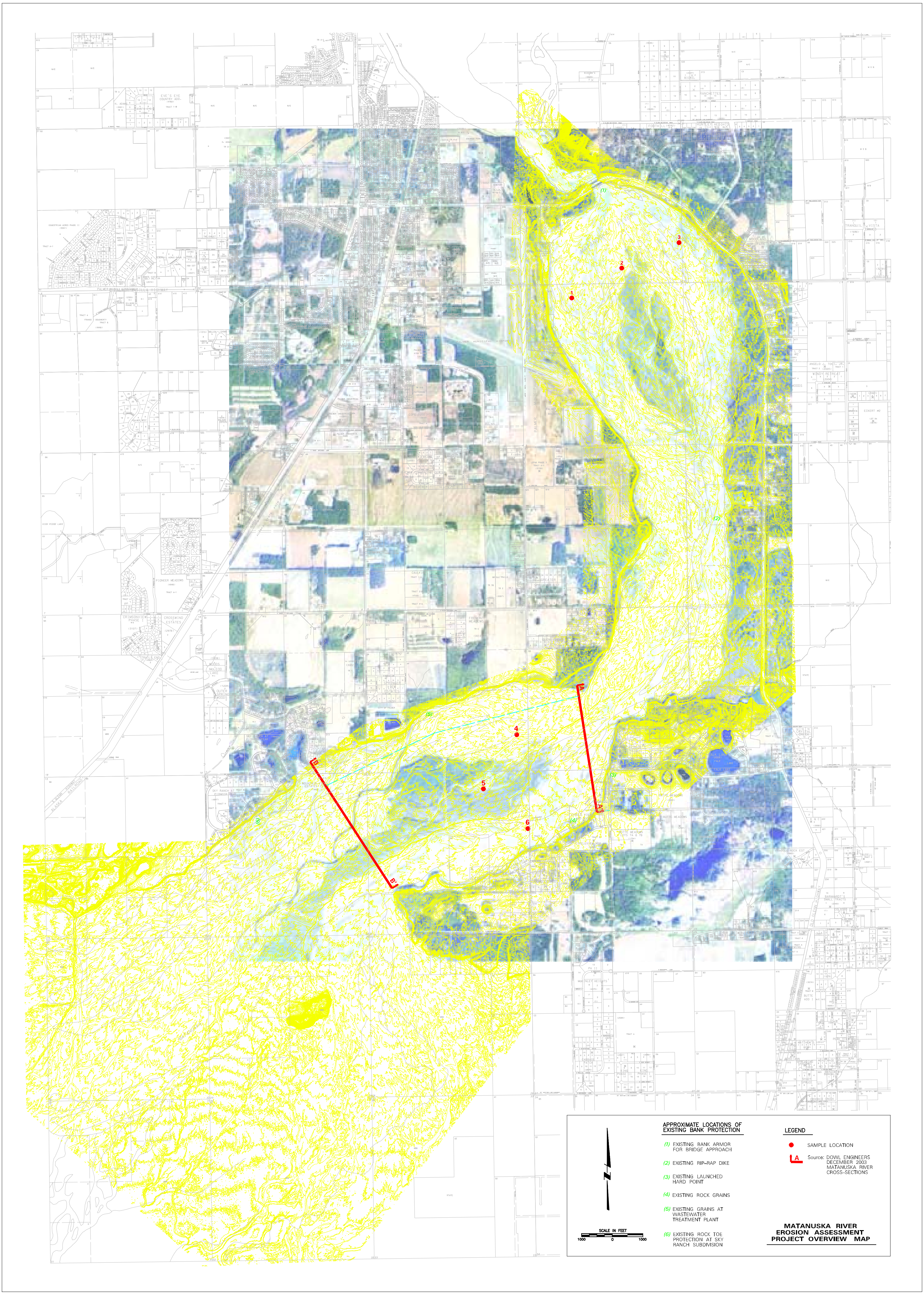
At a meeting with Aeromap and DOWL survey staff, we determined that a control survey could be used to measure the differences between the ellipsoid approximation of elevations used by the LiDAR data processing and orthometric heights common to conventional surveying. The 1995 survey used conventional surveying techniques but did not adjust elevations to NAVD88 benchmarks. In July 2004, DOWL connected LiDAR ground control points to orthometric features, as well as control points to orthometric features, as well as recovering the ground based control for the 1995 cross sections. These data were tied to network of well documented orthographic control.

The cross sections were controlled off a monument on the S. Bodenburg Loop Road and then tied together. This cross section survey information was taken and compared to the LiDAR data as a quality check on the LiDAR. The comparison showed a discrepancy between the points (GEOID99 Orthometric Heights compared to the NAVD88 leveled elevations) of slightly greater than 2 meters (2.017 meters average). After rectifying the sets of data by this height, the data varied by no greater than 25 mm (nearly 1 inch). This verifies that the two data sets had an overall vertical shift rather than a warping or tilted data. The correlation provides confidence to the accuracy of the LiDAR data.

## Conclusion

The LiDAR and survey information do not rectify perfectly, however, vertical adjustments validate the LiDAR data and enables the data to be used with confidence for the purpose of the study.

Nick Smith
Engineer


APPROXIMATE LOCATIONS OF EXISTING BANK PROTECTION
(1) EXISTING BANK ARMOR FOR BRIDGE APPROACH
(2) EXISTING RIP-RAP DIKE
(3) EXISTING LAUNCHED HARD POINT
(4) EXISTING ROCK GRAINS
(5) EXISTING GRAINS AT WASTEWATER TREATMENT PLANT
(6) EXISTING ROCK TOE PROTECTION AT SKY RANCH SUBDIVISION
LEGEND
SAMPLE LOCATION
Source: DOWL ENGINEERS DECEMBER 2003 MATANUSKA RIVER CROSS-SECTIONS
SCALE IN FEET
1000 0 1000
1
2
3
4
5
6
A
A'
B
B'
MATANUSKA RIVER EROSION ASSESSMENT PROJECT OVERVIEW MAP

# MATANUSKA RIVER EROSION ASSESSMENT

## Design Study Report – Final

## VOLUME I: REPORT

MWH Job No. 1851040.010107

View of Matanuska River – Winter 2003

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MWH USDA NRCS

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| | |
|---|---|
| °F | degrees Fahrenheit |
| cfs | cubic feet per second |
| EPA | U. S. Environmental Protection Agency |
| GIS | Global Information System |
| LiDAR | Light Detection and Ranging |
| Mat-Su | Matanuska-Susitna |
| mg/L | milligrams per liter |
| mm | millimeter |
| NAAQS | National Ambient Air Quality Standards |
| **nhc** | Northwest Hydraulic Consultants |
| NRCS | Natural Resources Conservation Service |
| O&M | operation and maintenance |
| USFWS | U.S. Fish and Wildlife Service |
| USGS | U.S. Geological Survey |
| WWTP | wastewater treatment plant |

# EXECUTIVE SUMMARY

In response to community concerns of bank erosion along the Matanuska River, Alaska, the U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS) was granted funding from the U.S. Congress for a study of river processes and an assessment of options to control the erosion. NRCS awarded a contract to MWH through a competitive process to conduct this study and assessment. The MWH project team included additional expertise from Northwest Hydraulics Consultants, and Northern Economics, Inc. The Study Area encompasses the river floodplain and adjacent riparian lands on both sides of the river from the Old Glenn Highway Bridge downstream approximately 6 miles, through the Bodenburg Butte area. The project team conducted the evaluation from October 2003 through November 2004.

## RIVER PROCESSES

Initial steps involved reviewing the river processes and transport capabilities, using available historical information, and quantifying watershed characteristics, sediment loading, flow velocities, and geology. In addition, other background analyses including permitting processes, land use controls, and markets for gravel materials were performed. This background information was compiled in a series of technical memoranda, which are included as Volume II – Appendices. The investigation concentrated on the flow, river morphology, and sediment transport capabilities of the Matanuska River and what changes to the river may possibly be applied to affect erosion control.

Braided rivers like the Matanuska River have a complex, transient morphology characterized by flows that diverge and converge around major assemblages of emergent bars and vegetated islands. The splitting and re-joining of flow paths around channel deposits results in a very dynamic rate of channel activity relative to other types of channels.

Based on field investigation and modeling information, the MWH project team calculated the long-term average gravel replenishment rate for the Matanuska River at approximately 420,000 tons per year. Sand sized material dominates the suspended load at discharges less than 3,000 cubic feet per second (cfs), but there is a dramatic increase in the silt and clay fraction above that flow rate in conjunction with runoff from headwater glaciers. The daily discharge varies over a year from approximately 500 to 15,000 cfs, with occasional peak midsummer flows ranging from 20,000 to 30,000 cfs.

## ALTERNATIVE EROSION CONTROL METHODS CONSIDERED

Using this background information, the project team and NRCS jointly developed several alternatives for affecting erosion control. Each action alternative was considered to have a reasonable likelihood to control the bank erosion to threatened areas along the riverbank. Numerous other alternatives were eliminated from further consideration based on construction feasibility, effectiveness to this size and type of river, and/or other factors. Alternatives that were considered include:

- Alternative 1 – Gravel Removal

- Alternative 2 – Bank Protection
- Alternative 3 – Non-Structural Approach
- Alternative 4 – Combined Actions
- Alternative 5 – No Action

**Gravel Removal**. This method has been considered in the Study Area previously, but without an in-depth examination of the changes that may occur downstream, the size of excavation needed to affect the channel morphology, relative costs, and environmental consequences. The project team used computer modeling to estimate the effect of the channel excavations on flow pattern, hydraulic characteristics and sediment transport in the Study Area under various discharge rates. Results indicate that excavation trenches can be successful in reducing the velocity of the flow along the riverbanks, if careful consideration is given to the location and design of the excavation. Since braided channels, such as the Matanuska River, are subject to rapid shifting in response to sediment erosion and deposition, the trenches would need annual maintenance and adaptive management to remain stable and effective. The gravel removal excavations can reduce bank erosion, but will not eliminate the need for bank erosion protection of key facilities, properties, and locations of direct flow impingement on the bank.

Challenges include constraints imposed by fish migration, spawning, and rearing; cold weather operations during low-flow periods; and controlling flows to optimize access and excavation techniques.

**Bank Protection.** Spur dikes and riprap methods have both been used previously to provide bank protection along the Matanuska River. These methods have proved to be effective in providing erosion protection along the portion of riverbank where they have been applied. The existing spur dikes were installed near the Circle View Estates subdivision in 1991 and have withstood flows up to approximately 40,000 cfs. As has been the experience with the existing spur dikes, construction logistics and maintenance are challenges in the dynamic river environment. Furthermore, these methods are limited to the specific location where they are applied. Similar to those posed by gravel removal, flows affecting banks upstream or downstream of the bank protection would remain susceptible to bank erosion, and the effectiveness of the protection may be eliminated if the channel shifts away from the protected section of bank.

**Non-Structural Approach.** This method involves using land use controls to remove or minimize the human occupation along threatened portions of the riverbank. Public purchase of private property and regulatory mechanisms, including zoning restrictions, are potential approaches. While this alternative does not provide any protection of the bank to erosional forces, it removes the direct effect on the inhabitants in the area. Challenges include resistance from the community and the ability to enforce zoning restrictions.

**Combined Actions.** This method involves a combination of gravel removal, bank stabilization, and land buyout or set asides of selected areas. This alternative addresses the likelihood that each of the other alternatives is only feasible in specific locations. For example, due to the dynamic characteristics of the Matanuska River, the gravel removal option is not likely to provide bank protection in all areas of the river. The excavation should take place in reaches prone to high velocities and shear stresses that undermine the bank and cause erosion, such as the lower portion of the Study Area. Spur dikes and riprap would be placed where the bank erosion risk is greatest. The non-structural policies would be applied to those areas that are currently undeveloped.

**No Action.** This method does not provide any protection to the community or the riverbanks. The alternative was evaluated on the basis of land value loss due to annual erosion.

## COMPARISON OF ALTERNATIVES

In comparing the alternatives, the feasibility and costs must be addressed. The feasibility of each alternative is tied directly to the technical difficulty in implementing the alternative, the potential environmental consequences and associated permitting constraints, and the political ramifications.

**Feasibility.** A summary of the feasibility of each alternative is presented in Table ES-1. The alternative with the highest technical complexity is gravel extraction. Numerous operational issues are related to a large gravel removal operation in an active floodplain. To be effective, nearly 1.8 million cubic yards of material would have to be removed during initial construction. Additionally, annual excavation on the order of 500,000 tons of material would be needed to maintain the trenches once constructed.

**Table ES-1 Comparison of Feasibility of Alternatives**

| Alternative | Bank Protection Effectiveness | Technical Difficulty | Institutional Feasibility | Inspection And Maintenance Requirements |
|---|---|---|---|---|
| Gravel Removal | Moderate | High | High permitting constraints | Continuous/High |
| Bank Stabilization (riprap and spur dikes) | High | Moderate | Moderate permitting constraints | Yearly/Moderate |
| Non-Structural Approach | Low | High | Local authorization (City and Borough) needed; Highly political. | Infrequent/Low |
| Combined Actions | Highest | High | High permitting constraints; many stakeholders involved. | Continuous/High |
| No Action | Low | Low | Locally controversial | None |

Fish and aquatic wildlife resources are a principal concern in comparison of alternatives. However, baseline data on the fish resources of the Matanuska River are sparse. Sport, commercial, and subsistence fisheries on the Matanuska River are limited compared to other Southcentral Alaska streams. Permit constraints are likely to include limiting operations in the floodplain to periods of low flow and minimal fish migration. This constraint adds another level of difficulty to gravel extraction operations, as well as some constraints to construction of bank stabilization structures.

Both the Non-Structural and No Action Alternatives have potential political ramifications. The Non-Structural Alternative is likely to be difficult to implement in those areas with current development, due to resistance from the community to be bought out or relocated. The No Action Alternative does not result in protection to the community or the riverbanks. This alternative, while simple and relatively easy to implement on a technical standpoint, would not address the public concern that resulted in this study.

**Cost.** In comparing the cost of each alternative, assumptions were established to provide some basis of comparison. For gravel removal and construction of bank stabilization structures, cost estimates included assumptions on the type of equipment, hours of use, size and type of material, and value of the gravel. The Non-Structural and No Action alternatives make assumptions on the value of developed and undeveloped land, and the amount of land that would be lost per year.

The costs for implementing the Gravel Removal, Bank Stabilization, or the Combined Action Alternatives are relatively high (Table ES-2). This relates directly to the construction required to implement each alternative. The Non-Structural Approach Alternative has a relatively low cost, both initially and over the long-term (50 years). The Non-Structural approach, however, may have high political ramifications, as may the No Action Alternative, which has the lowest cost of all the alternatives.

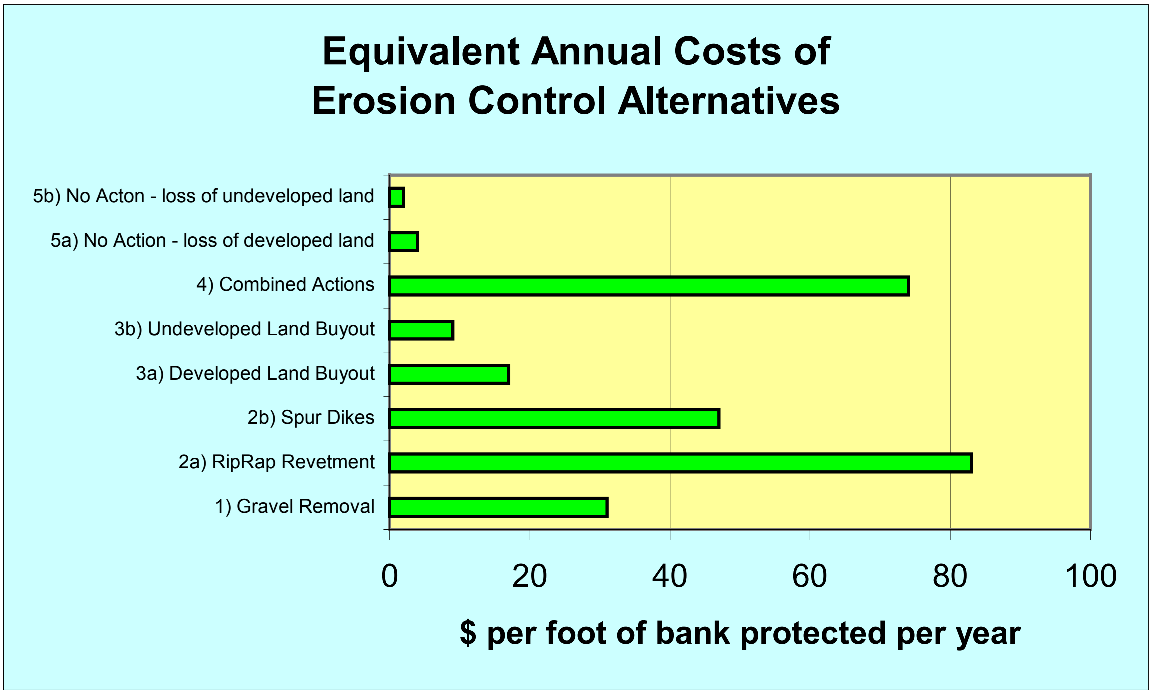
**Table ES-2 Comparison of Costs of Alternatives**

| Alternative | Initial Capital Cost ($/ft) | Equivalent Annual Cost ($/ft/yr)[1] |
|---|---|---|
| 1. Gravel Removal[2] | 661 | 31 |
| 2. Bank Stabilization | 1,236 (major riprap)<br>706 (spur dikes) | 83<br>47 |
| 3. Non-structural Approach[3] | 248 (developed land)<br>135 (undeveloped land) | 17<br>9 |
| 4. Combined Actions | 804 | 74 |
| 5. No Action | None | 4<br><br>2 |

Key:
1 – Based on a current value of 4 percent over a 50-year period.
2 – Annual cost is offset by revenue from sale of gravel.
3 – Assumes that this approach is applied to the entire Study Area, costs will vary for specific locations.
$/ft – dollars per foot
yr – year

Relative equivalent annual costs of the five erosion control alternatives are illustrated on Figure ES-1. The figure illustrates that the cost of any action alternative exceeds the estimated costs associated with allowing the continued loss of property due to erosion. Buyout of property has the lowest cost of any of the action alternatives, with higher costs associated with gravel removal and structural improvements.

**Figure ES-1 Equivalent Annual Costs of Erosion Control Alernatives**




## IMPLEMENTATION OF EROSION CONTROL MEASURES

Each of the alternatives considered in this evaluation has difficult issues associated with it. Costs for reducing erosion potential are considerable, and require appraisal of the benefits to the landowners or public at-large compared to potential commitment of funds.

The decision to move forward with an action plan requires the identification of an entity to lead the effort. The Matanuska Susitna Borough has implemented improvements in the past, but has not been able to muster public support for continual ownership and maintenance of a large-scale program. The Borough does have power to establish a service for implementation of capital improvements and maintenance costs associated with erosion protection. The State of Alaska would have significant interest as the land manager of the riverbed, owner of materials, and permitting agency. The Federal Government has no direct interest or mandate to offer any of the alternatives, although payback could be a source for funding through political channels. Private interests do not look like a solution due to the expense of infrastructure development required to achieve payback. Close consideration and public input is needed before a recommendation for action is developed.

# 1.0 INTRODUCTION

This section presents the need for action, land use, an overview of the project, a summary of background information and data collection, and closes with an introduction to the preliminary design concept phase of the work.

## 1.1 PURPOSE AND NEED

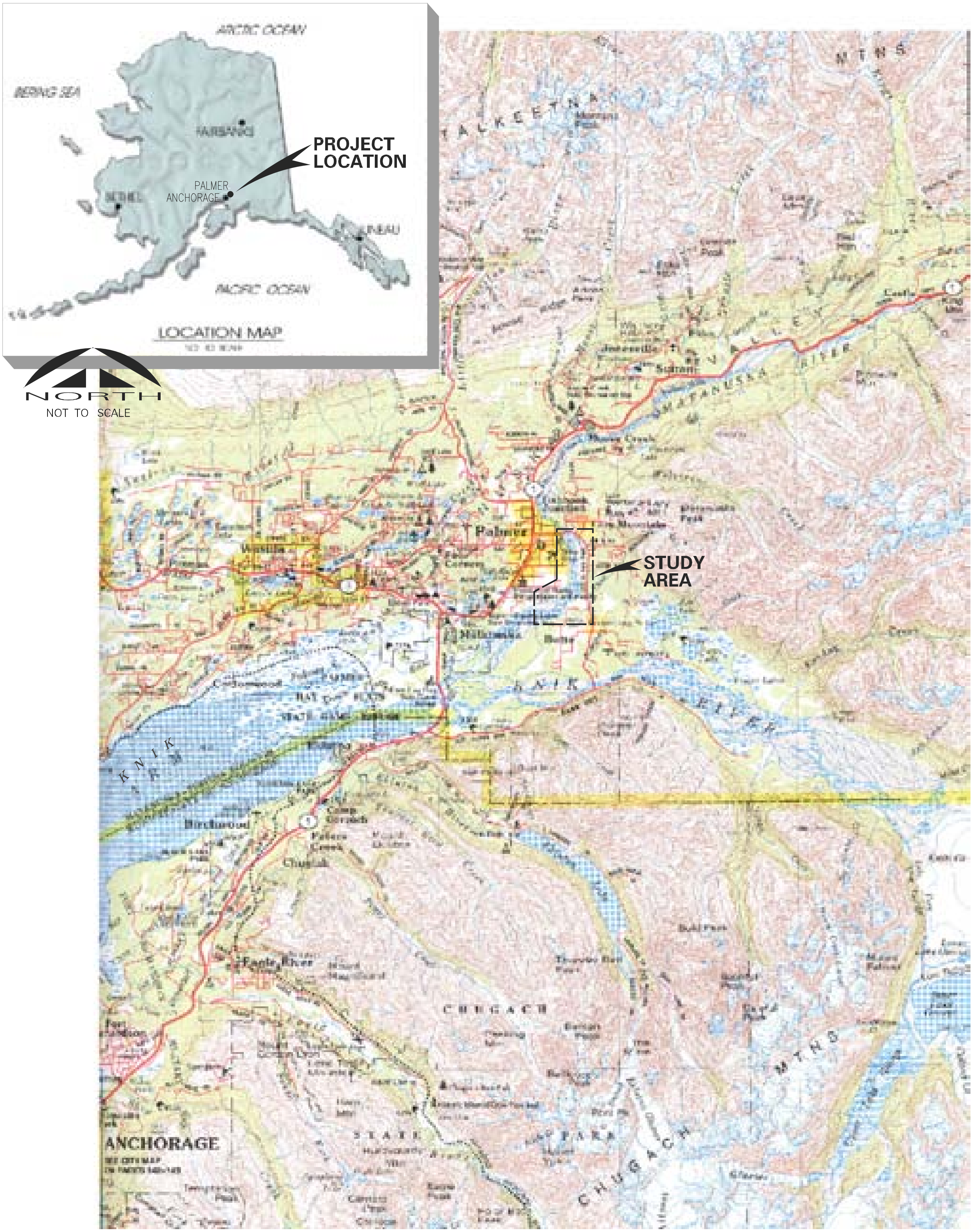
Since establishment of the Matanuska Colony in the 1930s, residents of the Matanuska Valley have enjoyed a rural lifestyle under the grandeur of Pioneer Peak, Lazy Mountain, and other peaks of the Talkeetna and Chugach Ranges (Figure 1-1). Within this valley is the magnificent Matanuska River, with typical midsummer flows reaching 30,000 cubic feet per second (cfs) or more, and carrying a tremendous burden of sediment from the Matanuska Glacier and the upper valley. As the river approaches Palmer and Bodenburg Butte, the stream gradient lessens and sediment is deposited, sometimes accumulating so rapidly that the water is abruptly forced to seek a new watercourse.

The resulting braided channel is characterized by a high width to depth ratio, and a propensity to migrate horizontally in relatively short time periods, eroding the toe of the banks on the margins of the floodplain. As the toe of the banks is attacked by the river, sloughing occurs and property at the terrace level is sacrificed to the river bottomlands, which are under ownership of the State of Alaska. Structures are also at risk, as sloughing of the banks undermines foundations of buildings and utilities. Over the years, structures and acres of farmlands have been swallowed by high water eroding the streambank. This ongoing erosion and threat to structures and land necessitated a closer look at erosion control options and the potential for success, as described in detail in this report.

## 1.2 LAND USE

Land use varies on the east side of the Matanuska River near Palmer. The Old Glenn Highway parallels the river along the eastern side, from the bridge to Bodenburg Butte. Near the Old Glenn Highway, the area is primarily residential, with some small businesses and agricultural use. The area downriver remains primarily residential, with some farming. A power transmission line owned by Matanuska Electric Association extends across the river from the Circle View Estates area towards the City of Palmer.

On the western side of the Matanuska River lies the City of Palmer and the Palmer Airport. The airport is in relatively close proximity to the Matanuska River, although it does not appear to be in imminent danger from erosion. Farther downriver, but still within the City of Palmer, is the Palmer Wastewater Treatment Plant (WWTP). This treatment plant was threatened by erosion prior to the mid- to late 1980s, when the active channel was located on the west side of the river. With the exception of the WWTP and a small gravel pit, land use along this area of the bank is typified by residential use.




MWH
Anchorage, Alaska

FIGURE 1–1

USNRCS
MATANUSKA RIVER EROSION ASSESSMENT – DESIGN STUDY REPORT

**LOCATION AND VICINITY MAP**

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## 1.3 PROJECT OVERVIEW

MWH was contracted by the U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS) to evaluate erosion problems along the Matanuska River near Palmer, Alaska. The Study Area extends from the Old Glenn Highway Bridge to the tidal influence zone near the confluence with the Knik River (Figure 1-2). MWH was tasked with assessing the erosion along the Study Area and evaluating potential long-term solutions to minimize future erosion problems. Northwest Hydraulics Consultants (**nhc**) and Northern Economics were subcontracted by MWH as part of the team for this study. The work was divided into two phases in order to ensure a scientific approach to the problem of erosion control, as discussed below.

### 1.3.1 Phase 1 – Background Information

The first phase of work primarily involved data collection and background information. Numerous documents exist that examine the Matanuska River. The majority of available literature dates back to the early 1980s, with some documents dated as early as 1972 (Appendix A). Existing literature encompassed newspaper articles to reports on the design and installation of the existing bank protection (spur dikes). These reports included a variety of information on the history of the river and areas threatened by erosion.

#### 1.3.1.1 Field Information

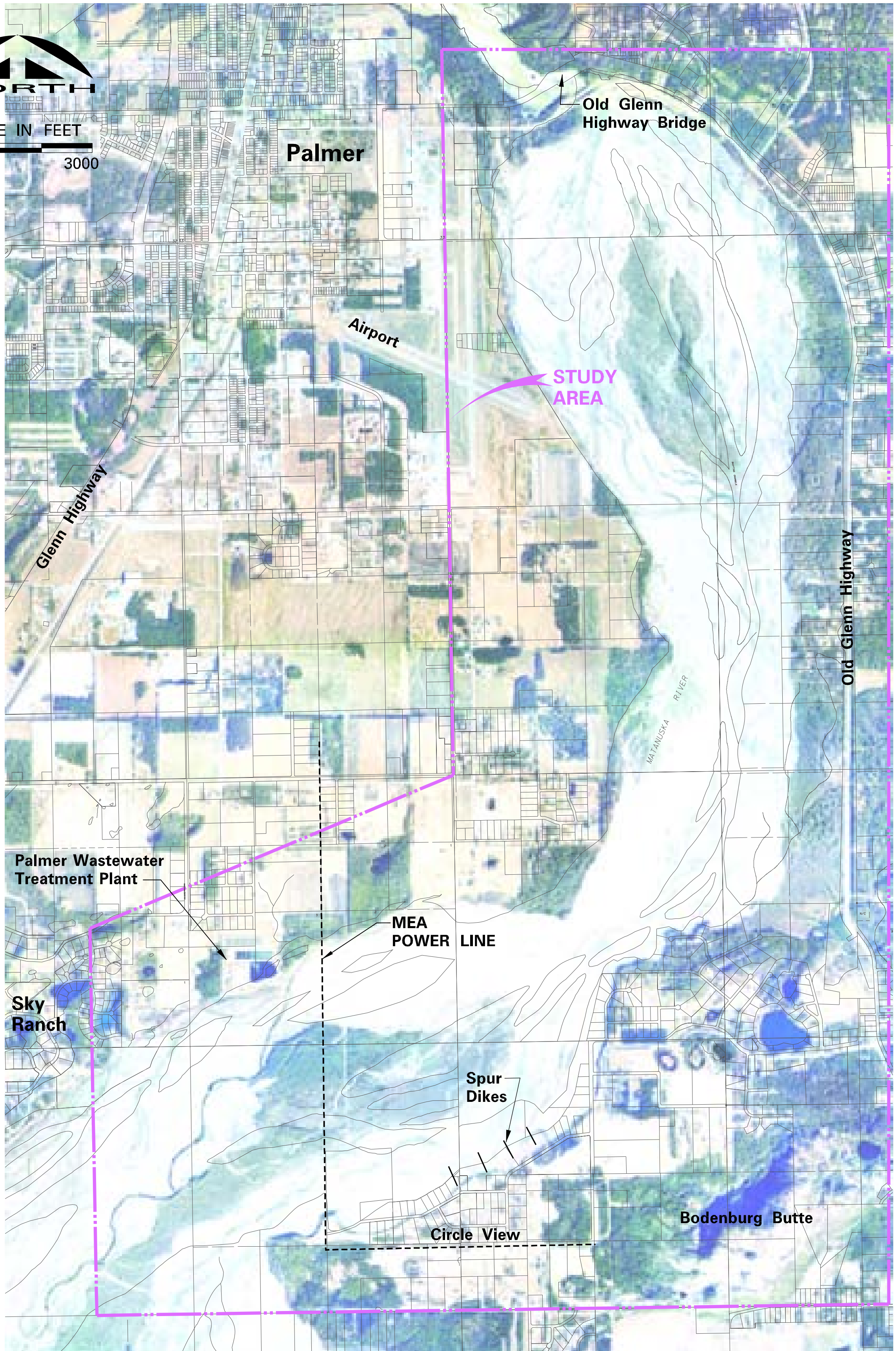
Field investigation included several steps: field reconnaissance, survey data, and sediment data gathering. First, MWH, **nhc,** and NRCS personnel conducted the field reconnaissance as the initial step in understanding the river hydraulics (Appendix B). Second, a topographical survey of the Matanuska River was conducted along the Study Area using Light Detection And Ranging (LiDAR), combined with field surveying techniques. The survey data included detailed mapping and profiles of the channel, which were used as base profile information for later modeling efforts and added to the understanding of channel morphology.

Lastly, the field investigation included sampling of the bedload sediment (Appendix C) and observations on surface material. This investigation was conducted to determine the type of material present in the channel, the propensity for material transport (based on its size), and to gain a better understanding of the river hydraulics.

#### 1.3.1.2 Background Information

The next piece of background information collected was hydrologic data. MWH gathered information and evaluated the watershed characteristics, streamflow patterns, and precipitation data, among other information (Appendix D). This data shows how the watershed and river respond to climatic change, especially temperature and precipitation.

Information from the existing literature, field investigations, hydrologic analysis, and the survey and LiDAR data were gathered together in order to conduct a channel hydraulic analysis. The analysis was conducted using the HEC-RAS 3.1 one-dimensional flow model, developed by the Hydrological Engineering Center, U.S. Army Corps of Engineers (Appendix E). This evaluation was used to develop boundary conditions for the two-dimensional model in Phase 2.

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MWH
Anchorage, Alaska

FIGURE 1–2

USNRCS
MATANUSKA RIVER EROSION ASSESSMENT – DESIGN STUDY REPORT

**MATANUSKA RIVER STUDY AREA**

Channel stability analysis was then conducted by **nhc** using the above information and additional site inspections (Appendix F). During the summer of 2004, the Matanuska River reached a flow of approximately 40,000 cfs, which resulted in severe bank erosion within the Study Area in the days and weeks following the peak discharge. Observations of the river during this time period added to the understanding of the river flows and erosion patterns for use in modeling potential future river behavior.

Permitting, regulatory, and environmental constraints were also evaluated during Phase 1 to establish potential data gaps. This provided an outline of the potential roadblocks to management activities within the Matanuska River, including the primary agencies that would have involvement in any management activity within the river (Appendix G).

### 1.3.2 Phase 2 – Preliminary Design Concepts

MWH and **nhc** evaluated the information gathered in Phase 1 for feasibility and the potential for successful erosion control on the Matanuska River in the Study Area. There are numerous elements of the Matanuska River that will define the requirements for an effective erosion control scheme. The key features of the Matanuska River are summarized below.

**Bank erosion near a powerline.**

**River Characteristics.** The Matanuska River is typical of a glacial fed river. There are wide, highly braided reaches with vegetated islands separated by narrower, more stable zones. The multiple channels in the wide braided reaches will continue to sweep across and fill (or partly fill) the braided surface. The narrower sections are controlled by the presence of less erodable materials in the riverbank. Braided streams are characterized by a high sediment load carried during certain times of the year (associated with high flow levels), and limited sediment transport during low flow periods. Total sediment load carried by the river is comprised of suspended sediment and bed loads.

**Suspended Sediment Load.** Suspended sediment load is the material in the river flow that will not settle out in the Study Area. The suspended sediment is broken into suspended sand load and total annual suspended load. Average annual suspended sand load is estimated at 1.63 million tons per year (**nhc**, June 2004). The total suspended load is estimated to be 6.65 million tons annually. Therefore, silt-clay material comprises nearly 80 percent of the total suspended material, with sand comprising approximately 20 percent.

**Bed load material**

**Bed Load.** Bed load of the Matanuska River is approximately 7 percent of the total sediment load; therefore, the chance for local deposition to trigger avulsions (changes in channel direction and form) is also high. The estimated annual average bed load amounts to 0.5 million tons of material per year. This material ranges in size from fine sand to coarse gravel. Based on a review of the channel profile and available bed material samples, it is believed the Study Area can be nominally considered a “transport reach,” with increasing deposition as the river flattens and approaches the tidally influenced zone near the river mouth.

**Channel Sediments.** The channel deposits contain an appreciable amount of sand, up to approximately 20 percent in some samples. This implies some of the suspended sand load could be deposited in excavations, if gravel removal is used for erosion control.

These factors were taken into consideration in development of the alternatives presented in Section 3. They were used to determine which of the considered alternatives should be excluded from further analysis.

## 2.0 THE AFFECTED ENVIRONMENT

This section describes the physical, biological, and human environment of the Study Area. The information in the sediment transport subsection of the physical environment is particularly important for the formulation of project design concepts and alternatives.

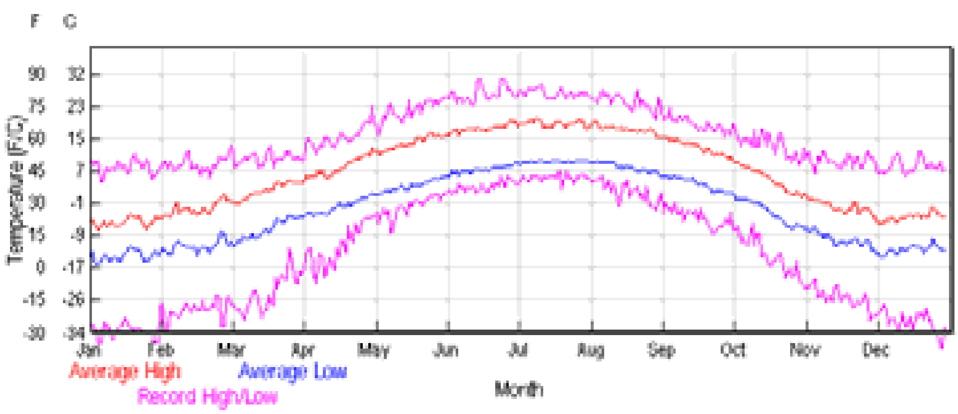
### 2.1 PHYSICAL ENVIRONMENT

This subsection describes the climate, air quality, physical features, hydrology, and sediment transport. Information on geology and soils is included in the physical features subsection. Sediment load is described in the subsection on sediment transport.

#### 2.1.1 Climate

The Study Area is within the Matanuska-Susitna (Mat-Su) Borough, just outside the city limits of the City of Palmer, Alaska. The number of daylight hours in the Palmer area ranges from about 5 to 19 per day. The climate is considered "mild coastal," with temperatures ranging from 6 to 67 degrees Fahrenheit (°F). The average temperature in December and January is 13°F, with the average temperature in July and August at 58°F (Mat-Su, 2003). A graph of the average temperatures (www.weatherunderground.com) for the area is shown on Figure 2-1.

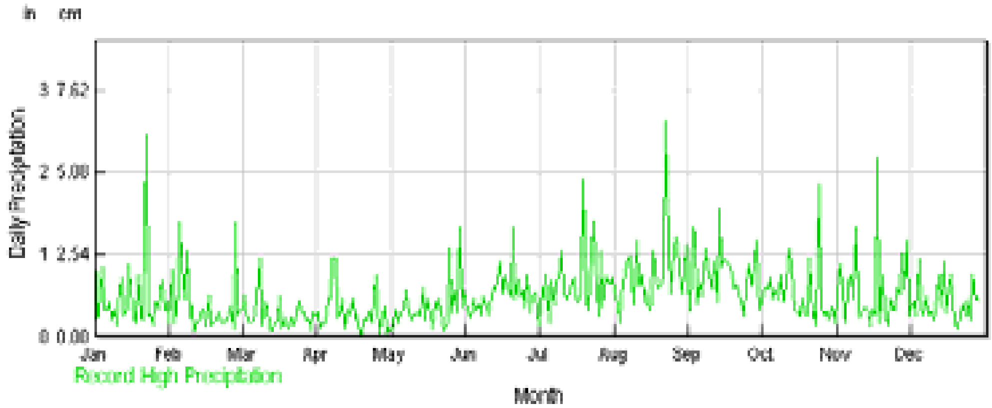
**Figure 2-1 Average Temperatures and Records for Palmer**




The Alaska Range and the Talkeetna Mountains to the north and Chugach Mountains to the south protect the Matanuska Valley from the extreme winter cold of the Alaska Interior. Thawing temperatures can occur in midwinter under the occasional invasion of warm maritime air from the south and southwest. Normal winter patterns result in little snow and primarily clear skies.

The area averages 16.5 inches of precipitation per year, with the highest average monthly rainfall at 2.65 inches and the highest average monthly snowfall at 9.3 inches. A graph illustrating the distribution of precipitation producing events is shown on Figure 2-2.

**Figure 2-2 Record Daily Precipitation for Palmer**




### 2.1.2 Air Quality

In compliance with the 1970 Clean Air Act and the 1977 and 1990 Amendments, the U.S. Environmental Protection Agency (EPA) promulgated the National Ambient Air Quality Standards (NAAQS) and regulations. NAAQS have been issued for six "criteria" pollutants: sulfur oxides, carbon monoxide, ozone, nitrogen oxides, lead, and inhalable particulate matter. Alaska has adopted the federal NAAQS.

The Study Area is in the Cook Inlet Intrastate Air Quality Control Region, which is designated as unclassified for the six criteria pollutants. The area is also within a Class II airshed designated by the Alaska Department of Environmental Conservation under 18 Alaska Administrative Code 50.015. Class II airsheds are generally free of pollution and may accommodate some industrial activity.

Although some industrial activity exists, air quality in the Study Area is considered good. Localized emissions of particulate matter, carbon monoxide, sulfur oxides, nitrogen oxides, and hydrocarbons are possible. EPA data for the Mat-Su Borough, where the Study Area is located, indicated that 152,902 total tons of emissions were released into the air during 1999. Table 2-1 presents the breakdown of emission types.

**Table 2-1 Air Emissions in the Mat-Su Borough**

| Emission Type | Tons (in 1999) |
|---|---|
| Particulate matter <2.5 micrometers in size | 10,013 |
| Particulate matter <10 micrometers in size (inclusive) | 23,094 |
| Carbon monoxide | 116,915 |
| Volatile organic compounds (hydrocarbons) | 7, 129 |
| Others (Nitrogen oxides, sulfur dioxide, ammonia) | 5,764 |

Key:
< – less than

The Mat-Su Borough is growing in population and economy. An increase in the amount of emissions is expected with growth; however, it has not been quantified for the area. In addition, the area is subject to smoke from wildfires and dust particles entrained in the air from the floodplain.

### 2.1.3 Physical Features

Physical features are presented below as topographic or geologic.

#### 2.1.3.1 Topography

The Matanuska River valley lies between the Talkeetna Mountain Range to the north, and the Chugach Mountains, to the south and east. Portions of the upper reaches of both the Talkeetna and Chugach Mountain tributaries to the Matanuska River are covered with glaciers, so stream tributaries to the Matanuska River may be glacial or non-glacial in origin (MWH, 2004d). The primary glacier in the watershed is the Matanuska Glacier, which begins above Norway Peak and extends to Lion Head. The average elevation of the drainage is 4,000 feet, and it encompasses over 2,000 square miles.

The lower portion of the Matanuska River, starting near the Old Glenn Highway Bridge in Palmer, is typified by a broad, braided floodplain. Bedrock outcroppings constrain the river at several locations, with the channel being influenced by several active fault lines. The sandy gravel channel banks allow for significant lateral migration of the river bottom across the floodplain. In some areas, the floodplain is up to 1-mile wide. As shown in the photo to the right, the channel meanders across the floodplain, with possible changes in the main channel location based on snowmelt and storm events.

#### 2.1.3.2 Geology

The lower Matanuska Valley lies in a structural trough that trends northeast-southwest. The northwest border of the trough is defined by the Castle Mountain Fault, along which older rocks of the Talkeetna Mountains (mostly Cretaceous and tertiary-age granitic intrusives and sedimentary rocks) (LaSage, 1992) have been thrown up against younger rocks on the valley floor (Barnes, 1962). The Chugach Mountains are composed of Cretaceous-Jurassic metasedimentary and metaigneous rocks. The Talkeetna Mountains are composed of granitic and gneissic rocks (MWH, 2004d).

Faulting occurs throughout the region. Major faults include the Castle Mountain Fault in the Talkeetna Mountains to the north, and the Border Ranges fault in the Chugach Mountains to the south (ADNR, 1998). Folding and faulting has deformed the rocks of the valley floor. The

March 27, 1964, earthquake caused regional subsidence of about 2 feet in the lower third of the valley (Plafker, 1969).

Younger deposits in the basin are the result of the last major ice expansion. Glacier drift, including till, was deposited over scoured bedrock and, as the ice receded, ice-contact deposits such as kames, eskers, and crevasse fills produced uneven terrain. Winds in the lower valley resulted in aeolian deposits northwest of the mouth of the river (Trainer, 1961).

The Matanuska River flows through a variety of deposits. Glacial outwash deposits are common and consist of primarily stratified sediments, chiefly sand and gravel with some silt and clay intermixed. Outwash is characteristically removed or washed out material from a glacier by meltwater streams and deposited in front of or beyond the terminal moraine or the margin of the active glacier. Materials generally grade to a finer texture with increasing distance from a glacial source (ADNR, 1998).

Other deposits present in the Matanuska Valley include moraines, glacial drift (material deposited by the glacial ice), floodplains, terraces, and alluvial fans. Glacial drift is an unsorted and unstratified mixture of clay, sand, gravel, and boulders. Floodplain, terrace, and alluvial fan deposits are typically well stratified silt, sand, and gravel (ADNR, 1998).

#### 2.1.3.3 Soil Classification

A sediment investigation was conducted in December 2003 to characterize the material present in the Matanuska River channel bottom (MWH, 2004b). Samples were collected at two cross-sections within the Study Area (Figure 2-3) and sieve analyses conducted. Sieve results indicated that the subsurface material is relatively uniform at both cross-section locations. An average $D_{90}$ value of 37.13 millimeters (mm) and a $D_{50}$ of 11.71 mm was identified along the channel. The $D_{90}$ value represents the grain size where 90 percent of the sample (by weight) passes the given size class. Investigation results also indicated that cobbles are only apparent along the active channel. Coarse gravel was the predominant surface material identified. Sediments that are cobble and gravel size are primarily quartz and granite.

### 2.1.4 Hydrology

Hydrology is presented from both a water quantity and quality perspective.

#### 2.1.4.1 Water Resouces – Quantity

USGS Stream Gage #15284000 is located on the Matanuska River at the Old Glenn Highway Bridge in Palmer. Daily mean average flows are available from the gauge for water years 1950 through 1972, 1986, 1992, and 2002, with partial records for 1973 and 2000. Figure 2-4 shows the daily discharge from 28 years of records, compared to daily discharge record from 2004. Discharge typically varies seasonally from approximately 500 to 15,000 cfs during higher flows. A peak flow of 82,100 cfs occurred in 1971, but this reading was affected by the failure of a lake embankment on Granite Creek, a tributary of the Matanuska River (ADNR, 1998). The historic peak discharge, for the USGS record through 2001, actually occurred in 1995, with a discharge

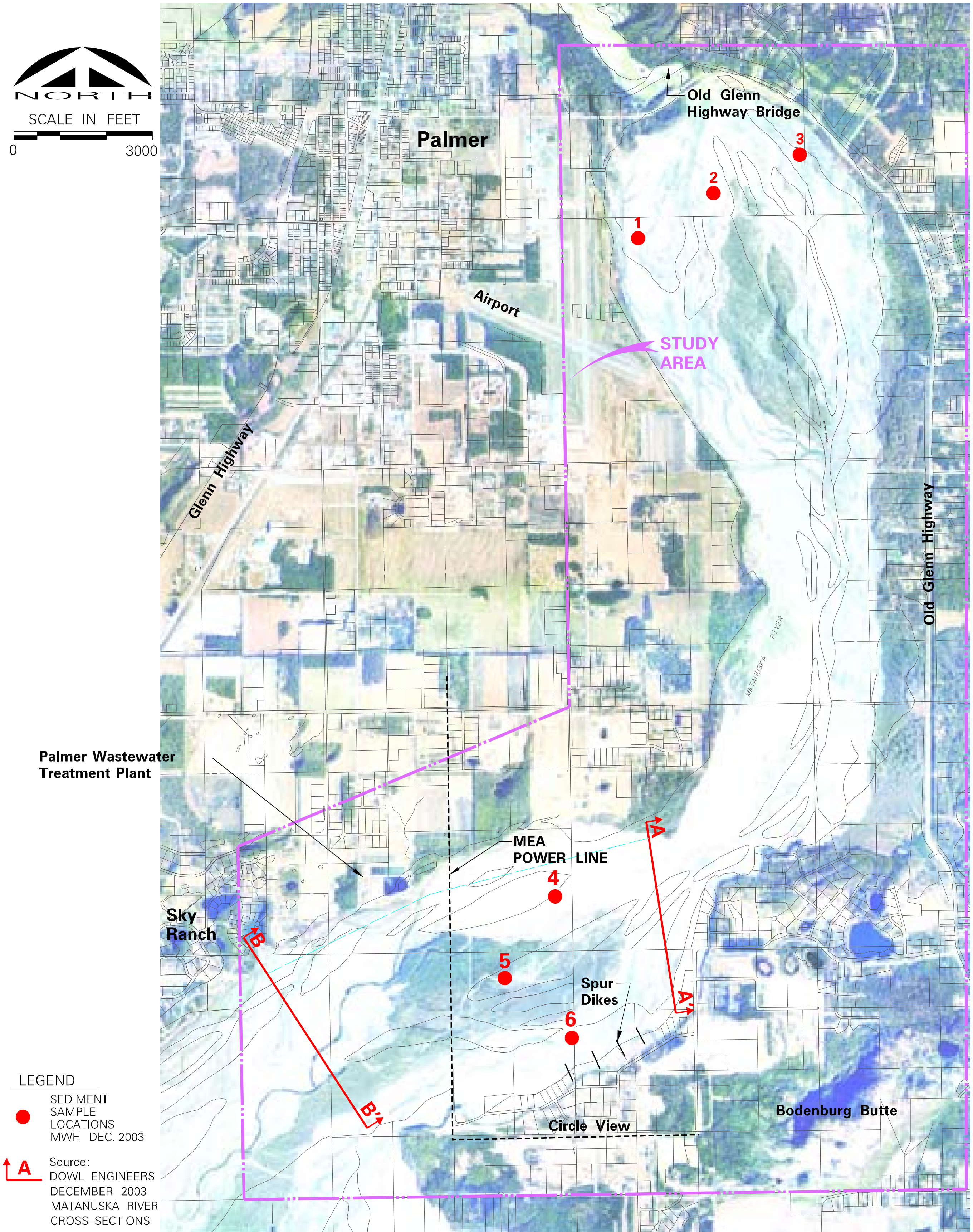



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FIGURE 2–3

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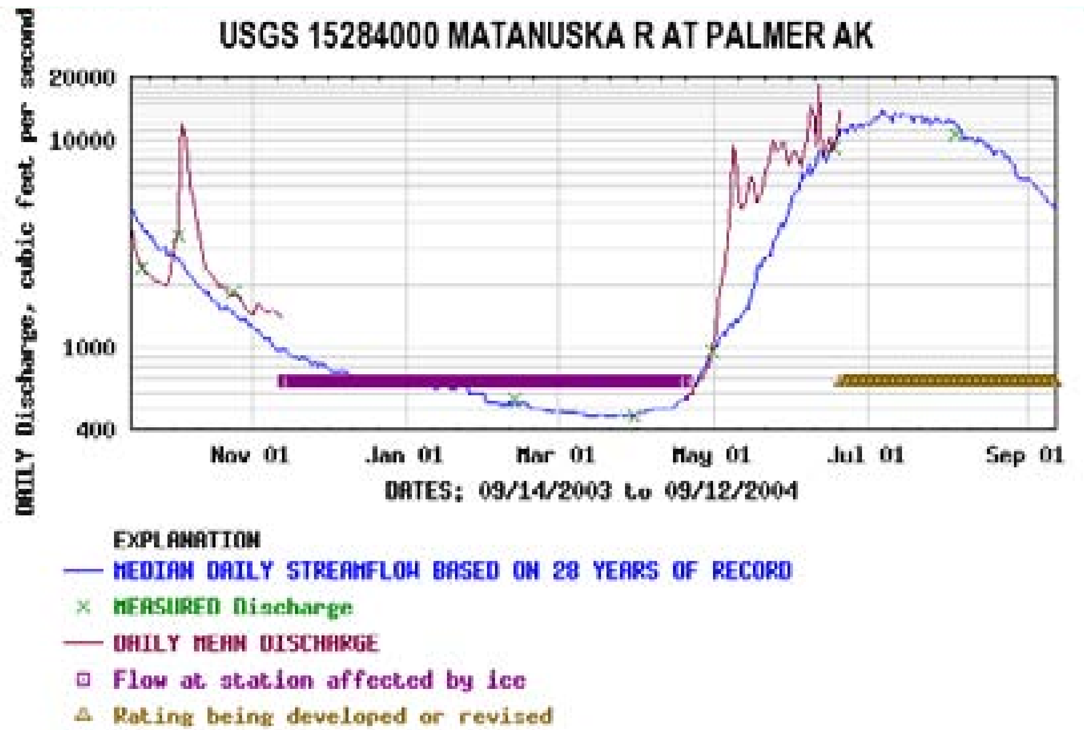
**SEDIMENT SAMPLE AND CROSS–SECTION LOCATIONS**

of approximately 46,000 cfs. A higher historical peak discharge may have taken place during the July 2004; however, this data is provisional and not included in Figure 2-4.

**Figure 2-4 Daily Discharge in the Matanuska River at Palmer**




The quantity of water in the Matanuska River is highly dependent on both precipitation and the melt rate of the upland glaciers. Streamflow shows a strong seasonal variation, with 70 percent of the annual flow occurring from June through August (MWH, 2004d). Mean monthly flows are lowest during March and April, with discharges of approximately 450 to 500 cfs in a typical year. This coincides with the lowest levels of precipitation during the year. During this period, the Matanuska River is closest to its annual baseflow. Groundwater discharge becomes the dominant water supply to the river during this period (ADNR, 1998).

Groundwater flow in the Palmer area trends from the south to the southwest (Jokela et al., 1990; TERRASAT, 1998). Aerial photography interpretation and well log data also indicate that the reach immediately downstream from the Old Glenn Highway Bridge is a losing reach, with water leaving the river along that reach and contributing to the ground water recharge. Along the lower portion of the Study Area, groundwater from the surrounding area adds to the river discharge.

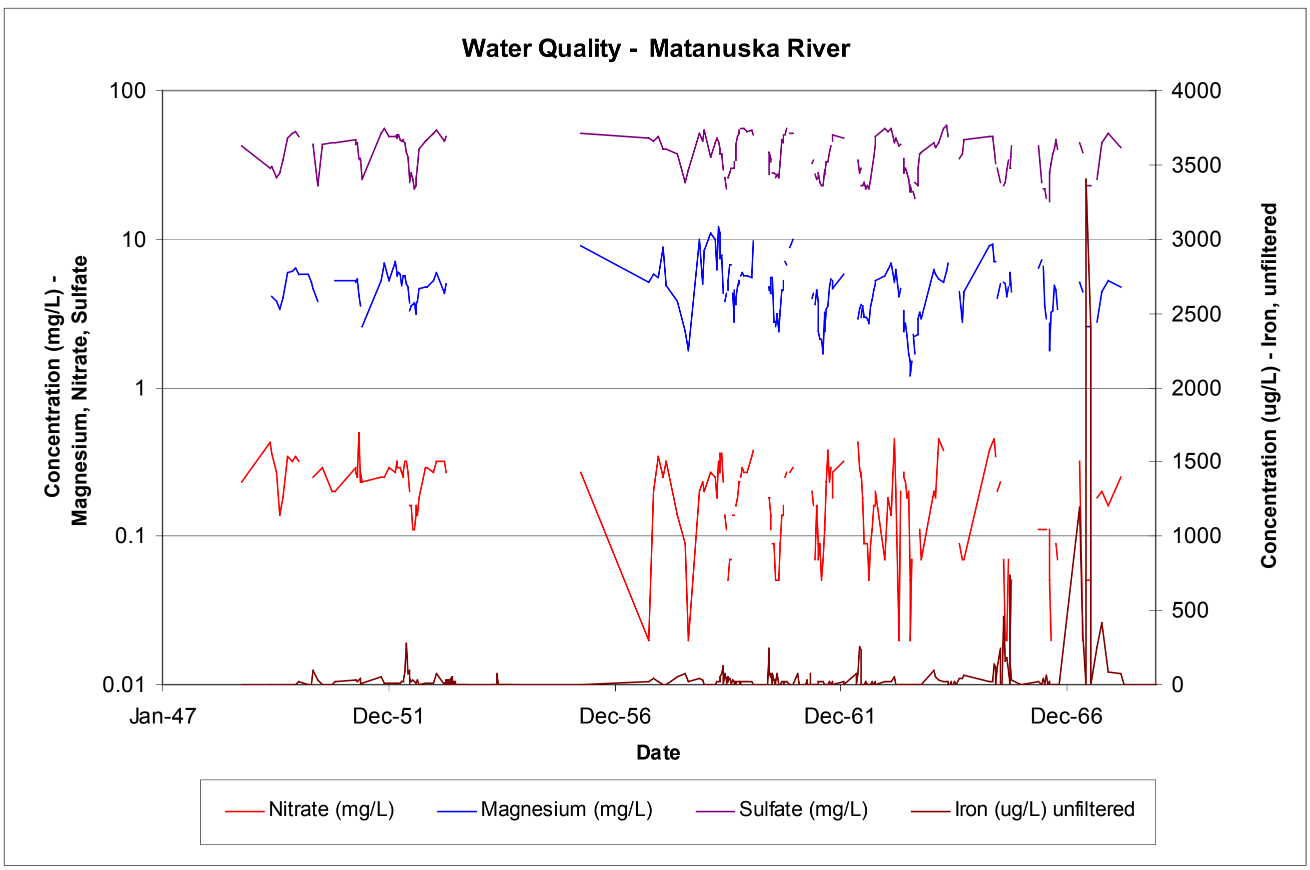
#### 2.1.4.2 Water Resources – Quality

USGS records at the Old Glenn Highway Bridge gauging station provide the majority of the available water quality data for the Matanuska River in the Study Area. The data gathered at this station includes 548 data points for parameter groups such as: basic stream flow, nutrients, major and minor inorganic constituents, and physical and sediment properties. Most of these records are inadequate for use in evaluating the water quality of the watershed. Water quality parameters with importance in watershed evaluation, in addition to apparently adequate records, included discharge, specific conductance, nitrate, magnesium, sulfate, iron, and suspended sediment. Most of these records span the years from 1948 to 1954, 1957 to 1968, and then only periodic measurements through 2003. Based on the other parameters with an adequate record, a picture of the water quality variability between 1947 and 1968 can be seen. Data after 1968 is too infrequent to make comparisons.

Likely the most significant water quality parameter for the Matanuska River is the high level of suspended sediment load. Runoff from the Matanuska Glacier drives the transport of sediment derived from the glacier and tributaries throughout the Matanuska Valley.

As shown on Figure 2-5, nitrate, magnesium, and sulfate had adequate records and were used in evaluating the Matanuska River water quality, but these provide only limited information. Magnesium values ranged from 1.2 to 12 milligrams per liter (mg/L), and sulfate ranged from 18 to 58 mg/L. The range of values is higher than expected, considering that glaciers and snowmelt waters do not contribute minerals to the river water. Nitrate values ranged from 0 to 0.56 mg/L, which is relatively low, but also expected since the watershed is 80 percent undeveloped and well vegetated. Iron concentrations increase in the late 1960s; however, the record is inadequate to determine if this is a long-term change.

**Figure 2-5 Matanuska River Water Quality**



Changes in the water quality of the Matanuska River are primarily associated with variations in the quality of the runoff from changes in the intensity, location, and type of uses in the watershed, not from the snowmelt or glacial contributions. An increase in human activities in the watershed can have an effect on the water quality and potential for contaminants. Currently, approximately 2 percent of the watershed is used agriculturally and 8 percent is considered roaded and urban, but this does not consider location.

### 2.1.5 Sediment Transport

The Matanuska Glacier is a principal source of sediment for the Matanuska River. Sediment discharge from the glacier (discharge from meltwater pools) is not coincident with peak discharge. Rather, it appears that the release of coarse sediment from the glacier is more dependent on drainage networks within the glacier ice than on peak discharges (Pearce et al., 2003). Steep, non-glacial tributaries downstream of the Matanuska Glacier, particularly those from the Talkeetna Mountains on the north side of the valley, are thought to contribute significantly more bedload to the river than the Matanuska Glacier. The Matanuska Glacier is likely to contribute more of the suspended load.

#### 2.1.5.1 Sediment Load and Transport

A total sediment budget is the volume of sediment moving past several locations, or gauging stations, along the mainstem of a river system. The total sediment volume is generally made up of suspended load and bedload. The suspended load consists of silt, clay, and sand and does not deposit on the bed of the river. Bedload consists of a portion of the sand load, plus the gravel load, that moves along the bed of the river. It should be noted that the sand load moves both as suspended load and bed load, but predominantly moves as suspended load. In gravel rivers, sediment measurements represent the suspended load, and researchers estimate the gravel (bedload) to range from 0 to 20 percent – depending on river characteristics.

The suspended sediment budget for the Matanuska River at Palmer was originally estimated by **nhc** (January 2004) as 5 million tons per year, with a bedload of 400,000 tons per year based on watershed characteristics. Subsequent technical analysis by **nhc** (June 2004) revised these estimates upwards to 6,650,000 tons per year for total suspended load and 420,000 to 685,000 tons per year for bed load. Annual total sediment load (including wash load) greater than 11,000,000 tons 10 percent of the time, greater than 7,130,000 tons 50 percent of the time, and greater than 4,300,000 tons 90 percent of the time. For the sediment budget analysis, the original 5,000,000 and 400,000 tons per year were used for suspended sediment and bed load, respectively.

The sand load, defined as material coarser than 0.063 millimeters (mm), was estimated to consist of 20 percent of the suspended load. The remaining material comprising the suspended load consisted of silt and clay finer than 0.063 mm. The proportion of sand-sized material dominates at low discharges, below 3,000 cfs, but the silt and clay fraction increases dramatically above this discharge value.

The bed load material was based on the available U.S. Geological Survey (USGS) data. Samples collected at discharges less than 1,500 cfs consisted primarily of sand, with a median grain size of less than 1 mm. Grain size increased with discharge, to a maximum grain size of 16 mm. Sediment transport volumes were then calculated based on water years with complete data sets, by correlating the rating curves to the flow record using a flow-bed load rating curve equation (**nhc**, 2004b). The average annual total bed load of approximately 420,000 tons is based on 27 years of data. This represents about 6.3 percent of the total annual suspended load and 26 percent of the suspended sand load.

Using bed-load equations and morphological methods, **nhc** estimated the annual loads presented in Table 2-2.

**Table 2-2 Suspended Loads in the Matanuska River at Palmer**

| Load Type | Amount (tons/year) |
|---|---|
| Total suspended load | 6,650,000 |
| Suspended sand load | 1,630,000 |
| Gravel bed load (direct measurement) | 420,000 |
| Gravel bed load (stream power equation) | 685,000 |
| Gravel bed load (morphologic method) | 426,000 |

The variability of annual bedload is defined by correlation coefficients of the sediment rating curves and standard deviations in the long-term (27-year) sediment transport statistics.

The sediment rating curves are:

- Suspended load (including wash load) – Correlation coefficient ( $r^2$) of 0.95
- Suspended bed material (>0.063 mm) load – Correlation coefficient ( $r^2$) of 0.97
- Bed load – Correlation coefficient ( $r^2$) of 0.75

The long-term sediment transport statistics are presented in Table 2-3.

**Table 2-3 Long-term (27 Years) Sediment Transport Statistics**

| Characteristic | Average Annual Amount (net tons) | Standard Deviation (net tons) |
|---|---|---|
| Total sediment load (bed material + wash load) | 7,070,000 | 2,360,000 |
| Total bed material (greater than 0.063 mm) load | 2,050,000 | 720,000 |
| Suspended load (including wash load) | 6,650,000 | 2,260,000 |
| Suspended bed material (>0.063 mm) load | 1,630,000 | 620,000 |
| Bed load | 420,000 | 98,000 |

Key:
> – greater than
mm – millimeters

The results provide a reasonable degree of confidence that the long-term average gravel replenishment rate is on the order of 0.5 million tons per year.

Contributions from the major tributaries were based on an approximate specific sediment yield value of 2,500 tons per square mile per year, and a higher value was used for the glacier reach. The result was an approximate suspended sediment budget, as shown by the upper line on Figure 2-6.

Figure 2-6 also shows that the load continues to increase until it reaches the wide Palmer Reach, then declines towards the delta. A preliminary approximation of the gravel budget is also presented (lower line). The plot indicates a loss of gravel into each wide alluvial fan reach. A large portion of the gravel generated from several large tributaries is trapped in the wide reaches, but serves as a future source of gravel.

#### 2.1.5.2 Geomorphology

The Matanuska Valley is a narrow structural feature 5 to 10 miles wide. The features of the current valley are, however, primarily the result of glacial movement during the Pleistocene and the actions of the Matanuska River itself. As a result, the lower Matanuska Valley is a wide, flat-bottomed valley, and the upper valley has the characteristic "U" – shape cross section, typical of glaciated valleys (ADNR, 1998).

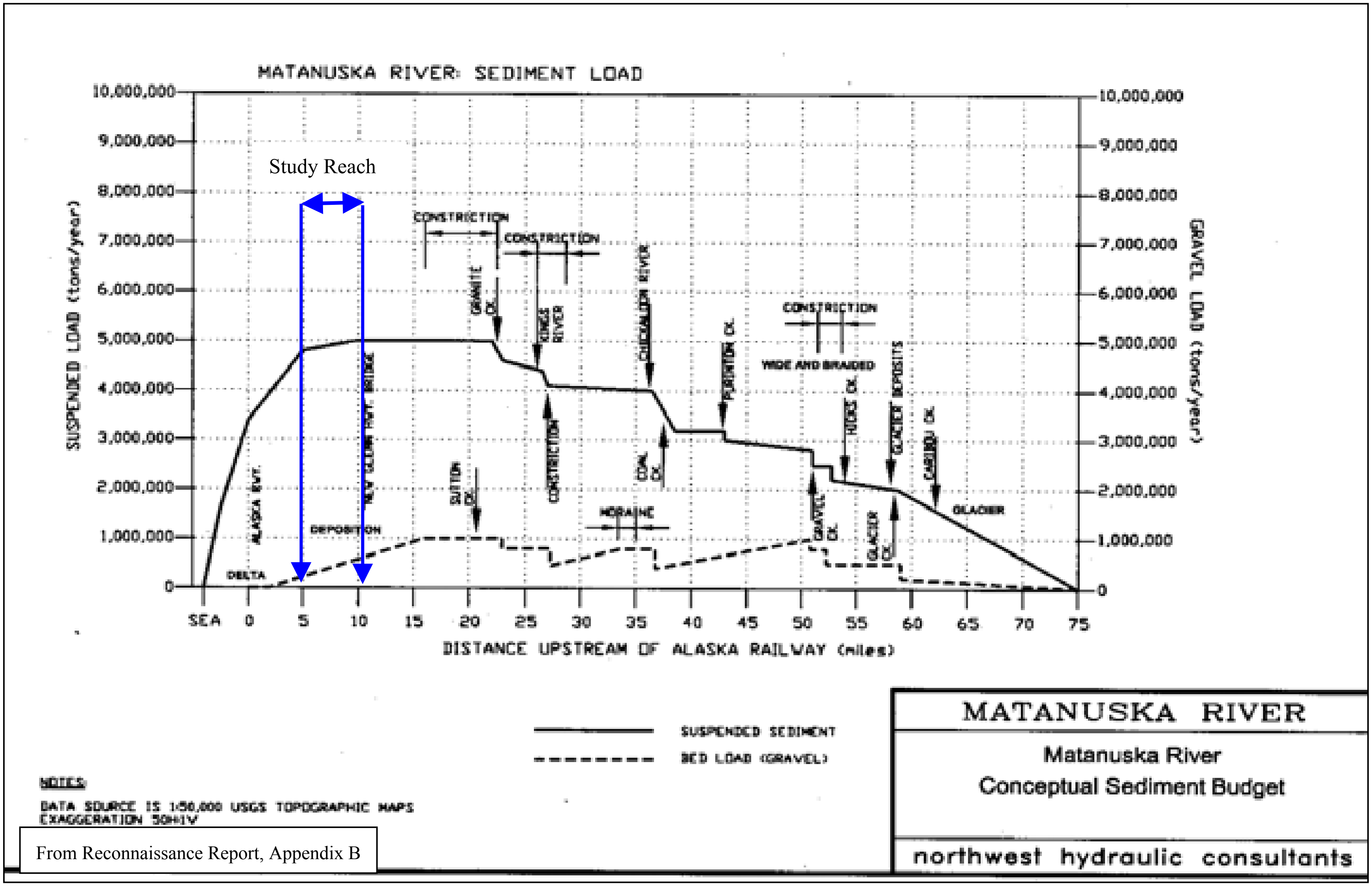
The Matanuska River has a watershed area of about 2,070 square miles, with about 10 percent (some 200 square miles) taken up by the Matanuska Glacier. The river empties into Cook Inlet where the Knik River joins it from the east. Large tributaries such as Gravel Creek, Chickaloon River, and Granite Creek contribute large quantities of sediment to the Matanuska River.

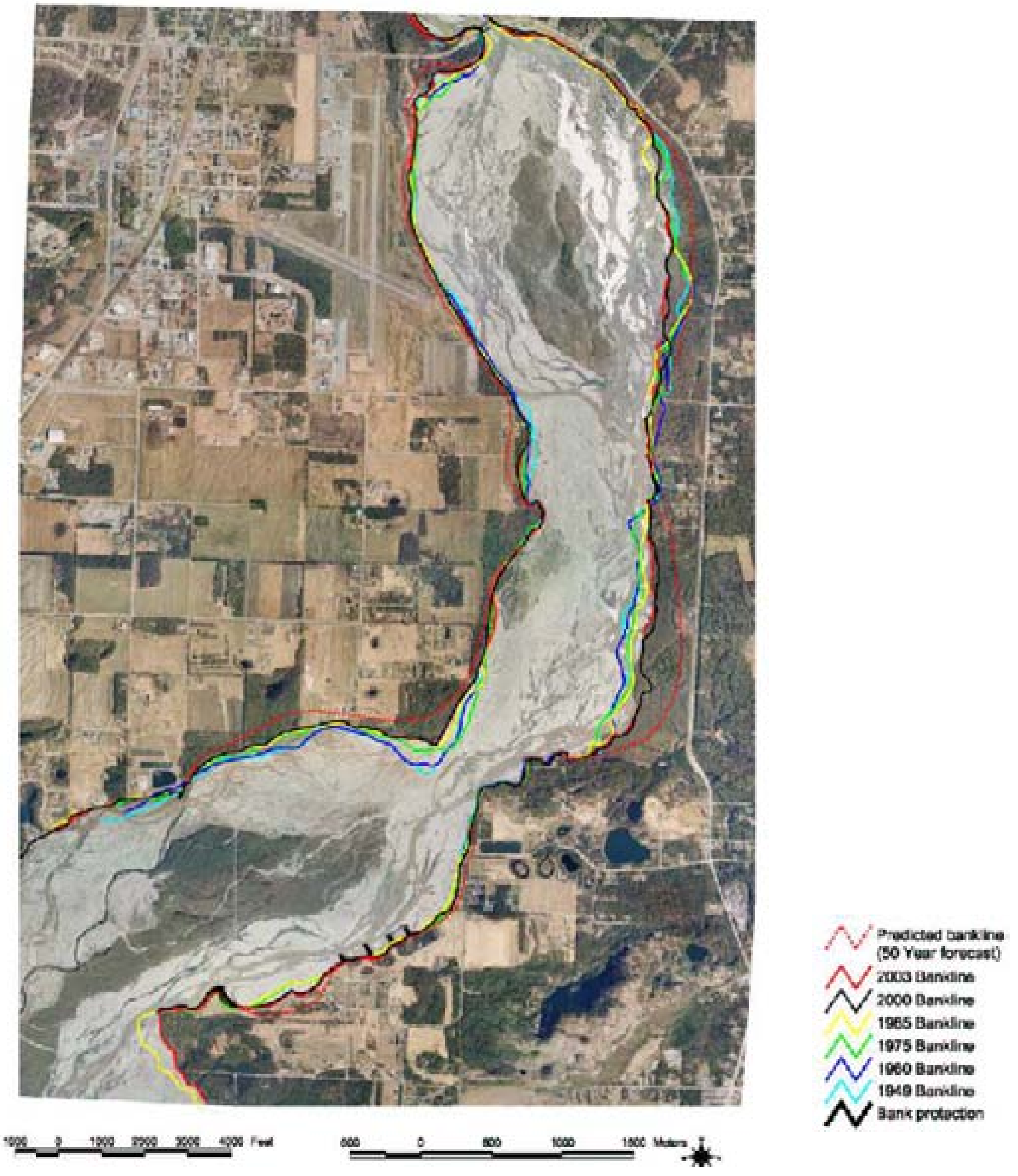
The Matanuska River has developed a series of confined alluvial fans that are separated by glacial debris or bedrock gorges, such as at the Old Glenn Highway Bridge at Palmer. This relatively narrow gorge results in a high velocity jet during high flows carrying sediment, which drops out as a central bar/island in the wide downstream river (**nhc**, 2004c). This deposition process results in the development of a confined alluvial fan, with the highest part of the fan being in the middle of the cross-section and active flow channels being pushed to each side – thereby eroding the channel banks.

In total, approximately 17 acres of riverbank were eroded between 1949 and 2000. These quantities represent only erosion of the floodplain or terraces adjacent to the outer riverbanks. Figure 2.7 presents the bank erosion progression from 1949 to 2003. This figure also shows a bankline forecast for 50 years in the future, showing the extent of erosion that is possible along the Study Area.

The total erosion and erosion rates over time from the Old Glenn Highway Bridge to the downstream pinch point (Reach 1), and from the pinch point to the end of the Study Area (Reach 2) are presented in Table 2-4. Erosion rates in feet per year are averages based on total square feet per year divided by reach length. This represents an increasing trend in erosion rate over the last 50 years for the Study Area.

**Figure 2-6 Matanuska River Sediment Load**






NOTES:
1) Background orthophoto dated May 9, 2000
2) Predicted bankline based on average yearly erosion rates and bank conditions
3) 2003 bankline interpretation based on LIDAR data analysis
4) Other bankline interpretations based on orthophoto analysis

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FIGURE 2-7

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**PREDICTED EXTENT AND EROSION (50-YR)**

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**Table 2-4 Reach Averaged Rates of Outer Bank Erosion**

| Period | Total Erosion (square feet) | | Erosion Rate (feet per year) | |
|---|---|---|---|---|
| | Upper Reach | Lower Reach | Upper Reach | Lower Reach |
| 1949-1975 | 122,902 | 110,530 | 2.71 | 7.15 |
| 1975-1985 | 128,119 | 37,856 | 7.35 | 4.47 |
| 1985-2000 | 263,184 | 81,601 | 10.06 | 6.42 |

The river slope averages approximately 0.005 feet per foot (Fahnestock and Bradley, 1973). The slope varies between the gorges and the confined fan reaches. Along the Study Area, the gradient is estimated at 0.0038 feet per foot, from a best-fit regression line through the long profile of the channel, based on the LiDAR survey data. Upstream from several gorges, the internal confined alluvial fans exhibit braided channel patterns that extend from valley wall to valley wall. A single dominant flow channel will sometimes be present, which shifts frequently across the gravel bed (**nhc**, 2004c). Figure 2.8 presents the existing channel geometry of the Matanuska River.

Braided rivers have a complex, transient morphology characterized by flows that diverge and converge around major assemblages of emergent bars and vegetated islands. The splitting and re-joining of flow paths around channel deposits results in a very dynamic rate of channel activity relative to other types of channels. As a consequence, bar migration, avulsions, and abandonment can all occur within a single flood event and, on small braided channels, significant channel change has been observed daily (Goff and Ashmore, 1994; Lane et al., 1995). Observed changes are also episodic, even at constant discharge, as sediment is delivered downstream in pulses (Nicholas et al., 1995).

Larger braided channels tend to exhibit less variability, in general, because the volume of material stored within the channels is greater than the sediment flux rate, so the time required to complete major modifications exceeds the duration of a single flood or freshet. Nevertheless, Fahnestock and Bradley (1973) suggested that the Matanuska River can rework bars over many days, and that radical modifications are apparent annually. A qualitative examination of channel morphology from two dates (representing pre- and post-freshet conditions) of aerial photography taken in 1981 confirms this observation (Figure 2.9). In addition, many avulsions are known to have occurred along the river over the past half-century and the entire braided floodplain within the reach is estimated to turn over every 75 years (**nhc**, June 2004).

## 2.2 BIOLOGICAL ENVIRONMENT

The biological elements reported in this section include vegetation, wetlands, fish, amphibians, birds, mammals, and other wildlife. No threatened or endangered species have been identified in the Study Area.

### 2.2.1 Vegetation

The major vegetation type in the Matanuska Valley is boreal, or taiga, forest (Viereck et al., 1992). Boreal forests occupy the valleys of "interior" south-central Alaska. These forest are

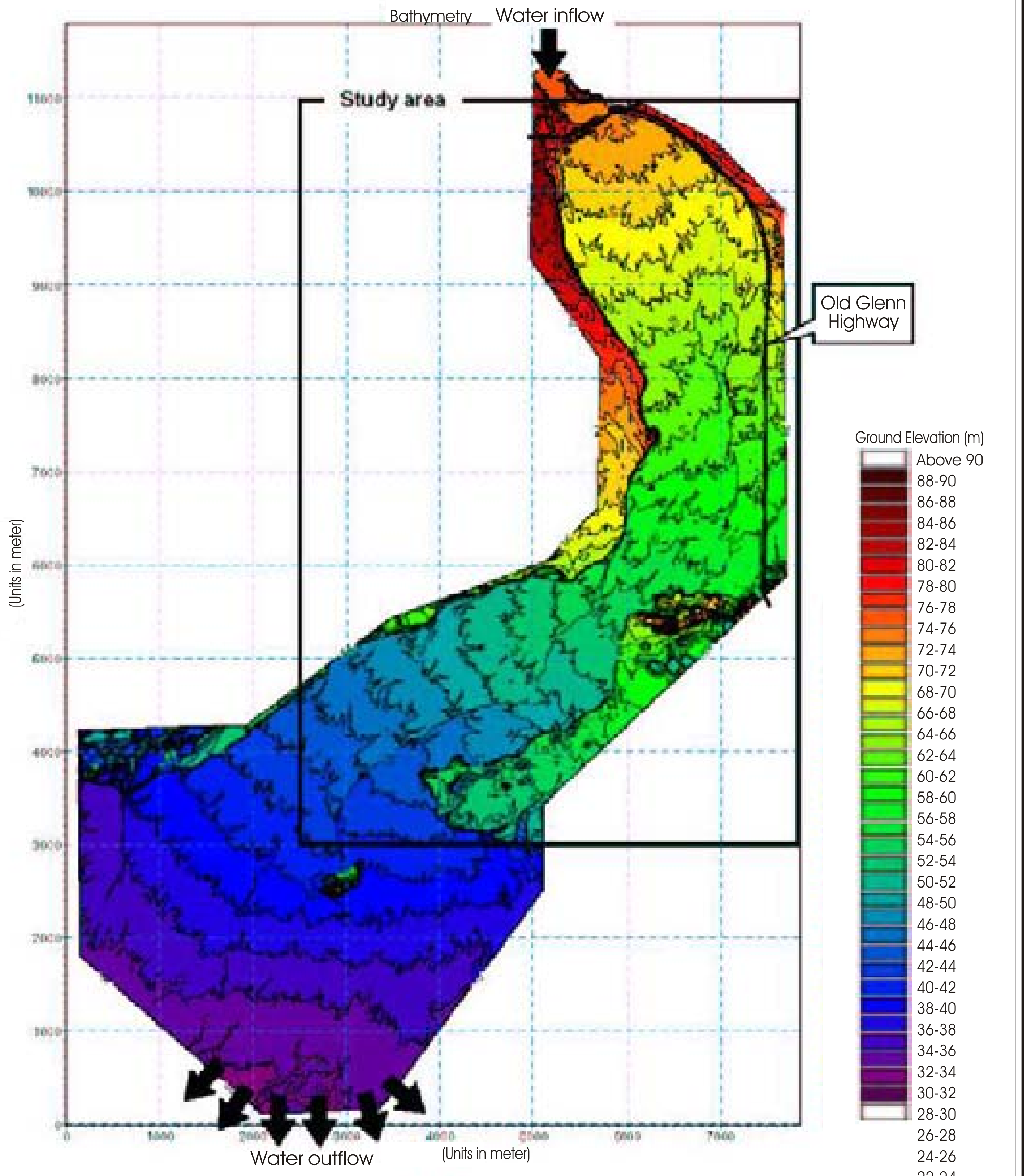


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FIGURE 2-8

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**EXISTING CHANNEL GEOMETRY**

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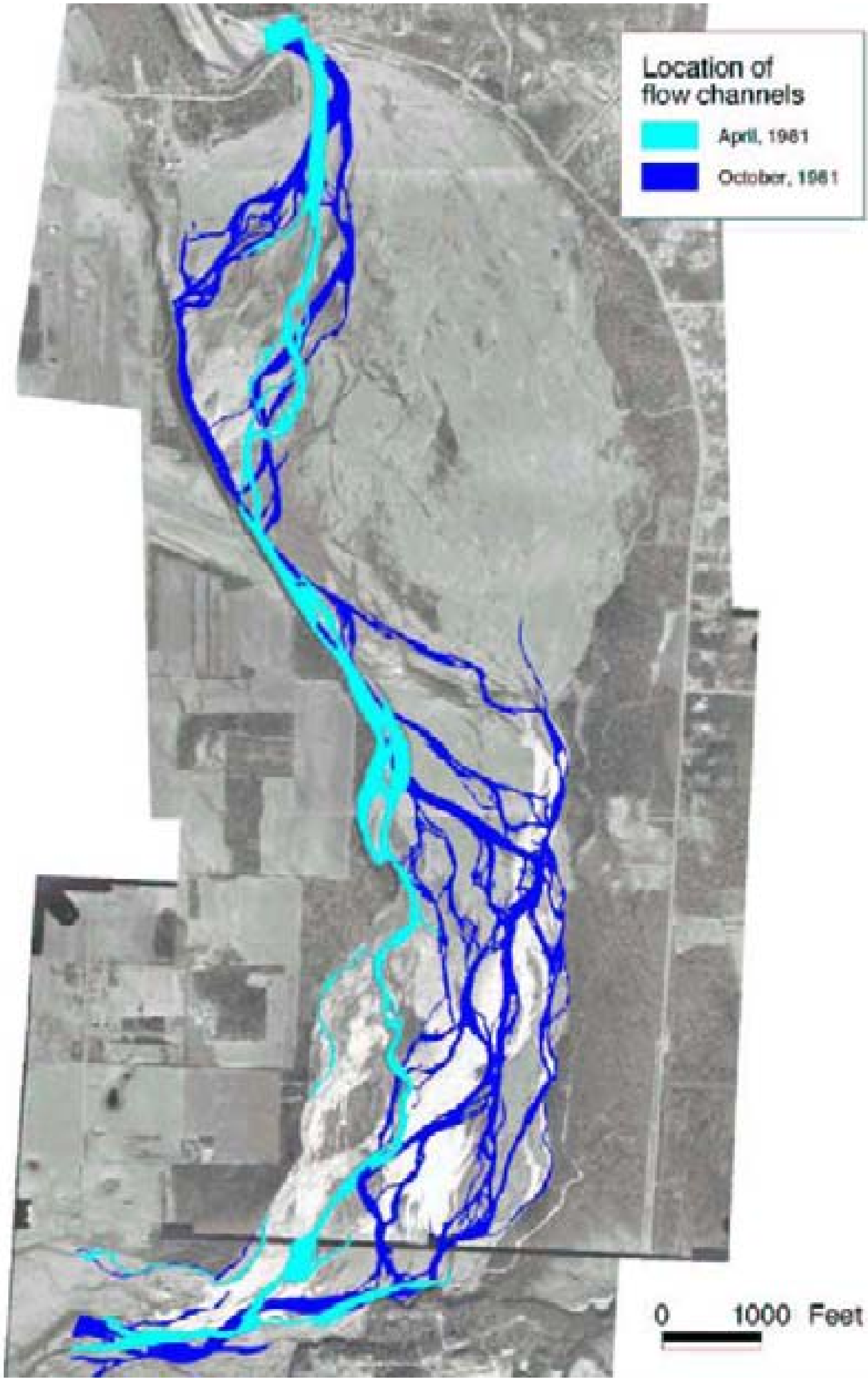


FIGURE 2-9

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**PRE- AND POST-FRESHET**
**MATANUSKA RIVER BRAIDED CHANNEL PATTERN**

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dominated by coniferous forests of black and white spruce (*Picea mariana* and *P. glauca.,* respectively), with extensive inclusions of deciduous paper birch (*Betula papyrifera*), aspen (*Populus tremuloides*), and balsam popular (*P. balsamifera*). Extensive mosaics of subarctic lowland sedge (*Carex* spp.), sedge-moss meadows, and bogs dominated by willows (*Salix* spp.), sweetgale (*Myrica gale*), or graminoids are common within the boreal forest vegetation type (MWH, 2003).

The boreal forest exists as a nearly continuous belt of coniferous trees across North America and Eurasia. Overlying formerly glaciated areas and areas of patchy permafrost on both continents, the forest is mosaic of successional and subclimax plant communities sensitive to varying environmental conditions. These forests now occupy valleys that were filled with glacier ice or glacial lakes during the last major glaciation. Boreal forests spread from interior Alaska (north of the Alaska Range) into south-central Alaska following the retreat of glaciers (http://climchange.cr.usgs.gov/research/alaska/alaskaB.html)

### 2.2.2 Wetlands

The general distribution and area of wetlands along the Matanuska River was mapped for the National Wetlands Inventory, and described in a U.S. Fish and Wildlife Service (USFWS) study of Alaska wetland status. The most common wetland delineation in the Project Area is Riverine, followed by smaller areas of Freshwater Forested/Shrub Wetland and Freshwater Emergent Wetland (Cowadrin et. al., 1979).

The *Riverine* classification is given to wetland and deepwater habitats contained within a channel with periodically or continuously moving water. The Riverine System includes all wetlands and deepwater habitats contained within a channel, with two exceptions: 1) wetlands dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens, and 2) habitats with water containing ocean-derived salts in excess of 0.5 parts per thousand. A channel is "an open conduit either naturally or artificially created which periodically or continuously contains moving water, or which forms a connecting link between two bodies of standing water" (Langbein and Iseri, 1960).

The Riverine System is bounded on the landward side by upland, the channel bank (including natural and man-made levees), or wetland dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens. In braided streams, the system is bounded by the banks, which form the outer limits of the depression where the braiding occurs.

The *Freshwater Forested/Shrub Wetland* is dominated by forests and shrubs – as its name implies. If vegetation (except pioneer species) covers 30 percent or more of the substrate, the Class is distinguished on the basis of the life form of the plants that constitute the uppermost layer of vegetation and that possess an areal coverage 30 percent or greater. For example, an area with 50 percent areal coverage of trees over a shrub layer with a 60 percent areal coverage would be classified as Forested Wetland (Cowardin et. al., 1979). An area with the same coverage of trees and shrubs, but with the trees less than 20 feet (6 meters) tall, would be classified as Scrub-Shrub Wetland.

Forested Wetlands are most common where moisture is relatively abundant, particularly along rivers and in the mountains. They occur only in the Palustrine and Estuarine Systems and normally possess an overstory of trees, an understory of young trees or shrubs, and a herbaceous layer. The Scrub-Shrub Wetland includes areas dominated by true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions. Scrub-Shrub Wetlands may represent a successional stage leading to Forested Wetland, or they may be relatively stable communities (Cowardin, et. al., 1979).

The *Freshwater Emergent Wetland* classification is less common in the Study Area and is characterized by erect, rooted, herbaceous hydrophytes (excluding mosses and lichens). This vegetation is present for most of the growing season in most years and is usually dominated by perennial plants. In areas with relatively stable climatic conditions, Emergent Wetlands maintain the same appearance year after year. In other areas, such as the prairies of the central United States, violent climatic fluctuations cause them to revert to an open water phase in some years (Stewart and Kantrud, 1972).

### 2.2.3 Fish and Amphibians

The Matanuska River watershed supports both anadromous and resident fish populations. The 11 species of fish within the Matanuska Valley watershed are: chinook, coho, and chum salmon, Dolly Varden char, rainbow trout, Arctic grayling, round whitefish, burbot, three-spine stickleback, nine-spine stickleback, and the longnose sucker. Spawning has been documented in both tributaries and the main stem of the Matanuska River (ADNR, 1998). Fish counts for the 1980s show increasing numbers of spawning chinook salmon in two tributaries of the Matanuska River. Data from 1989 indicates that the density of salmonids is, however, very low in several tributaries, as compared to other streams in Alaska. The distribution and numbers of these species within the Study Area is unknown.

For both anadromous and resident fish, an important habitat parameter is maintenance of stream flow for spawning and incubation success. Fish habitat types associated with the Matanuska River are the main-stem, slough, side channel, tributary mouth, and tributary. The changing morphology of side channels affects the number of salmon that spawn at the tributary mouth. Increased numbers of salmon are present when the channel shifts allow for additional access to the tributaries, providing adequate spawning habitat (ADNR, 1998).

### 2.2.4 Birds, Mammals, and Other Wildlife

The majority of information available on the wildlife along the Matanuska River pertains to the Moose Range that was established in 1984. This area, however, is located in the watershed upriver from the Study Area, to the north of the Matanuska River itself.

Moose are generally found throughout the watershed, including the Study Area. The watershed supports numerous other mammals including brown bear, black bear, caribou, Dall sheep, and mountain goat. Furbearing species within the watershed include: wolf, coyote, red fox, lynx, wolverine, mink, marten, weasel, red squirrel, Arctic ground squirrel, snowshoe hare, hoary marmot, pica, porcupine, beaver, muskrat, and others (ADNR, 1998). The distribution and numbers of these species within the Study Area is unknown.

Raptors likely to occur in the watershed include: bald eagle, golden eagle, northern harrier, sharp-skinned hawk, northern gashawk, merlin, rough-legged hawk, Swainson's hawk, red-tailed hawk, American kestrel, peregrine falcon, gyrfalcon, boreal owl, saw-whet owl, great gray owl, great horned owl, short-eared owl, snowy owl, and hawk owl. The northern goshawk was the only raptor observed in summer and winter. Many of these species may use the watershed as a migration corridor to Interior Alaska in early spring. The "open mixed forest" habitat type had the highest concentration of bird species, with a total of 24 species. Many of these species are summer residents. Birds that may be present in winter include the raven, black-billed magpie, northern shrikes, and ptarmigan (ADNR 1998).

Tidal and adjacent wetlands around the mouth of the Matanuska River are regionally important for waterfowl as staging and nesting habitat. The areas along the lower river are valuable moose wintering and calving habitat. Upriver and tributary areas of the Matanuska River provide important riverine habitat and migratory paths for many birds and mammals (USACE, 1999).

### 2.2.5 Threatened and Endangered Species

Before a plant or animal species can receive protection under the Endangered Species Act, it must first be placed on the Federal list of endangered and threatened wildlife and plants. The USFWS listing program follows a strict legal process to determine whether to list a species, depending on the degree of threat it faces. An "endangered" species is one that is in danger of extinction throughout all or a significant portion of its range. A "threatened" species is one that is likely to become endangered in the foreseeable future. The USFWS also maintains a list of plant and animals native to the United States that are candidates or proposed for possible addition to the Federal list. All of the USFWS's actions, from proposals to listings to removals ("delisting"), are announced through the Federal Register (USFWS, 2004a).

A total of 10 animals and 1 plant are listed as either threatened or endangered in the State of Alaska. Of these, none are found within the Mat-Su Borough or Cook Inlet. A single candidate for listing has been identified in the Cook Inlet waters – the Cook Inlet beluga whale (*Delphinapterus leucas).* No threatened or endangered species are known to be present within the Study Area (USFWS, 2004b).

## 2.3 HUMAN ENVIRONMENT

The human environment is presented in terms of land ownership and use, economy, socioeconomics, cultural resources, visual resources, noise, recreational resources, and subsistence use.

### 2.3.1 Land Ownership and Use

This section presents population growth before describing land use.

#### 2.3.1.1 Population

According to the U.S. Census Bureau, the 2003 population of the Mat-Su Borough is estimated at 68,335 people. The population increased by 49.5 percent from 1990 to 2000, and by an estimated 15.2 percent from 2000 to 2003. This growth rate makes the borough the fastest growing in the State and among the fastest growing areas in the country (U.S. Census, 2004).

Most of the residents are approximately 34 years of age, with about 88 percent of them being white. Residents resided in an estimated 27,485 housing units in 2002. With a land area of nearly 25,000 square miles, the population density remains low, with only 2.4 people per square mile (U.S. Census Bureau, 2000 data). Approximately one-half of the population in the Mat-Su Borough resides within a 100 square mile area between and around the cities of Palmer and Wasilla (Mat-Su, 2003).

#### 2.3.1.2 Land Use

Coal was mined in the Matanuska Valley from 1916 to 1967 in the vicinity of Chickaloon and Eska on the north side of the river (WCC and Goodson, 1984). The City of Palmer is the largest urban area in the valley and is located to the west of the river within the Study Area.

In the 1930s, lands northwest of the mouth of the Matanuska River were opened to agricultural development. The farming area is located in a roughly rectangular area 10 to 12 miles wide and extending from the Chugach Mountains west some 15 to 20 miles. Only a portion of this farmed area is within the Matanuska River watershed (MWH, 2004d). In 1997, the National Agricultural Database reported that farming lands in the Mat-Su Borough, Anchorage, Valdez, and Cordova area accounted for approximately 40,000 acres. The majority of this land, while not broken down in the national data, was located in the Mat-Su Borough.

Agriculture and mining are not expanding in the basin; some agriculture land is being converted to urban use and old mines are being reclaimed. Rapid urban growth continues, as evidenced by the 4.5 percent annual population growth in the City of Palmer over the last 10 years. However, much of the watershed remains undeveloped. An estimate of the current land use areas is shown in Table 2-5 (MWH, 2004d).

**Table 2-5 Estimated Areal Extent of Land Uses in the Matanuska Valley**

| Type of Land Use | Area (square miles) | Percent of Total Area |
|---|---|---|
| Agriculture | 40 | 2 |
| Mining | <20 | <1 |
| Roads and Urban | 150 | 8 |
| Undeveloped – vegetated | 1,670 | 80 |
| Undeveloped – glacier | 250 | 12 |
| **Total** | 2,070 | 100 |

Key:
< – less than

### 2.3.2 Economy and Socioeconomics

*Services* and *professional* are the predominant classification of employment for the region, making up just over 65 percent of the job market in the area. The current income and employment distribution is presented below.

#### 2.3.2.1 Wage and Income

In 1999, the average annual wage for workers in the Mat-Su Borough was $26,893, compared to $35,557 in Anchorage. The biggest reason for this differential is that a much larger percentage of the Mat-Su employment mix is in lower paying sectors, such as services and retail, and not in the sectors of oil, government, and transportation.

Personal income does not reflect the lower wages in the Mat-Su Borough. Some of this difference is attributed to the fact that many residents (approximately one-third) work in the higher paying sectors in Anchorage and elsewhere in the state (Mat-Su, 2003). The income distribution data from the 2000 U.S. Census is presented in Table 2-6.

**Table 2-6 Income Distribution**

| Category | Anchorage | Mat-Su Borough |
|---|---|---|
| Per Capita Income | $ 25,287 | $ 21,105 |
| Median Household Income | $ 55,546 | $ 51,221 |
| Median Family Income | NA | $ 56,939 |
| Persons in Poverty | NA | 6,419 |
| Percent Below Poverty | 7.3 | 11.0 |

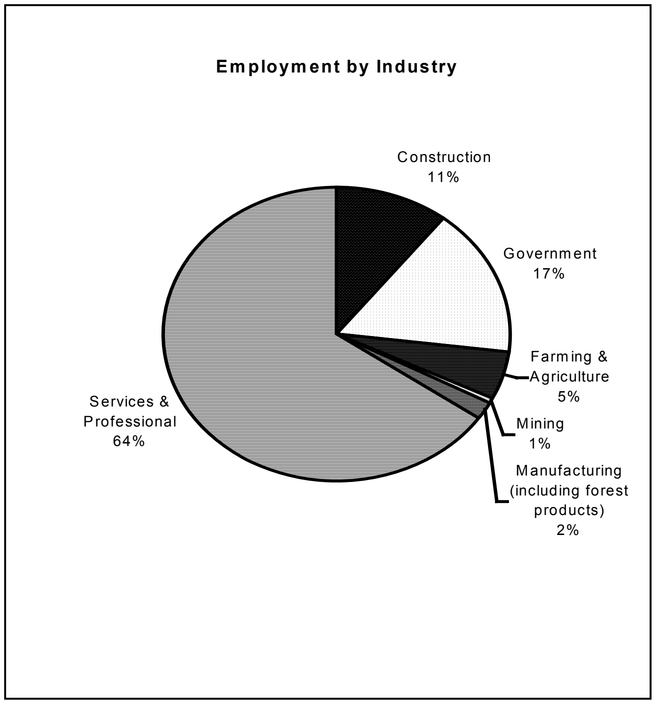
Key:
Mat-Su – Matanuska-Suisitna
NA – not available

#### 2.3.2.2 Employment

Mining and agriculture were the first major economic influences. Although the Mat-Su Borough remains the state's biggest agricultural producer, other economic forces now drive the economy. For the last four decades, the single biggest reason for the Borough's growth has been its proximity to the state's largest city (Anchorage). Recent reports estimate that about one-third of the Borough's labor force now commutes to Anchorage for employment (Mat-Su, 2003). Palmer's economy is based on a diversity of retail and other services, light manufacturing, and city, borough, state, and federal government (GPCC, 2004).

Employment in the area varies from construction to tourism. The University of Alaska has an Agricultural and Forestry Experiment Station Office and a district Cooperative Extension Service office in Palmer, along with the University's Matanuska Research Farm (GPCC, 2004). The primary employment in the area is classified as services and professional, with 64 percent, as shown on Figure 2-10 (Sonoran, 2002). Farming and agriculture are diminishing due to the rapid expansion of population in the area.

**Figure 2-10 Employment by Industry**




### 2.3.3 Cultural Resources

The Mat-Su Borough has a Historic Preservation Commission that oversees cultural preservation projects. The Borough assists in supporting six museums, each portraying local history in disparate geographical regions. Within the Mat-Su Borough, there are over 22 individual sites and four historic districts listed on the National Register of Historic Places. The 11 sites within the Palmer area are primarily located with the City of Palmer, or along the New Glenn Highway. The historic districts listed are: Palmer Colony Project, Talkeetna Mining Community, Golden Zone Mine, and Independence Mine (Mat-Su, 2003). Of these, only the Palmer Colony Project and Independence Mine are located within the Matanuska River Watershed. Neither location would be affected by activities within the Study Area.

The Old Glenn Highway follows part of a historic trail initially blazed by Lieutenant Castner in 1898. The highway was named for Castner's commanding Officer, Captain Glenn. The Glenn Highway is listed as a National Scenic By-Way (Mat-Su, 2003). The highway runs adjacent to the Matanuska River that separates two sets of scenic mountains, the Chugach and Talkeetna ranges. The Old Glenn Highway may be subject to erosion from the Matanuska River.

### 2.3.4 Visual Resources

Along the Study Area, the surrounding topography consists of relatively flat terrain located on a bench feature ranging from a few feet to 20 or 30 feet above the river. Bodenburg Butte is located to the southeast of the Study Area. The surrounding area consists of numerous mountains peaks. The Chugach and Talkeetna Mountains are both visible from the Study Area.

### 2.3.5 Noise

Current noise levels along the Study Area have not been measured. Known sources of noise in the area include the Palmer Airport, activities from periodic gravel extraction on the north side of the river, activity at the Palmer WWTP, maintenance of the existing spur dikes, and road construction. Little traffic is present in the area. Snowmachine and four-wheeler use may be present periodically along the dry portions of the river bed.

### 2.3.6 Recreational Resources

Recreational opportunities within the Matanuska River watershed are extensive. These include both summer and winter recreation. There are many trails and opportunities for those who enjoy hiking, hunting, fishing, berry-picking, four-wheeling, horseback riding, and biking in the summer, or snow machining, skiing, and dog mushing in the winter. The Matanuska River is home to a variety of game animals such as caribou, moose, Dall sheep, and bear. Area creeks, streams, and lakes contain extensive fishing opportunities (Mat-Su, 2003).

### 2.3.7 Subsistence Use

Subsistence use is documented within the Matanuska and Susitna River basins, which extend to the Cook Inlet, as grouped by the Alaska Native Science Commission and University of Alaska, Anchorage, Institute of Social and Economic Research. The Alaska Department of Fish and Game, Division of Subsistence, provided assistance to the research effort. Potential and historic subsistence use within distinct areas has been documented.

Within the Matanuska and Susitna River basins, subsistence use was identified. Subsistence items available include: berries, black bear, burbot, caribou, several fish species, moose, plants, several bird species and beluga whales. Limited subsistence use has been documented, but a greater amount of subsistence use than recorded may take place in the Study Area.

# 3.0 EROSION CONTROL ALTERNATIVES

This section of the report reviews five approaches to managing erosion along the Matanuska River in the study area:

- Alternative 1 – Gravel Removal
- Alternative 2 – Bank Stabilization
- Alternative 3 – Non-Structural Approaches
- Alternative 4 – Combined Actions
- Alternative 5 – No Action

Section 3.2, describing Alternative 2 – Bank Stabilization, presents several options that are eliminated from further consideration due to factors such as effectiveness, reliability, and constructability. The project team presents operation and maintenance (O&M) considerations, mitigation measures, and anticipated bank protection results for the gravel removal and bank stabilization alternatives (also called structural alternatives). Each subsection on an alternative ends with a description of its advantages and disadvantages. Section 3.5 presents the No Action Alternative (Alternative 5) and its advantages and disadvantages.

## 3.1 ALTERNATIVE 1 – GRAVEL REMOVAL

This alternative provides channel excavations (trenching) to re-route and alter the flow within the river. Channel excavation would be designed to reduce velocities and stresses upon banks during high and moderate flow events. In order to accomplish this, information regarding the dynamics of the river and where trenching would be most effective needed to be developed.

Computer modeling was used to estimate the effect of the channel excavations on flow pattern, hydraulic characteristics, and sediment transport in the Study Area. This evaluation was conducted for two flood events: the 2-year and 10-year peak flows. The flood flow hydraulics were numerically simulated for both existing and project conditions using the Danish Hydraulic Institute MIKE-21 two dimensional (2-d) fixed bed computer model (**nhc**, 2004e). Application of the MIKE-21 model provides a means to combine the computed hydrodynamic data, derived from topographic data and the HEC-RAS model (MWH, 2004c), with an understanding of geomorphic processes on the Matanuska River system to assess the outcomes of gravel extraction alternatives.

MIKE-21 is a recognized and tested tool for quantifying complex spatial flow hydraulics in braided channels characterized by irregular bed topography, such as the Matanuska River. This model was used to track alterations in flow depth, velocity, and sediment transport as a result of various bed configurations. The fixed-bed model, however, cannot predict changes in channel evolution due to changed hydraulic conditions and does not combine the hydrodynamics with the sediment transport computations.

The current sediment model is based on several assumptions: the bed topography is fixed, the water flow is steady, sediment is not routed between cells, and there is unlimited sediment supply to each cell. Therefore, the computed sediment fluxes represent the capacity of the water flow to transport sediment, and not the actual sediment transport during a given hydrologic event. Results from the sediment transport computations presented can only be used to identify potential areas of erosion or deposition, and provide an indication of the initial rate at which sediment transport will occur. It must be recognized that the river system is dynamic and sediment transport will respond actively to changes in channel form associated with sediment flux.

Once the modeling of the river under existing conditions was completed, a series of excavated trenches were inserted into the model and their effects on the flows were determined. The location of the proposed gravel trenches and pit trap are shown on Figure 3-1.

The project team modeled three trenches that were 10 feet deep, 500 feet wide, and 2,500, 3,300, and 6,500 feet long – upstream to downstream. A gravel trap located at the downstream end of the upstream trench was 16 feet deep and 1,150 feet wide. The three trenches had a total excavated volume of 2.2 million cubic yards, or 3.3 million tons. The gravel trap excavated volume was 600,000 cubic yards, or 900,000 tons. Since the average bankfull cross-sectional area is approximately 5,431 square feet, these trenches create a large change in the channel configuration, which why sediment is trapped. These configurations were intended for initial base line modeling only, future planning and modeling will be needed to adjust the trenches to maximize effectiveness.

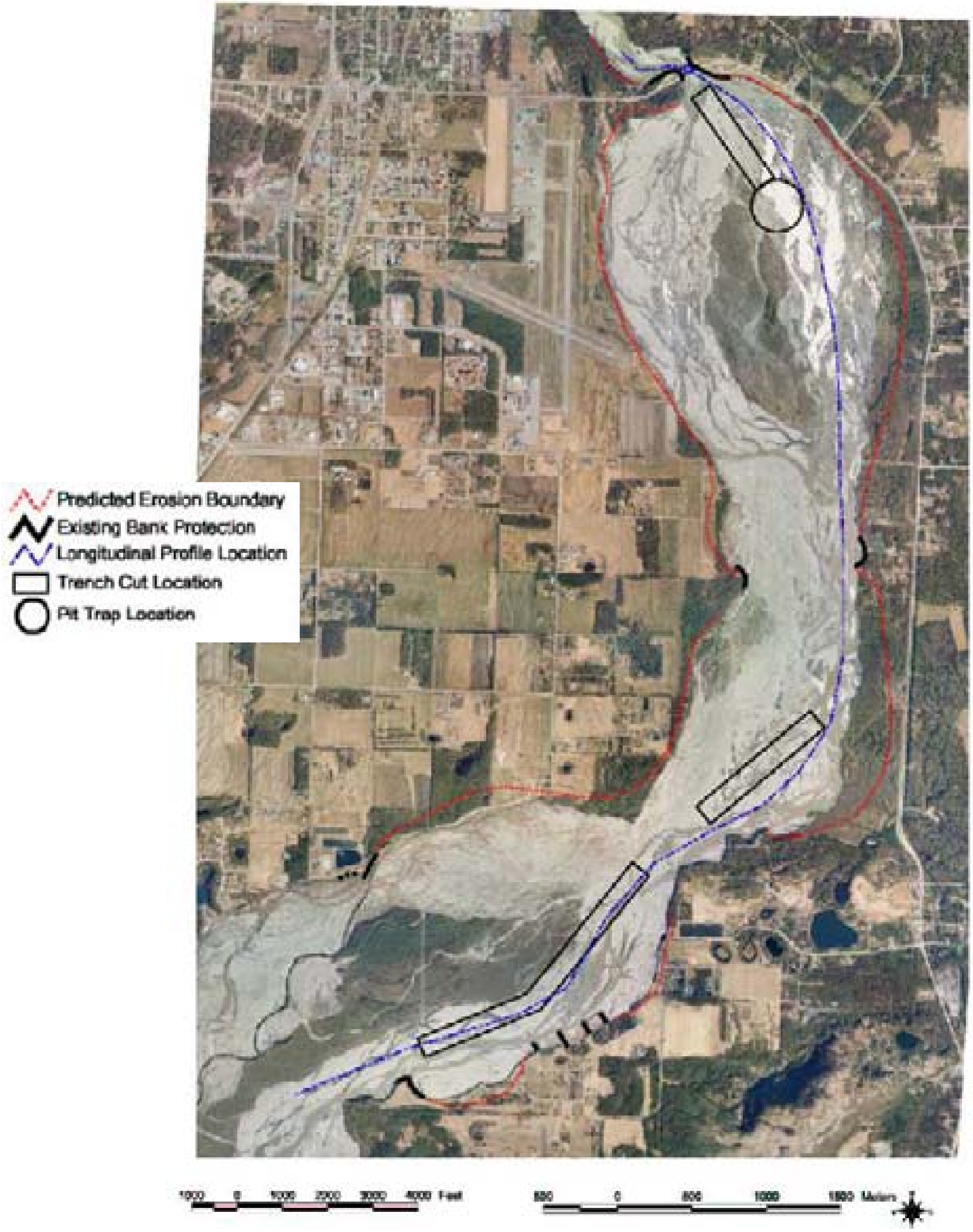
### 3.1.1 General Strategy

In order to provide reliable bank protection, the excavations need to maintain the main flow in the middle of the active channel to reduce river velocities and stresses near the erodable riverbank. Therefore, the risk of the river naturally bypassing the excavated channel needs to be addressed.

From a geomorphologic perspective, the behavior of the excavated channels is of concern on the Matanuska River, since natural river instability may impact the effectiveness of the trenches to re-direct flows and reduce water levels. Since braided channels characteristically exhibit irregular and unpredictable morphologic development, there can be no guarantee that the proposed excavations will remain stable for a significant time period (i.e. multiple freshet seasons) to reduce flood levels and redirect flows, as intended.

In addition, there is a risk that bank erosion could continue due to flow in the smaller sub-channels even if the trenched channels are constructed. If an appreciable amount of the flow remains outside of the excavated channel, bank erosion may continue. In addition, flows through the initially straight excavations will likely erode their banks and eventually result in irregular excavated channel patterns with flow paths deviating from the constructed alignment. Specific analytical techniques for assessing these processes are described in greater detail in the MIKE-21 Model Technical Memorandum (Appendix E).

An adaptive management approach for implementing and maintaining the gravel extraction trenches is highly recommended. Channel bed response in braided river systems is very unpredictable, and a high degree of uncertainty in predicted bed change and channel response




northwest hydraulic consultants

MWH
Anchorage, Alaska

FIGURE 3-1

USNRCS
MATANUSKA RIVER EROSION ASSESSMENT - DESIGN STUDY REPORT

**MODEL EXCAVATION LOCATIONS**

JOB No. 1851040.010107 File: \USNRC\MAT-SU\DesignStudyReport\final\fig3-1.cdr

exists. After implementing a gravel extraction trench, observation of the locations and magnitude of channel bed deposition or erosion after a freshet season provide a means to assess project performance. For example, periodic modifications to the location, configuration, and size of both the trenches and gravel trap would be necessary to ensure their long-term effectiveness.

This empirical observation of bed change should be combined with updated hydraulic modeling to develop a revised excavation plan that reduces the adverse effects of channel deposition and avulsion, and reduces near bank velocity and depth. Responsibilities and technical requirements for assessing modifications to the operations would have to be carefully laid out for this alternative to be successful. In summary, in spite of the dynamic characteristics of the Matanuska River, the gravel extraction excavations can reduce bank erosion but will not eliminate the need for bank erosion protection of key facilities, properties, and locations of direct flow impingement on bank locations.

### 3.1.2 Modeling Results

Excavations were modeled to show their effectiveness on mitigating stresses on the banks during high flow regimes. The results are displayed in Figures 7 through 29 of the MIKE-21 Model Technical Memorandum (Appendix E). Modeling shows beneficial results of reducing flow velocities and shear stress on banks due to the two trenches near Bodenburg Butte. The uppermost excavation near the Old Glenn Highway Bridge adversely affected the east bank of the Matanuska River by increasing velocities and depths in this region. Therefore, excavation and gravel removal in the region of the two downstream trenches that were modeled should be considered. Additional analysis might define an upstream trench near the Old Glenn Highway Bridge that would be effective.

### 3.1.3 Gravel Movement and Stockpiling

The gravel removal operation requires developing access to the riverbed; excavating, loading trucks, and hauling the gravel out of the gravel trap and/or trenches; and stockpiling the material for later sale or use.

#### 3.1.3.1 Riverbed Access

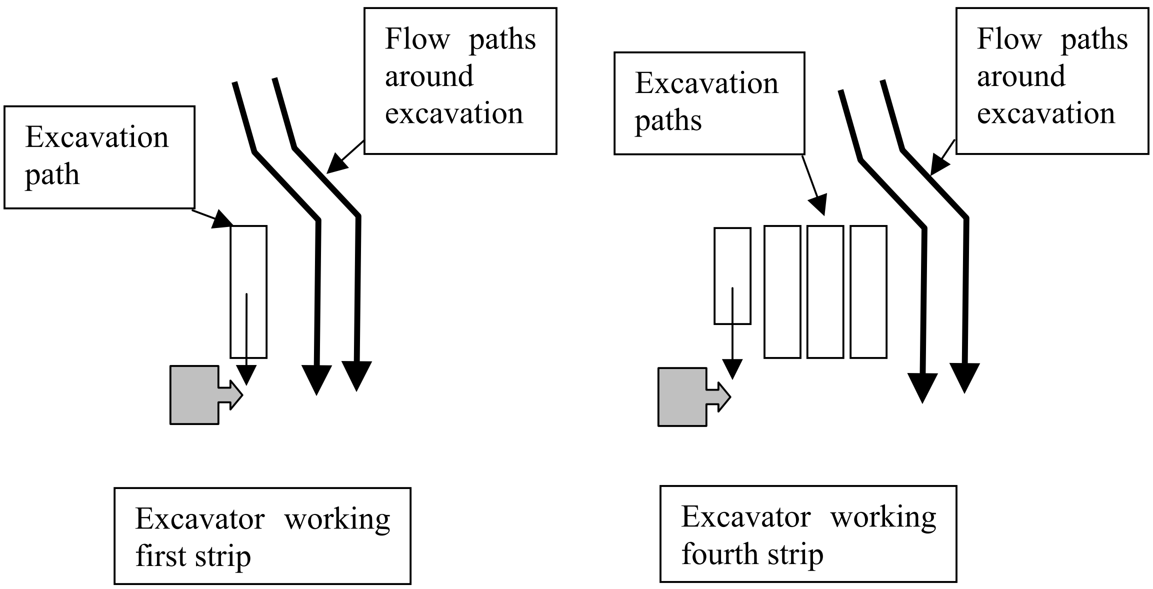
Access to the riverbed would be through public right-of-way, easement, or property purchases. On the west side of the river, there are possible access points near Mountain View Estates, Glenn View, or driveways just south of the airport along the riverbank. On the east side of the river, there are possible access points near the Circle View Subdivision along the spur dikes, at the 90 degree bend on the South Bodenburg Loop Road, and along the Old Glenn Highway just east of the end of the upstream island. Numerous other private access points are scattered along the river.

Access ramps likely will need to be constructed from the bank to the riverbed for equipment such as excavators, dump trucks, and other vehicles. Access ramps should be a minimum of 14 feet wide, and properly sloped and compacted to allow heavy equipment access.

#### 3.1.3.2 Excavation, Movement, and Stockpiling

An excavator would likely remove material from the gravel trap and, if necessary, trenches in strips, each excavated from the outermost upstream point moving downstream. Each subsequent strip would be closer to the innermost edge of the designed excavation, as shown on Figure 3-2. The excavation could be bermed at the upstream end to prevent flow from entering the excavation to facilitate construction.

**Figure 3-2 Excavation Plan**




This excavated material would be placed in dump trucks (as large as feasible) and delivered to a buyer or a staging area. Staging areas for stockpiling need to be within close proximity of the river excavation. Ease of access to the site is also essential. Conveyors and crushers could be added to improve the quantity, quality, and the placement of the material in response to market demand.

#### 3.1.3.3 Excavation Timing

Excavations should take place during low flow and minimal fish impact periods, likely prior to significant fish migration. This sets the excavation period in the challenging cold months of November through February or March, depending on anadromous fish smolt out-migration dates. Excavations must be coordinated with all permitting guidelines.

### 3.1.4 Constructability Issues

The size of the trenches would require construction of a large-scale mining operation. Initial construction of two downstream trenches would require excavating nearly 1.8 million cubic yards of material. Employing four excavators and twenty 22-yard end dump trucks, 24 loads per truck per day could result in the trenches being excavated in 250 days. If excavation is limited to the 4 or 5 late fall to early spring months, it would be a challenge to construct the two trenches in less than 2 years.

In addition, groundwater may pose a significant challenge for excavations of this size in this reach of the Matanuska River. The use of specialized excavation equipment may be required to remove material from the excavation after initial removal is completed, if groundwater significantly infiltrates a trench. In addition, construction is anticipated to take place during low flow periods, which may limit the effect of groundwater on a trench. Since the potential for long-term groundwater issues and the type of equipment that may be needed cannot be foreseen, these were not included in estimating the cost of excavation activities.

### 3.1.5 Demobilization and Restoration

Due to seasonal excavation constraints, the 'in-stream' work will be demobilized on an annual basis during initial construction and annual maintenance. This demobilization will include removal of equipment from the riverbed, restoration of disturbed areas outside of the trench excavations, restoration of vegetation disturbed within the riverbed, and a survey of final excavations.

### 3.1.6 Operation and Maintenance

Equipment should stay out of waterways as much as possible to avoid unnecessary impacts to the riverbed and possible water hazards. Equipment should be cleaned, maintained, and frequently checked for leaks, fragile hoses, and piping.

Due to high sediment loads in the river, the extracted volumes of the trenches and gravel pit will be replaced with the transported sediment in a few (i.e., 2 to 5) years, assuming no annual gravel removal. Therefore, annual monitoring and maintenance of the excavations are necessary to ensure their long-term effectiveness and desired performance. Inspection and maintenance of the excavations should include:

- Condition of trench and amount of sediment holding capacity remaining in the trench.
- Effectiveness of trenching and impacts to side and downstream banks.
- Potential for avulsion (change in channel direction and form).
- Buildup of materials within adjacent areas.

Maintenance will include removal of gravel from the gravel trap and, perhaps, the trenched channels. Since annual gravel deposition is estimated on the order of 500,000 tons per year, two excavators and 10 end dump trucks making 24 round trips per day for 59 days may be needed to maintain the rate of gravel removal required for continued success of the gravel removal alternative. This gravel may be stockpiled for sale on the open market.

### 3.1.7 Mitigation Measures

Mitigation measures for gravel mining and excavation operations within the riverbed and floodplain include:

- Proper care and inspection of equipment to eliminate oil and other contaminant leaks and spills. Prepare spill plans, if necessary.
- Working in dry riverbed where possible to avoid in-stream work issues and hazards.
- Managing gravel extraction operations to avoid or minimize damage to riverbanks and riparian habitats.
- The cumulative impacts of gravel extraction operations to anadromous fishes and their habitats could be addressed by the federal, state, and local resource management and permitting agencies.
- Repairing, rehabilitating, and restoring the riverbed where disturbed (outside of the excavation area).

### 3.1.8 Anticipated Bank Protection Results

Modeling results show the potential for reducing the threat of erosion. However, the risk of an avulsion or other future river change that would de-stabilize the bank cannot be avoided. While short-term protection to the riverbank may be significant, long-term protection will require active maintenance and continued operation of gravel excavation. Even with long-term diligent trenched channel maintenance, the risk of bank erosion will not be completely eliminated. The likelihood that the excavation of gravel will provide protection during a 25-year flood event has not been quantified. In addition, a single event during the beginning of the summer flows could potentially fill the trenches and eliminate any bank protection achieved by previous excavations.

### 3.1.9 Advantages

The advantages of Alternative 1 include:

- Possible revenue generation from gravel mining.
- Ability to channel the river away from the susceptible banks.
- Ability to reduce the likelihood of bank erosion for the short-term.

### 3.1.10 Disadvantages

The disadvantages of Alternative 1 include:

- Winter operational challenges.
- Potential groundwater control challenges.
- Revenues not guaranteed, value of gravel and markets are variable.
- Bank stability not guaranteed, high flows may still affect the bank.

- Gravel mining must be continuous, adaptive, and long-term.
- Offers no protection from a rapid avulsion event.

## 3.2 ALTERNATIVE 2 – BANK STABILIZATION

The Bank Stabilization Alternative will use conventional river training and bank armoring structures to provide additional bank protection. This alternative was evaluated because gravel mining and other alternatives may not be feasible due to factors such as environmental regulations, economic viability, community needs, or inadequate technical performance.

### 3.2.1 Stabilization Options

Numerous bank stabilization methods have been used with varying successes within waterways of the United States. These are described in more detail in *Bank Stabilization Techniques* (MWH, 2004a). Based upon cost, constructability, permitting difficulty, and bank stabilization effectiveness, two methods that appear to be practical for long-term stabilization along the Matanuska River are riprap placement and spur dike installation.

**Riprap.** Riprap has been shown to be effective in protecting river banks in numerous applications. This option simply armors the bank with large rock that can withstand the forces and stresses from the river. Riprap would be installed from several feet above flood stage to several feet below channel bed elevations to the scour depth. Estimates of the length of bank needing protection have not been made in this report due to the subjectivity of these estimates.

**Spur Dikes.** Four spur dikes were constructed along the Matanuska River (near Bodenburg Butte) in 1992 to protect the bank from erosion (Figure 1-3). The existing spurs have withstood flows of over 30,000 cfs. These spur dikes have been effective in eliminating bank erosion along the stretches where constructed and should be considered for bank protection. New spurs are best located along the bank at locations that have experienced considerable erosion in the past, since they prevent the thalweg from reaching the bank.

#### 3.2.1.1 Options Considered and Eliminated From Further Study

Numerous bank stabilization efforts were eliminated from possible further consideration due to constructability, effectiveness, and/or other factors. These alternatives are briefly discussed below.

**Biotechnical Techniques.** This effort includes woody plantings, or herbaceous cover. It was determined that the Matanuska River is too massive and the banks too easily eroded for these efforts alone to fortify the bank enough to withstand the forces of the river.

**Subsurface Drainage Systems.** These systems increase slope stability by decreasing soil-pore pressure. Subsurface drainage systems can be installed in a variety of configurations, including chimney drains, collection drains, and gravel seams. They may include gravity or pumped systems. A 1968 soil survey of the Matanuska Valley Area (USDA, 1968) describes the soil type in the Study Area as primarily Bodenburg association with Susitna-Nicklason association, to the south. Both of these soil types are well-draining silt or fine sands, and would not be practical for this application. These systems also appear to be impractical for the Matanuska River, since the river system is too large for this type of an application.

**Floodplain Roughness.** This technique consists of installing items within the river to reduce energy in the flow. An increase in roughness is affected by the presence of live trees, shrubs, and large woody or other debris in the floodplain. This was determined to be impractical for the Matanuska River, since the river system is too large and variable for this type of an application.

**Gabions.** These are rocks encased in metal cages that armor the bank. These appear impractical for the Study Area because they are expensive, labor intensive to construct, and can be subject to scour failure.

### 3.2.2 Operation and Maintenance

The condition of any bank stabilization method, especially spur dikes or riprap, must be inspected on an annual basis and after any high flow events. Maintenance may include replacement of the construction materials that shift or disappear during high flows.

### 3.2.3 Mitigation Measures

Mitigation measures for bank stabilization construction within the riverbed, banks, and floodplain include:

- Proper care and inspection of equipment to eliminate oil and other contaminant leaks and spills. Spill plans are to be completed as necessary.
- Working in dry riverbed, where possible, to avoid in-stream work issues.
- Repairing, rehabilitating, or restoring the riverbed where disturbed in construction areas.
- Ensuring imported materials are clean and from known sources.
- Protecting fish habitat should be maximized where possible.

### 3.2.4 Anticipated Bank Protection Results

Installed riprap protects a bank from the stresses of higher velocity water along it. This armoring is not meant to alter the flow of the river, but typically does cause some local scour. In addition, riprap usually provides protection only to the section of bank that is armored.

The intended effect of spur dikes is to shift the thalweg away from the bank. The new thalweg alignment may, however, affect the downstream channel or banks. Appropriate spacing and sizing of spur dikes is important to reduce effects on downstream banks.

### 3.2.5 Advantages

The advantages of Alternative 2 include:

- Immediate protection of erosion prone areas.
- Ability to protect specific areas.
- Effectiveness of spur dikes and riprap efforts are known.
- Continued development in protected areas may be acceptable.
- Possible increase in nearby property values.

### 3.2.6 Disadvantages

The disadvantages of Alternative 2 include:

- Stabilization construction efforts can be costly and labor intensive.
- Bank stabilization efforts require long-term access to the property for maintenance of structures.
- The bank stabilization is only effective in the immediate vicinity of where it is constructed.
- Spur dikes or riprap generally do not create a favorable habitat for aquatic life due to a lack of vegetation and cover.
- These structures create the need for a long-term maintenance program.

## 3.3 ALTERNATIVE 3 – NON-STRUCTURAL APPROACHES

Non-structural approaches do not require construction or physical alteration of the riverbank. These could include zoning, land use changes, riparian setbacks, easements, public education, or even relocation of human structures and residents.

Land use measures that guide growth and development represent a potentially cost effective means of addressing the impact of river erosion. Northern Economics, Inc. provided the project team with an overview of the planning framework that could be the foundation for land use measures to address the effects of erosion (NEI, 2004b).

One result is a recommendation that the Mat-Su Borough prepare an updated Flood Mitigation Plan. Such a plan would enable the Borough or other entities to qualify for Flood Mitigation Assistance grants. Eligible activities include elevation of structures, relocation of flood-threatened (erosion-prone) insurable structures, and acquisition. Monies are available through a state administered, cost-share program for grants that can cover planning for flood mitigation, technical assistance, and mitigation projects.

In addition, the following is recommended:

- Real estate disclosure is critical in apprising current homeowners and potential homebuyers about flood hazard risk. Disclosure of erosion hazard risk should be required in the real estate transactions.
- Provide local realtors and lending institutions with Global Information System (GIS) copies of the Flood Insurance Rate Maps.
- Utilize GIS and other technologies (e.g. modeling) to analyze erosion risk.
- The Mat-Su Borough should consider seeking public input on utilizing property acquisition as a technique for willing sellers to sell flood-prone property.
- Identify appropriate properties for protection because of flood risks. Depending on public input, the Mat-Su Borough should pursue acquisition, conservation easements, or flood hazard protection regulations.

Some techniques for implementing such non-structural methods are discussed further below.

### 3.3.1 Zoning And Land Use Change

Zoning along the Matanuska River is described as a "least restrictive" area. This means that there are minimal restrictions on the type of development near the river. In addition to this zoning regulation, land use must comply with the federal Coastal Management Plan requirements near the river. The Mat-Su Borough planning department has proposed more extensive zoning requirements for the Matanuska River area, but these ideas have not been adopted.

An erosion management option involves altering the existing zoning of the area to encourage development that is at lower risk of continual erosion. For example, the City of Palmer or the Mat-Su Borough could use zoning to limit the development of new residences in areas with a high potential for erosion. Zoning and land use issues are politically difficult to resolve and private landowners may be adverse to changes that alter property use or value.

### 3.3.2 Riparian Setbacks

Setbacks from the river may be another method of ensuring, at least temporarily, that structures are not at risk from erosion of the riverbank. The Mat-Su Borough has setback requirements for the Matanuska River of 75 feet from the high water mark to any structure or footing, although exemptions can be made to come within these limits. However, this setback requirement may not provide an adequate buffer, since 100 linear feet of previously usable land near Circle View Estates eroded in 2004 due to high summer flows.

### 3.3.3 Public Education

Public education is important in order to relay information to Borough and City officials, potential property owners, developers, and other interested parties who have property interests along the Matanuska River. Real estate transactions particularly should be accompanied by information on erosion risk for affected properties. This information could help influence and alter property use practices in the area voluntarily. Numerous sources such as television, radio, newspapers, real estate professionals, bulletins, flyers, and radio could disseminate information. This would require a long-term effort, avoiding complacency during periods of little active erosion.

### 3.3.4 Relocation and/or Acquisition

Homes and structures could be relocated to locations away from erosion threats. Public acquisition of conservation easements or whole properties would clearly eliminate the risks to private individuals associated with development of areas at risk. This would likely only occur through voluntary or compensatory methods. Compensation could be an expensive option and may not be acceptable to local landowners.

### 3.3.5 Anticipated Results

Non-structural approaches can reduce the cost of property damage due to erosion, but are also potentially controversial. Furthermore, non-structural approaches will not eliminate or reduce bank erosion. Costs for these non-structural efforts are potentially much less expensive relative to structural alternatives. They can, however, be difficult to implement.

### 3.3.6 Advantages

The advantages of a non-structural approach:

- Greatest protection for future development projects.
- Reduces property damage from erosion.
- Enhances riparian habitat.
- Costs could be significantly less than structural alternatives.

### 3.3.7 Disadvantages

The disadvantages of non-structural approach:

- Community resistance due to perceived loss of property rights.
- Does not reduce erosion.
- Eliminates property from future development potential.

## 3.4 ALTERNATIVE 4 – COMBINED ACTIONS

This erosion management approach involves a combination of channel removal, bank stabilization, and non-structural approaches. As discussed in Section 3.1, models show that trench excavation may help reduce riverbank and property erosion, but may not be all that is required to reduce this risk. Combined actions may be needed.

The combined action considered in this report is:

- Constructing **bank stabilization structures** where bank erosion is at greatest risk. This includes a combination of spur dikes and riprap.
- Adopting new, **non-structural** policies and/or regulations regarding land use planning, zoning, and setbacks for undeveloped land.
- Implementing an annual **gravel removal** operation. Excavation should take place in reaches prone to high velocities and shear stresses that undermine the bank and cause erosion, such as the lower two of three reaches studied for this report. The mining areas would be determined by refining the modeling presented in this report and targeting areas to be protected.

### 3.4.1 Advantages

The advantages of Alternative 4 include:

- Most effective of the studied alternatives for erosion management.
- Possible revenue generation from gravel mining.
- Ability to transfer the thalweg of the river away from the susceptible banks.
- Ability to dynamically manage river process changes as they occur.
- Immediate protection of erosion prone areas.
- Development along river remains an option due to protection.
- Possible increase in nearby property values.
- Protection of riparian habitat on land protected from human occupation.

### 3.4.2 Disadvantages

The disadvantages of Alternative 4 include:

- Loss of some future land development opportunities.
- Winter gravel removal operation challenges.
- Potential groundwater control challenges for gravel removal operation.
- Gravel removal operation revenues not guaranteed, value of gravel and markets are variable.
- Gravel removal operation must be continuous, adaptive, and long-term.
- Spur dike or riprap stabilization generally does not create favorable habitat for aquatic life due to lack of vegetation and cover.

- Bank stabilization structures create the need for a long-term maintenance program.

## 3.5 ALTERNATIVE 5 – NO ACTION

The No Action Alternative would include leaving the river, banks, zoning, and land use as is. This alternative would maintain current river dynamics with frequent wild fluctuations in river routing and significant erosion within several areas in the study area. No bank protection would be added, and land use would remain as currently practiced. The results of erosion mapping by **nhc** include a map of the predicted 50-year erosion and the 50-year erosion boundary (Figure 2-7) if no future action is taken. The project team interpreted this map into zones of high, medium, and low risk of future erosion (Figure 3-3). Almost 10 miles of the Matanuska River banks in the Study Area are potentially at high risk of erosion.

### 3.5.1 Advantages

The advantages of Alternative 5 include:

- No short-term costs.
- No additional regulations to landowners.
- No planning or permitting efforts required.
- No loss of aquatic habitat due to structural approaches.

### 3.5.2 Disadvantages

The disadvantages of Alternative 5 include:

- Continued risk of erosion of property near Circle View Subdivision and other areas along almost 10 miles of Matanuska River bank in the Study Area.
- Risk of avulsion of the main river channels, resulting in erosion to areas not currently under erosion pressure.
- Continued lack of zoning and land use requirements.
- Catastrophic erosion could be politically unacceptable and possibly legally risky if bank protection efforts are not made.
- Costs to private landowners to protect property.

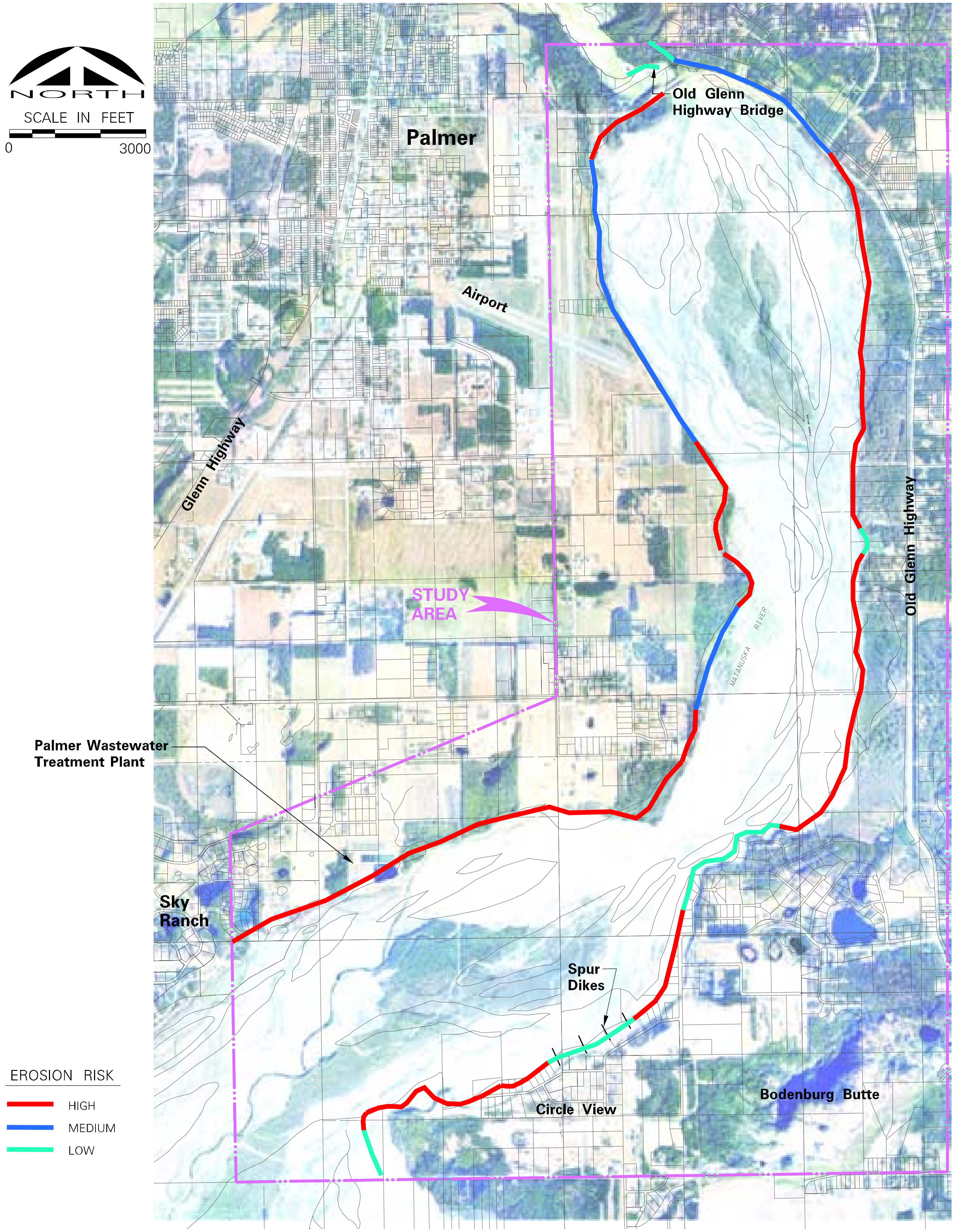



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FIGURE 3–3

USNRCS
MATANUSKA RIVER EROSION ASSESSMENT – DESIGN STUDY REPORT

**ZONES OF EROSION RISK POTENTIAL**

# 4.0 COMPARISON OF ALTERNATIVES

This section presents a comparison of the five alternatives in terms of feasibility, cost, and environmental consequences. The cost subsection includes the current value of life cycle cost and its equivalent average annual cost.

## 4.1 FEASIBILITY

Several factors affect the feasibility of each alternative:

- Bank Protection Effectiveness – If installed as planned, what level of protection from erosion is provided?
- Technical Difficulty – How difficult is the alternative to construct or implement?
- Institutional Feasibility – What government agencies will be involved, how difficult is the permitting and regulatory process?
- Inspection and Maintenance Requirements – What is the required inspection frequency and maintenance effort?

These factors are compared in Table 4-1.

**Table 4-1 Comparison of Feasibility of Alternatives**

| Alternative | Bank Protection Effectiveness | Technical Difficulty | Institutional Feasibility | Inspection And Maintenance Requirements |
|---|---|---|---|---|
| Gravel Removal | Moderate | High | High permitting constraints | Continuous/High |
| Bank Stabilization (riprap and spur dikes) | High | Moderate | Moderate permitting constraints | Yearly/Moderate |
| Non-Structural Approaches | Low | High | Local authorization (City and Borough) needed; Highly political. | Infrequent/Low |
| Combined Actions | Highest | High | High permitting constraints; many stakeholders involved. | Continuous/High |
| No Action | Low | Low | Locally controversial | None |

## 4.2 COST AND BENEFITS

It is beyond the scope of this study to provide preliminary engineering of a preferred alternative. Hence, cost estimates are conceptual and based on typical elements, plans, and sections associated with the design concepts presented in Section 4.2.1.

### 4.2.1 Design Concepts

#### 4.2.1.1 Gravel Removal

The concept is a trench or series of trenches 10 feet deep, 500 feet wide, and of various lengths from 2,500 to 6,500 feet (Figure 4-1). A gravel trap 1,150 feet wide and 16 feet deep is required for each 10,000 feet of trench. Other elements include an access road and a stockpile area on the alluvial terrace. Placement of the trenches and other elements must be determined during the design phase.

For purposes of conceptual cost estimating, the project team made the following assumptions for the initial excavation of the trenches and gravel trap:

- Use of four excavators and twenty 22-yard end dump trucks for initial excavation.
- Dump trucks make 24 round trips per day.
- Excavate and remove for 250 days.
- Monthly equipment lease rates.

The project team made the following assumptions for the annual excavation and gravel removal:

- 500,000 tons of removal per year.
- Use of two excavators and ten 22-yard end dump trucks for annual excavation.
- Dump trucks make 24 round trips per day.
- Excavate and remove for 59 days.
- Monthly equipment lease rates.

#### 4.2.1.2 Bank Stabilization

The two design concepts are riprap (Figure 4-2) and spur dikes (Figure 4-3). Two types of riprap are shown. The moderate riprap is for use on banks adjacent to gravel removal trenches. The major riprap is for banks outside of the protection zone from any gravel removal operations.

The scour depth, riprap size, freeboard, and top of riprap must be determined during design. Similarly, the length, riprap coverage and size, angle to bank, and height of spur dikes must be determined during the design phase.

For purposes of conceptual cost estimating, the project team made the following assumptions for moderate riprap:

- Top of riprap will be 12 feet above existing grade.
- Two to one side slope.
- Toe to depth of scour will be 4 feet below existing grade.
- Toe width of 4 feet.
- 2-foot thick riprap on sides and in the toe.

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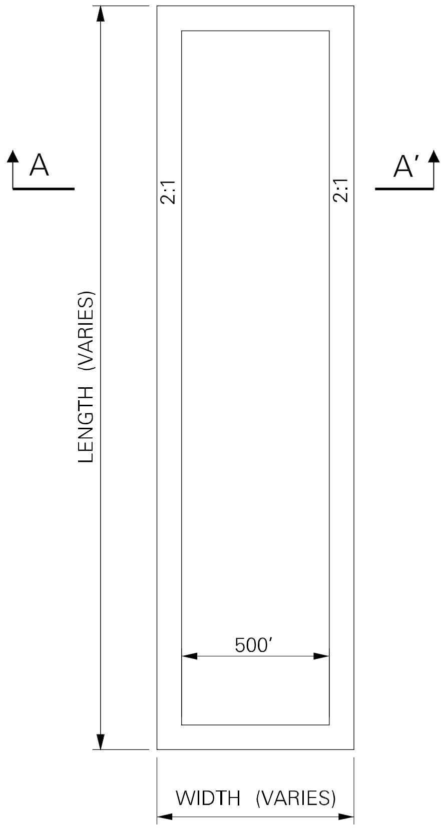


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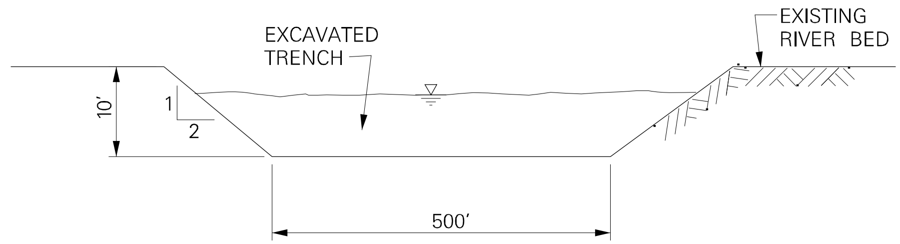


SECTION A – A'
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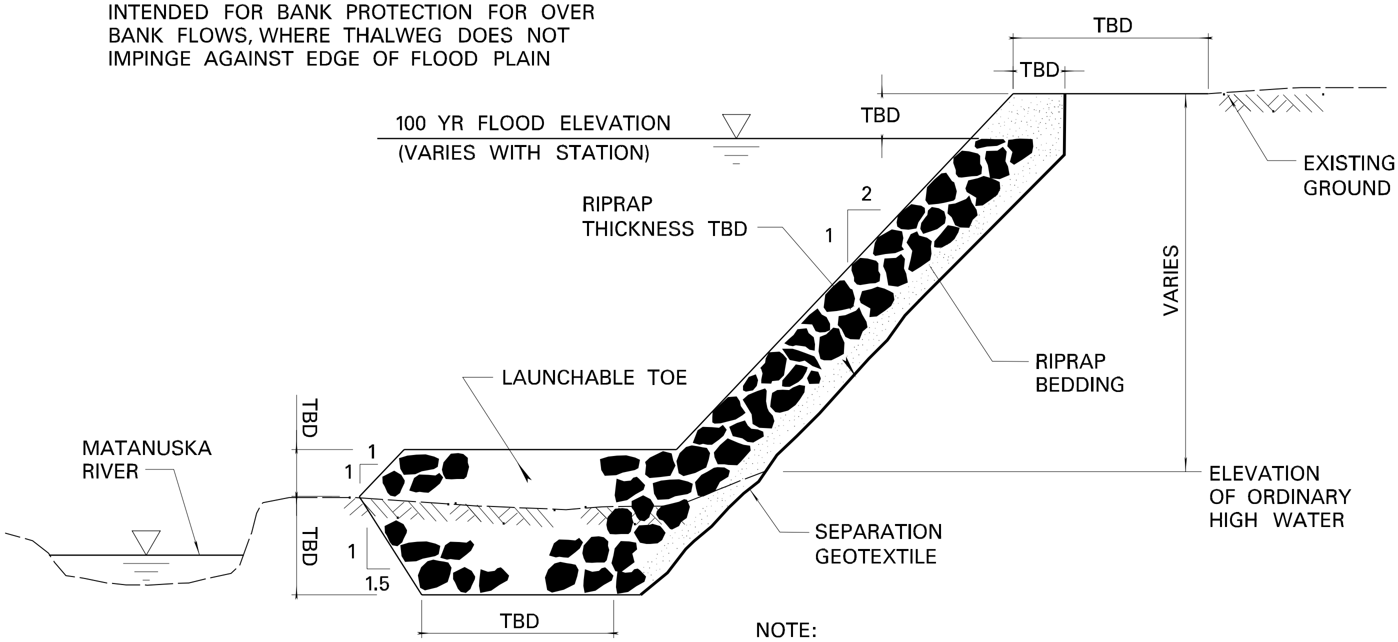
FIGURE 4–1

USNRCS
MATANUSKA RIVER EROSION ASSESSMENT – DESIGN STUDY REPORT

**GRAVEL MINING PLAN AND SECTION**

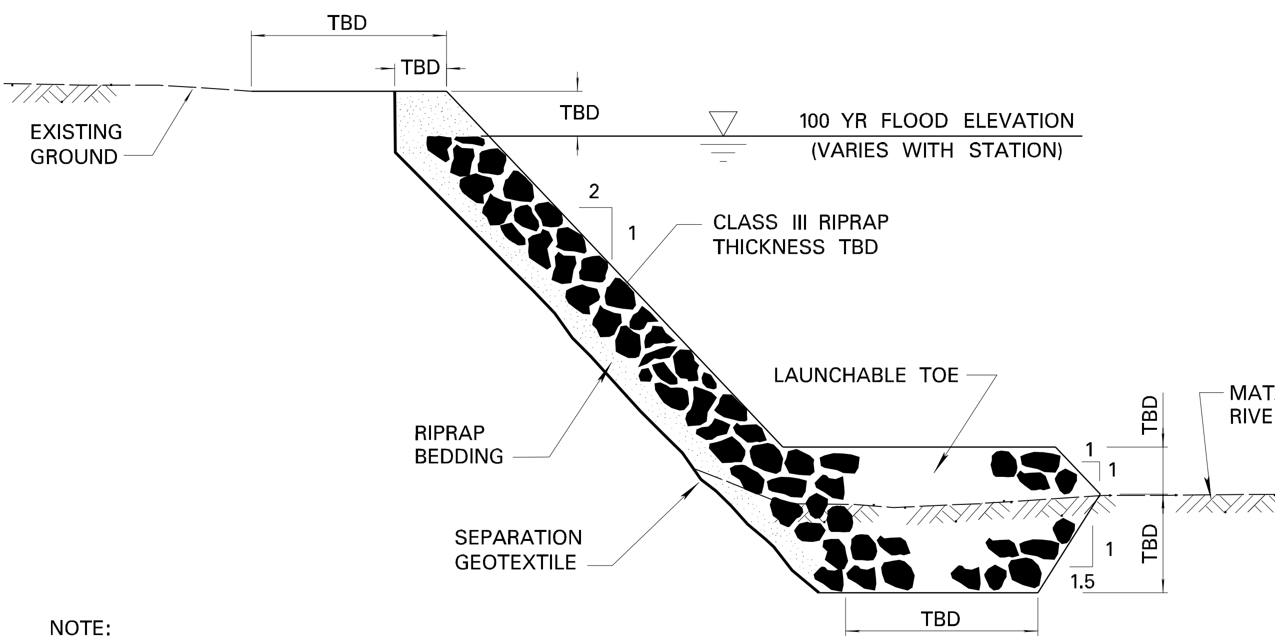
INTENDED FOR BANK PROTECTION FOR OVER BANK FLOWS, WHERE THALWEG DOES NOT IMPINGE AGAINST EDGE OF FLOOD PLAIN




NOTE:
DEPTHS AND WIDTHS TO BE DETERMINED (TBD) DEPENDING UPON SITE SPECIFIC SCOUR DEPTHS, BANK HEIGHTS AND RIPRAP THICKNESS

## MATANUSKA RIVER BANK STABILIZATION – MODERATE RIPRAP

NOT TO SCALE




NOTE:
DEPTHS AND WIDTHS TO BE DETERMINED (TBD) DEPENDING UPON SITE SPECIFIC SCOUR DEPTHS, BANK HEIGHTS AND RIPRAP THICKNESS

## MATANUSKA RIVER BANK STABILIZATION – MAJOR RIPRAP

NOT TO SCALE

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FIGURE 4–2

USNRCS
MATANUSKA RIVER EROSION ASSESSMENT – DESIGN STUDY REPORT

**RIPRAP BANK STABILIZATION SECTIONS**

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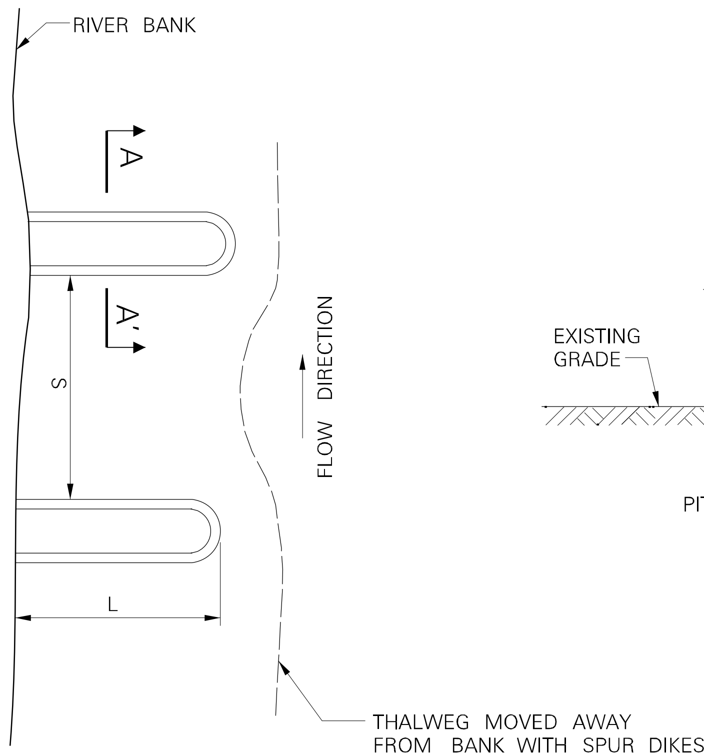


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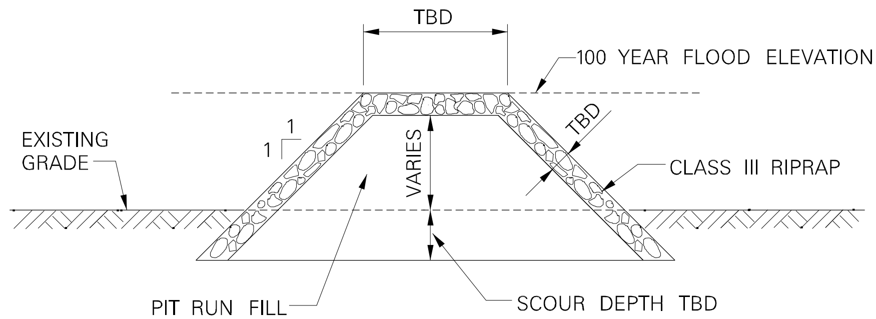


SECTION A – A'
NOT TO SCALE

NOTE:
LENGTH OF SPACE BETWEEN SPUR DIKES (S) IS ASSUMED TO EQUAL TWICE THE LENGTH OF THE SPUR DIKE ITSELF (L).

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FIGURE 4–3

USNRCS
MATANUSKA RIVER EROSION ASSESSMENT – DESIGN STUDY REPORT

**SPUR DIKE PLAN AND SECTION**

- 6-inch thick bedding material under riprap.
- Annual maintenance equals 2 percent of initial project cost.

For purposes of conceptual cost estimating, the project team made the following assumptions for major riprap:

- Top of riprap will be 16 feet above existing grade.
- Two to one side slope.
- Toe to depth of scour will be 4 feet below existing grade.
- Toe width of 6 feet.
- 3-foot thick Class III riprap on sides and in the toe.
- 6-inch thick bedding material under riprap.
- Annual maintenance equals 2 percent of initial project cost.

For purposes of conceptual cost estimating, the project team made the following assumptions for spur dikes:

- Length of bank protected equals twice the length of the spur dike.
- Dikes will be 12 feet high and 14 feet wide at the top.
- One to one side slope.
- 3-foot thick Class III riprap on top and sides.
- 6-inch thick bedding material under riprap.
- Excavation and placement of new material 4 feet below existing grade.
- Dikes will be 200 feet long.
- Annual maintenance equals 2 percent of initial project cost.

#### 4.2.1.3 Non-structural Approaches

The design concept is public land purchase or to legally set aside from human occupation land threatened by erosion from the Matanuska River. The project team estimated land value for two primary types of land purchase or protection from occupation: developed and undeveloped. These were further refined to account for the width of the protection zone and the density of the houses in the zone (Figure 4-4).

#### 4.2.1.4 Combined Actions

The design concept is a combination of structural approaches (gravel removal and bank stabilization) and non-structural approaches (Figure 4-5). The project team assumed the total length of bank protection consists of 25 percent each: gravel removal with moderate riprap on one of the adjacent banks, major riprap, spur dikes, and land purchase or set aside. The team further assumed that the land purchased or set aside is undeveloped.

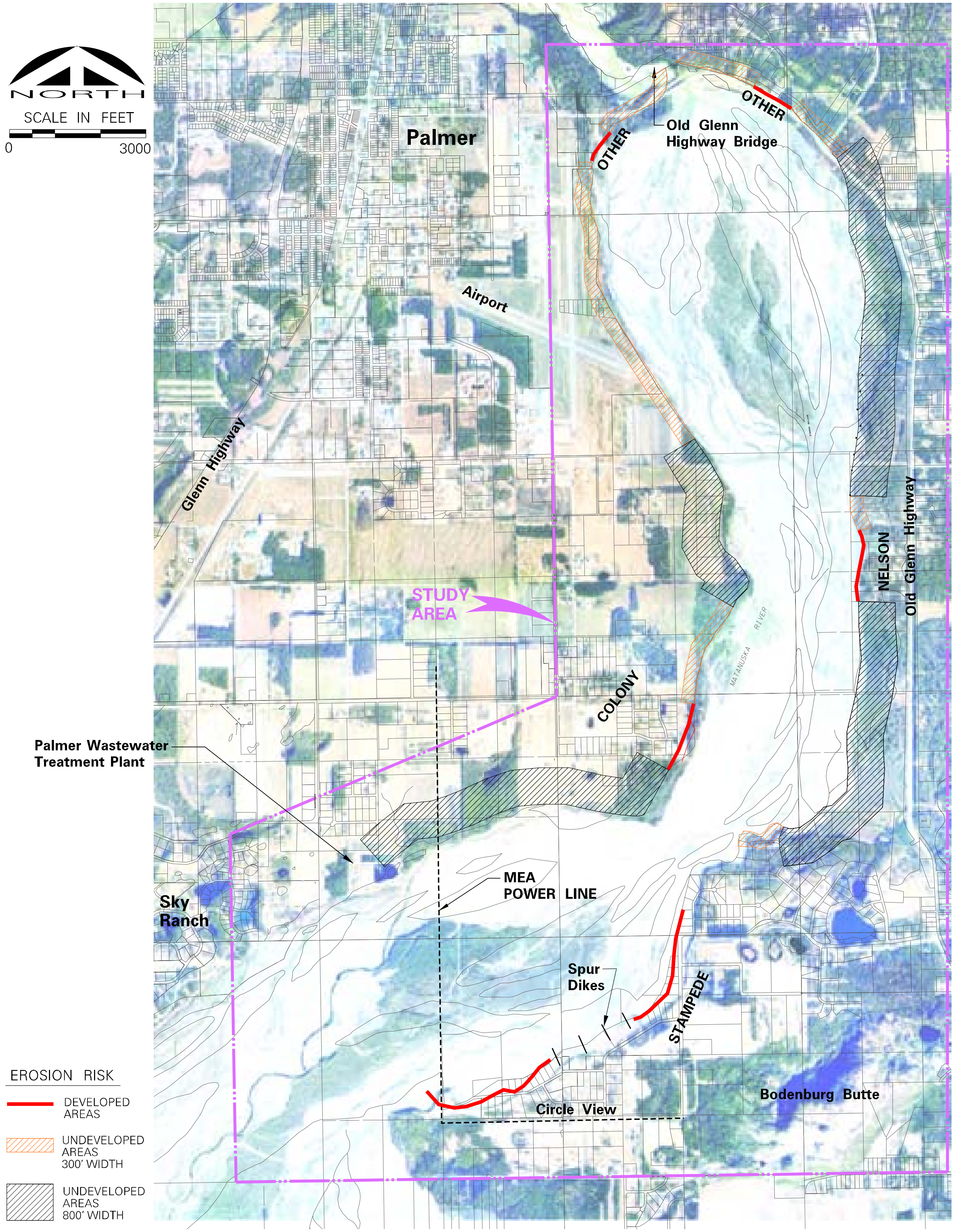


FIGURE 4–4

USNRCS

MATANUSKA RIVER EROSION ASSESSMENT – DESIGN STUDY REPORT

**LAND CLASSIFICATION – NON STRUCTURAL**

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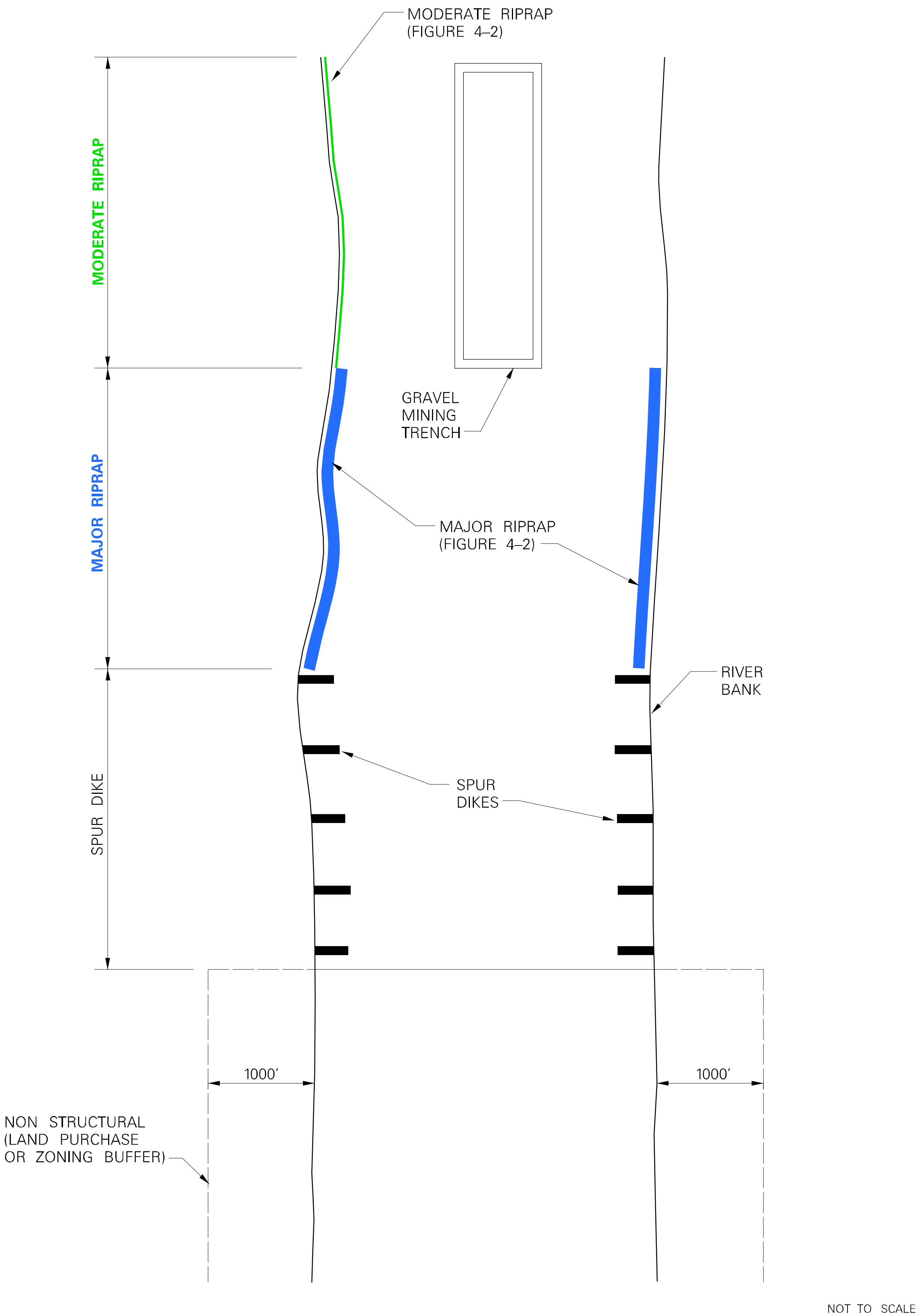


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FIGURE 4–5

USNRCS
MATANUSKA RIVER EROSION ASSESSMENT – DESIGN STUDY REPORT

**COMBINED ACTIONS – CONCEPTUAL PLAN**

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Note that a combined action could include purchase or vacating developed land, but this was not included in the cost estimate. The project team included moderate riprap on one bank for the gravel removal alternative to provide added protection in the event of a major channel shift or avulsion.

### 4.2.2 Cost Estimates

This section presents an estimate of the initial capital cost and subsequent annual O&M cost for each alternative. Costs are presented as total cost per foot of protected bank

#### 4.2.2.1 Gravel Removal

The initial capital and annual O&M cost estimates for gravel removal are presented in Table 4-2.

**Table 4-2 Initial Capital and Annual O&M Costs of Gravel Removal**

| Item | Unit | Cost Per Unit ($) | # Units Per Foot of Protected Bank | Cost Per Foot ($) |
|---|---|---|---|---|
| **Initial Capital Cost** | | | | |
| Excavate Trenches | Cubic Yard | 2.3 | 193 | 447 |
| Excavate Gravel Pit | Cubic Yard | 2.3 | 76 | 175 |
| Access Track | Foot | 10 | 0.5 | 5 |
| Stockpile Area | Acre | 3500 | 0.002 | 7 |
| Mobilization And Office | Lump Sum | 160,000 | 0.0001 | 16 |
| Engineering And Surveying | Lump Sum | 105,000 | 0.0001 | 11 |
| **Total** | | | | **661** |
| **Annual O&M Cost** | | | | |
| Excavate Gravel Pit and Trenches | Cubic Yard | 2.4 | 32 | 75 |
| Annual Mobilization and Demobilization | Lump Sum | 65,000 | 0.0001 | 7 |
| Annual Engineering, Permitting, and Surveying | Lump Sum | 105,000 | 0.0001 | 11 |
| **Total** | | | | **93** |

Key:
O&M – operation and maintenance

Marketing the gravel can offset the cost of gravel removal. The 2004 price list from AAA Valley Gravel, Inc. indicates pit run gravel at $3.00 per ton, or $4.50 per cubic yard. Annual revenues at $3.00 per ton would be approximately $1.5 million, or about $150 per foot of protected bank. However, there will be added costs associated with preparing the stockpiled material for sale and bringing the gravel to market.

It appears that selling the gravel at fair market value can offset most and probably all of the annual cost of gravel removal. Therefore, in the current value analysis presented in Section

4.2.3, the annual O&M cost for gravel removal operations equals the revenues received from gravel sale, resulting in a no net annual cost.

#### 4.2.2.2 Bank Stabilization

The bank stabilization design concepts evaluated in this cost estimate include major riprap, moderate riprap, and spur dikes. The initial capital and annual O&M cost estimates for bank stabilization utilizing major riprap are presented in Table 4-3.

**Table 4-3 Initial Capital and Annual O&M Costs of Bank Stabilization – Major Riprap**

| Item | Unit | Cost Per Unit ($) | # Units Per Foot of Protected Bank | Cost Per Foot ($) |
|---|---|---|---|---|
| **Initial Capital Costs** | | | | |
| Excavation | Cubic Yard | 8.0 | 1.0 | 8 |
| Place Riprap | Ton | 150 | 7.8 | 1,167 |
| Place Bedding | Ton | 3.5 | 1.1 | 4 |
| Geotextile | Square Yard | 1.3 | 4.0 | 5 |
| Design, Permitting, and Surveying | Lump Sum | 120,000 | 0.0003 | 40 |
| Mobilization | Lump Sum | 36,000 | 0.0003 | 12 |
| **Total** | | | | **1,236** |
| **Annual O&M Costs** | | | | |
| Maintenance | Annual Cost | 73,880 | 0.0003 | 25 |
| **Total** | | | | **25** |

Key:
O&M – operation and maintenance

The initial capital and annual O&M cost estimates for bank stabilization utilizing moderate riprap are presented in Table 4-4.

**Table 4-4 Initial Capital and Annual O&M Costs of Bank Stabilization – Moderate Riprap**

| Item | Unit | Cost Per Unit ($) | # Units Per Foot Of Protected Bank | Cost Per Foot ($) |
|---|---|---|---|---|
| **Initial Capital Costs** | | | | |
| Excavation of Toe | Cubic Yard | 8.0 | 0.6 | 5 |
| Place Riprap | Ton | 100 | 4.2 | 419 |
| Place Bedding | Ton | 3.5 | 0.8 | 3 |
| Geotextile | Square Yard | 1.3 | 3.0 | 4 |
| Design, Permitting, and Surveying | Lump Sum | 120,000 | 0.0003 | 40 |
| Mobilization | Lump Sum | 15,000 | 0.0003 | 5 |
| **Total** | | | | **483** |
| **Annual O&M Costs** | | | | |
| Maintenance | Annual Cost | 37,533 | 0.0003333 | 13 |
| **Total** | | | | **13** |

Key:
O&M – operation and maintenance

The initial capital and annual O&M costs for bank stabilization utilizing spur dikes are presented in Table 4-5.

**Table 4-5 Initial Capital and Annual O&M Costs of Bank Stabilization – Spur Dikes**

| Item | Unit | Cost Per Unit ($) | # Units Per Foot of Protected Bank | Cost Per Foot ($) |
|---|---|---|---|---|
| **Initial Capital Costs** | | | | |
| Excavation | Cubic Yard | 6.0 | 3.0 | 18 |
| Place Riprap | Ton | 150 | 4.3 | 640 |
| Place Bedding | Ton | 3.5 | 5.0 | 17 |
| Mobilization | Each Spur Dike | 3,000 | 0.0025 | 8 |
| Engineering, Permitting, and Surveying | Each Spur Dike | 9,000 | 0.0025 | 23 |
| **Total** | | | | **706** |
| **Annual O&M Costs** | | | | |
| Maintenance | Annual Cost | 5600 | 0.0025 | 14 |
| **Total** | | | | **14** |

Key:
O&M – operation and maintenance

### 4.2.2.3 Non-structural Approaches

The non-structural design concepts evaluated in this cost estimate include purchasing developed and undeveloped land. Undeveloped land is valued at $10,000 per acre. A developed parcel was valued at the average home price in Palmer and Wasilla ($125,000). This base value was adjusted upward to $150,000 or $200,000 per home in order to consider the development of the property in specific subdivisions with known area conditions. The study area was subdivided into reaches of developed or undeveloped land with one of the following characteristics:

- Undeveloped land with a protection zone width of 300 feet.
- Undeveloped land with a protection zone width of 800 feet.
- Developed land in the Circle View/ Stampede area, with a protection zone width of 800 feet.
- Developed land in the Colony Subdivision area, with a protection zone width of 800 feet.
- Developed land in the Nelson Subdivision area, with a protection zone width of 800 feet.
- Developed land in other areas, with a protection zone width of 200 feet.

The initial capital and annual O&M cost estimates are presented in Table 4-6.

**Table 4-6 Initial Capital and Annual O&M Costs Of Non-Structural Approach – Developed and Undeveloped Land**

| Item | Unit | Cost Per Unit ($) | # Units Per Foot Of Protected Bank | Cost Per Foot ($) |
|---|---|---|---|---|
| **Initial Capital Costs** | | | | |
| Undeveloped Land (300 feet wide) | Acre | 10,000 | 0.00689 | 69 |

**Table 4-6 (cont.) Initial Capital and Annual O&M Costs Of Non-Structural Approach – Developed and Undeveloped Land**

| Item | Unit | Cost Per Unit ($) | # Units Per Foot Of Protected Bank | Cost Per Foot ($) |
|---|---|---|---|---|
| **Initial Capital Costs (cont.)** | | | | |
| Undeveloped Land (800 feet wide) | Acres | 10,000 | 0.01837 | 184 |
| Developed Land: Circle View/Stampede | Home with Land | 150,000 | 0.0013[1] | 200 |
| Colony Subdivision | Home with Land | 200,000 | 0.0027[1] | 533 |
| Nelson Subdivision | Home with Land | 150,000 | 0.0020[1] | 300 |
| Other Developed Area | Home with Land | 125,000 | 0.0010[1] | 125 |
| **Total** | | | | **1,411** |
| **Annual O&M Costs** | | | | |
| Land (300 feet wide) | Annual Cost | 200 | 0.00689 | 1 |
| Land (800 feet wide) | Annual Cost | 200 | 0.01837 | 4 |
| Developed Land[1] – Circle View/ Stampede | Annual Cost | 3,000 | 0.0013 | 4 |
| Colony Subdivision | Annual Cost | 4,000 | 0.0027 | 11 |
| Nelson Subdivision | Annual Cost | 3,000 | 0.0020 | 6 |
| Other Developed Area | Annual Cost | 2,500 | 0.0010 | 3 |
| **Total** | | | | **29** |

Key:

O&M – operation and maintenance
1 – based on width of protected zone and actual number of homes present in that zone.

#### 4.2.2.4 Combined Actions

The initial capital and annual O&M cost estimates for a combined approach are presented in Table 4-7. The project team assumed that only undeveloped land would be considered for purchase under this action, with 50 percent of the undeveloped land having a 300-foot wide protection zone, and 50 percent having an 800-foot wide protection zone.

**Table 4-7 Initial Capital and Annual O&M Costs of Combined Actions**

| Item | Unit | Cost Per Unit ($) | # Units Per Foot Of Protected Bank | Cost Per Foot ($) |
|---|---|---|---|---|
| **Initial Capital Cost** | | | | |
| Gravel Operation | Foot of protected bank | 661 | 0.25 | 165 |
| Moderate Riprap | Foot of protected bank | 483 | 0.25 | 121 |
| Major Riprap | Foot of protected bank | 1,236 | 0.25 | 309 |
| Spur Dike | Foot of protected bank | 706 | 0.25 | 177 |
| Non-structural Approach – Undeveloped Land (300 ft) | Foot of protected bank | 69 | 0.125 | 9 |
| Non-structural Approach – Undeveloped Land (800 ft) | Foot of protected bank | 184 | 0.125 | 23 |
| **Total** | | | | **804** |

**Table 4-7 (cont.) Initial Capital and Annual O&M Costs of Combined Actions**

| Item | Unit | Cost Per Unit ($) | # Units Per Foot Of Protected Bank | Cost Per Foot ($) |
|---|---|---|---|---|
| **Annual O&M Costs** | | | | |
| Gravel Operation | Foot of protected bank | 93 | 0.25 | 23 |
| Moderate Riprap | Foot of protected bank | 13 | 0.25 | 3 |
| Major Riprap | Foot of protected bank | 25 | 0.25 | 6 |
| Spur Dike | Foot of protected bank | 14 | 0.25 | 4 |
| Non-structural Approach (300-ft width) | Foot of protected bank | 1 | 0.125 | <1 |
| Non-structural Approach (800-ft width) | Foot of protected bank | 4 | 0.125 | <1 |
| **Total** | | | | **37** |

Key:
< – less than
ft – feet/foot
O&M – operation and maintenance

#### 4.2.2.5 No Action

There is no initial capital cost associated with the No Action Alternative. The annual O&M cost is essentially the market value of the land, which is the current value of land estimated to be lost over the next 50 years. The project team assumed an average annual loss of 1/3-acre per year over a bank length of 1,500 feet, or 10 feet into the upper terrace. Undeveloped land is valued at $10,000 per acre. Developed land is valued at $18,000 per acre based on home values from $125,000 to $200,000, and the actual location and densities of development in the study area. Home values in the subdivisions were valued at $150,000 to $200,000. With these assumptions, the average annual cost of lost land is $2 per foot of bank for undeveloped land and $4 per foot of bank for land with structures (developed land).

### 4.2.3 Cost and Benefit Comparison

Section 4.2.2 presents the estimated cost of each erosion management alternative as initial capital and annual O&M in dollars per foot of bank protected. This section presents these costs adjusted back to current value of life cycle cost and equivalent annual cost. The current value computations are based on an annual discount rate of 4 percent and a 50-year life. Table 4-8 compares the cost of the action alternatives to the benefit associated with the No Action Alternative 5 cost.

**Table 4-8 Comparison of Costs of Alternatives**

| Alternative | Initial Capital Cost ($/ft) | Annual O&M Cost ($/ft) | Current Value of Life Cycle Cost[1] ($/ft) | Equivalent Annual Cost ($/ft/year) |
|---|---|---|---|---|
| 1. Gravel Removal | 661 | 0[2] | 661 | 31 |
| 2. Bank Stabilization | 1,236 (major riprap)<br>706 (spur dikes) | 25<br>14 | 1,773<br>1,007 | 83<br>47 |

**Table 4-8 (cont.) Comparison of Costs of Alternatives**

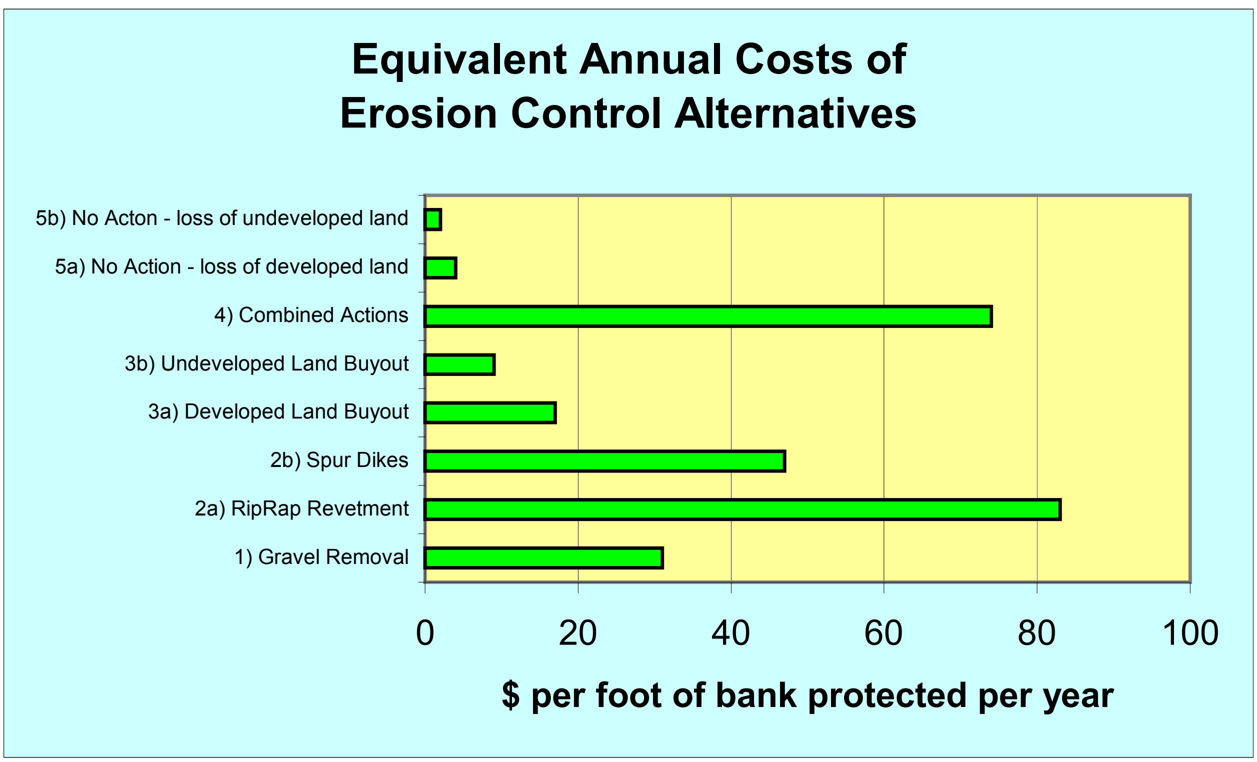
| Alternative | Initial Capital Cost ($/ft) | Annual O&M Cost ($/ft) | Current Value of Life Cycle Cost[1] ($/ft) | Equivalent Annual Cost ($/ft/year) |
|---|---|---|---|---|
| 3. Non-structural Approach[3] | 248 (developed land)<br>135 (undeveloped land) | 5<br>3 | 355<br>199 | 17<br>9 |
| 4. Combined Actions | 804 | 37 | 1,599 | 74 |
| 5. No Action | None | 4 (developed land)<br>2 (undeveloped land) | 86<br>43 | 4<br>2 |

Key:

1 – Current value at 4 percent over a 50-year period.
2 – Annual cost is offset by revenue from sale of gravel.
3 – Assumes that this approach is applied to the entire Study Area, costs will vary for specific locations.
$/ft – dollars per foot
O&M – operation and maintenance

Relative equivalent annual costs of the five erosion control alternatives are illustrated on Figure 4-6. The figure illustrates that the cost of any action alternative exceeds the estimated costs associated with allowing the continued loss of property due to erosion. Buyout of property has the lowest cost of any of the action alternatives, with higher costs associated with gravel removal and structural improvements.

**Figure 4-6 Equivalent Annual Costs of Erosion Control Alernatives**



## 4.3 ENVIRONMENTAL CONSEQUENCES

This section provides a comparison of the environmental consequences of each of the five alternatives for erosion management. Table 4-9 provides the project team's definition of significant environmental impact for the physical, biological, and human environments. The baseline condition is equivalent to No Action Alternative 5. This alternative is presented first, since it is the basis on which the project team judged the significance of impacts for the structural and non-structural alternatives.

Erosion control activities are unlikely to significantly alter the character of the Matanuska River and the physical, biological, and social environment of the watershed. Most importantly, the overall flow regime of the river and sediment transport will not be materially affected by any of the alternatives. Stabilization of banks will benefit preservation of the upland riparian outwash terrace and the value of properties potentially affected by continuing erosion. Impacts during construction of erosion control structures may include localized short-term impacts to air and water quality. Such effects are mitigated by permitting through the regulatory authority of the State of Alaska and Federal Government.

Fish habitat has not been quantitatively assessed in the study area. Changes in braided channels induced by gravel excavation or bank stabilization treatments may affect the velocity, depth, and quality of cover associated with the various assemblage of channels at any cross section of the floodplain. However, such effects are expected to be localized and very small compared to the scale of the floodplain and river system.

Table 4-9 Comparison of Environmental Consequences of Alternatives

| Topic | Definition of Significant Impact[1] | Alternative 5: No Action Baseline Condition | Alternative 1: Gravel Excavation | Alternative 2: Bank Stabilization | Alternative 3: Non-Structural Approaches | Alternative 4: Combined Bank Stabilization, Gravel Excavation, and Non-structural Approaches |
|---|---|---|---|---|---|---|
| **Physical Environment** | | | | | | |
| Air | A significant impact is one where air emissions from a project result in violation of National Ambient Air Quality Standards or applicable permits. | The area has few vehicle, equipment, or industrial emitters that affect air quality. Air quality is sometimes affected by smoke from forest fires, or dust particles entrained into the air from the Matanuska River floodplain. | Air quality emissions result from heavy equipment use during construction of the gravel-mining infrastructure and ongoing operation. Potential exposure of fine silty material to high winds. | Air quality emissions result from heavy equipment use during construction of the bank protection infrastructure. | No change from baseline condition. | Air quality emissions result from heavy equipment use during construction of the gravel-mining and bank protection infrastructure, and ongoing operation and maintenance. |
| Topography/ Geology | A significant impact is one where the overall character of the topography or geology is permanently changed. | The broad braided channel of the Matanuska River below the Glenn Highway Bridge is a dominant topographic feature of the landscape, encompassing an area larger than the town of Palmer and nearby suburban development. | Slight change of channel topography due to excavation. | Deepening of some channel reaches at toe of banks. | No change from baseline condition. | Slight change in channel topography due to excavation and deepening at toe of protected banks. |
| Soil | A significant impact is one where soil is lost from productivity for a long time period. | Soil of the glacial outwash terrace above the Matanuska River floodplain is better developed than the gravel bars and islands existing down on the floodplain. Continued bank failure due to erosion at the margins of the floodplain. Expect loss of 1/3-acre of outwash terrace soil on residential and agricultural land use within the study area on an annual average basis | Containment of flood flows and reduced occurrence of avulsion will allow gradual creation of more complex soil structure over drier portions of the floodplain. | Reduced loss of outwash terrace soil. | No change from baseline condition. | Reduced loss of outwash terrace soil. Containment of flood flows and reduced occurrence of avulsion will allow gradual creation of more complex soil structure over drier portions of the floodplain. |
| Hydrology | A significant impact is one where surface or ground water flow patterns are disrupted so as to result in down-gradient changes in flood frequency or ground water recharge potential. | Streamflow is a function of climatological patterns within the contributing watershed. Local human actions have no effect on influent flows, except for stream diversions or other consumptive use. | No change from baseline condition. | No change from baseline condition. | No change from baseline condition. | No change from baseline condition. |
| Water Quantity/ Supply | A significant impact is one that affects ground water recharge to the extent that a measurable shift occurs in water table elevations, lake levels, or streamflow. | Water levels at typical streamflow levels have potential to affect ground water elevations in wells on the adjacent glacial outwash terrace. | Projected changes in stream water levels would not result in a significant change in water tables. | Projected changes in stream water levels would not result in a significant change in water tables. | No change from baseline condition. | Projected changes in stream water levels would not result in a significant change in water tables. |
| Stream Geomorphology | A significant impact is one where surface flow patterns are disrupted so as to result in down-gradient changes in stream types or groundwater recharge potential. | Stream systems currently are in dynamic equilibrium associated with channel dimensions, patterns, and profile gradient and sediment transport regime. River continues to avulse in response to changes in sediment transport with respect to flow. | River induced into central deepwater channels, diverting channels away from eroding stream bank, but potentially concentrating flow flowing out of constructed channels.<br>Bank will still be subject to attack during avulsion. | Bank protection will likely amplify flow in the channel at the toe, leading to increasing depths and velocities adjacent to the hardening spurs or riprap. | No change from baseline condition. | River induced into central deepwater channels, diverting channels away from eroding stream bank, but potentially concentrating flow flowing out of constructed channels. Bank protection will likely amplify flow in the channel at the toe, leading to increasing depths and velocities adjacent to the hardening spurs or riprap. |

**Table 4-9 Comparison of Environmental Consequences of Alternatives**

| Topic | Definition of Significant Impact[1] | Alternative 5: No Action Baseline Condition | Alternative 1: Gravel Excavation | Alternative 2: Bank Stabilization | Alternative 3: Non-Structural Approaches | Alternative 4: Combined Bank Stabilization, Gravel Excavation, and Non-structural Approaches |
|---|---|---|---|---|---|---|
| **Physical Environment (cont.)** | | | | | | |
| Sediment Transport | A significant impact changes the net transport of material carried by the river and affects the character and distribution of sediments in downstream channel environments. | Annual transport of sediment by the river through the Study Area is flow-dependant, but expected to be on the order of 6 million tons per year. Sediment transport remains highly variable, with little predictable behavior of the channel from year-to-year.<br>Bank erosion contributes to downstream sediment load. | Capture of sediment by excavated channels is likely, and will require maintenance and additional gravel removal over time to ensure the continued functionality of gravel mining as an erosion control step. | Hardened bank can lead to more depth and scour at edge of stream. Potential deposition of sediments between spur dikes. | No change from baseline condition. | Capture of sediment by excavated channels is likely, and will require maintenance and additional gravel removal over time to ensure the continued functionality of gravel mining as an erosion control step. Hardened bank can lead to more depth and scour at edge of stream. Potential deposition of sediments between spur dikes. |
| Water Quality | A significant impact is one that results in a measurable degradation of water quality in violation of State of Alaska Water Quality Standards. | The Matanuska River experiences huge variations in turbidity in conjunction with glacial discharges and associated channel sediment mobilization. Erosion has launched materials potentially contaminated with petroleum products and fertilizer from homesites and farms into the river. Discharge of contaminants is viewed as insignificant in comparison to overall streamflow. | Potential for introduction of contaminants from equipment in the riverbed. Potential increase in turbidity during low flow period due to excavation. Potential for modest reduction in turbidity at margin of river associated with concentration of discharge in channel and concurrent settlement of suspended load. Reduced erosion of potentially contaminated residential, industrial, and farmlands. | Potential for introduction of contaminants from construction equipment in the floodplain. Reduced erosion of potentially contaminated residential, industrial, and farmlands. | Same erosion of potentially contaminated residential, industrial, and farmlands as baseline condition. Reduced future potential due to curtailment of development. | Potential for introduction of contaminants from construction equipment. Potential increase in turbidity during low flow period due to excavation in gravel removal reaches. Reduced erosion of potentially contaminated residential, industrial, and farmlands. |
| **Biological Environment** | | | | | | |
| Vegetation | A significant impact is one where a shift occurs in the general distribution of vegetation types in the Study Area, or there is a loss of viability of unique populations or uncommon species. | Vegetation on the Matanuska River floodplain is limited. Immigrant populations of alder, willow, and other pioneer species establish within a few years of a channel change resulting from episodic sediment deposition. Continued loss of riparian fringe vegetation. More mature forest types are lost from the glacial outwash terrace as erosion occurs along forested banks. | Potential increased diversity on the river bank through protection of vegetative communities. Limited change on floodplain to vegetation diversity or quantity anticipated. | Limits loss of riparian vegetation in concert with bank protection. May require some vegetation removal to accomplish stabilization. Optionally, may incorporate new vegetative plantings as stabilization method. | Continued loss of riparian fringe vegetation. Potential to preserve natural habitat as a component of land development restriction. | Limits loss of riparian vegetation in concert with bank protection. May require some vegetation removal to accomplish stabilization. Potential increased diversity through establishment of new vegetative communities on the fringe of the floodplain. Optionally, may incorporate new vegetative plantings as stabilization method. |
| Wetlands | A significant impact is one that results in a change in the relative distribution of wetland types, or loss of unique or uncommon wetland functions in the Study Area. A loss of wetlands is considered to be significant under the Clean Water Act and Executive Order 11990. | U.S. Fish and Wildlife Service has identified wetlands on a regional scale through its National Wetlands Inventory. The three types in the Project Area are riverine, freshwater/shrub wetland, and freshwater emergent wetland. | Requires analysis of potential wetland creation by virtue of excavation in the floodplain. | Some potential for encroachment on riparian wetlands through construction of structural improvements | Potential to preserve wetlands as a component of land development restriction. | Requires analysis of potential wetland creation by virtue of excavation in the floodplain. Some potential for encroachment on riparian wetlands through construction of structural improvements. Potential to preserve wetlands as a component of land development restriction. |

**Table 4-9 Comparison of Environmental Consequences of Alternatives**

| Topic | Definition of Significant Impact[1] | Alternative 5: No Action Baseline Condition | Alternative 1: Gravel Excavation | Alternative 2: Bank Stabilization | Alternative 3: Non-Structural Approaches | Alternative 4: Combined Bank Stabilization, Gravel Excavation, and Non-structural Approaches |
|---|---|---|---|---|---|---|
| **Biological Environment (cont.)** | | | | | | |
| Fish | A significant impact is one that results in direct loss of high value anadromous or resident fish habitat (e.g. known spawning, rearing, or over-wintering areas); restriction of fish passage; or direct mortality or measurable sub-lethal effects on the sustainability of regional fish populations. | Fish use of the Matanuska River includes passage to tributary spawning, rearing, and over-wintering areas, and depends on a system of channels providing variety of conditions with respect to cover, depth, velocity, water quality, temperature, and food supply. Hard data on Matanuska River fish resources is limited, so the effect of changes to habitat is largely speculative. Continued high degree of variability of habitat type in time and place, depending on streamflow and degree of channel avulsion and large woody debris transport. Diversity of habitat dependent on streamflow variability and amount of side-channels and sloughs. | Potential excavation in river during fish migration periods. Velocities and depth generally decrease at river margins. | Velocities and depth generally increase at river margins. | No change from baseline condition. | Potential excavation in river during fish migration periods. Some increase and some decrease in velocities and depth at river margins. |
| Birds | A significant impact is one that results in: loss of high value habitat; measurable affects on distribution, abundance, or movement in the project area; or in direct mortality or measurable sub-lethal effects on the sustainability of regional bird populations. | The broad gravel floodplain of the Matanuska River supports use by many species of raptors, waterfowl, shorebirds, and passerines. The relative abundance and distribution of avian life in braided floodplains versus upland wooded areas is undocumented. Potential loss of nesting in riparian wooded areas due to erosion. | Limited potential for effects to bird use. Some loss of shorebird habitat associated with earthmoving activities on the floodplain. Some potential for reduction of habitat loss due to erosion. | Some loss of shorebird habitat associated with earthmoving activities on the edge of the floodplain. Some potential for reduction of habitat loss due to erosion. | Protecting upland riparian lands from human occupation may improve potential for avian habitat. However, potential remains for reduction of habitat loss due to erosion. | Some loss of shorebird habitat associated with earthmoving activities on the floodplain. Some potential for reduction of habitat loss due to erosion. Protecting upland riparian lands from human occupation may improve potential for avian habitat. |
| Mammals and Other Wildlife | A significant impact is one that results in: loss of high value habitat; measurable affects on wildlife distribution, abundance, or movements in the project area; or in direct mortality or measurable sublethal effects that affect the sustainability of regional populations. | Upland wooded areas generally support a richer and more diverse system than the barren gravel floodplain. Loss of uplands to erosion has consequential loss of habitat. Two significant mid-river bars provide habitat. | Some loss of habitat associated with earthmoving activities on the floodplain. Potential for reduction loss of upland wooded areas due to erosion. | Some loss of habitat associated with earthmoving activities on the edge of the floodplain. Potential for reduction loss of upland wooded areas due to erosion. | Protecting upland riparian lands from human occupation may improve potential for wildlife habitat. However, potential remains for loss of uplands to erosion and consequential loss of habitat. | Some loss of habitat associated with earthmoving activities on the floodplain. Potential for reduction loss of upland wooded areas due to erosion. Protecting upland riparian lands from human occupation may improve potential for wildlife habitat. |
| Threatened and Endangered Species | A significant impact is one that results in a taking, including disturbance, or a loss or alteration of critical habitat. | There are no known threatened or endangered species in the Study Area. Therefore, the project cannot result in a disturbance, loss, or alteration of critical habitat. No impact reasonably foreseen. | No impact reasonably foreseen. | No impact reasonably foreseen. | No change from baseline condition. | No impact reasonably foreseen. |
| **Human Environment** | | | | | | |
| Land Use | A significant impact is one that results in a project being inconsistent with laws and regulations, or approved land use plans or policies. | Loss of 1/3-acre of land of unzoned use on an average annual basis. Erosion may result in loss of powerline in the future. | Reduced land loss. | Reduced land loss. Better protection than Alternative 1. | No change from baseline condition. | Further reduction in potential for loss of upland areas. |

**Table 4-9 Comparison of Environmental Consequences of Alternatives**

| Topic | Definition of Significant Impact[1] | Alternative 5: No Action Baseline Condition | Alternative 1: Gravel Excavation | Alternative 2: Bank Stabilization | Alternative 3: Non-Structural Approaches | Alternative 4: Combined Bank Stabilization, Gravel Excavation, and Non-structural Approaches |
|---|---|---|---|---|---|---|
| **Human Environment (cont.)** | | | | | | |
| Socioeconomics | A significant impact is one that results in a measurable shift in the volume of economic activity, or where increased population and demand for services cannot be accommodated by existing infrastructure. | Damage associated with property loss due to erosion amounts to $3,500 on an average annual basis for undeveloped property and $70,000 for developed property. Potential loss of powerline. | Introduces new construction jobs and 24 long-term seasonal gravel-mining operation jobs. Provides sand and gravel building materials for large-scale projects. May increase or decrease land values, and associated Borough property tax income, depending on the land location and immediate threat to erosion. | Introduces new construction jobs and periodic maintenance jobs. Protects land values and Borough property tax income. | Potential changes in land development and Borough tax revenue to reserve lands from human occupation. Reduces road and other infrastructure maintenance and upgrade costs. | Introduces new construction jobs, 24 gravel-mining operation jobs annually, and periodic maintenance jobs annually. Provides sand and gravel building materials for large-scale projects. Protects land values and Borough property tax income. |
| Cultural Resources | A significant impact is one where there would be a loss or degradation of archeological or historic sites. | Reworking of the floodplain by the braided stream channel limits the significance of the Matanuska River as a resource area for archaeological or historic sites. | Unlikely to encounter cultural sites on floodplain. | Bank protection improvements may require cultural resource screening of affected areas. | Potential to identify high-risk bank erosion areas for cultural resource evaluation. | Bank protection improvements may require cultural resource screening of affected areas. |
| Visual Resources | A significant impact occurs where the nature of the vista accessible to the public is changed by project features or activities. | Public access to viewpoints over the river floodplain is limited. Changes resulting from improvements and ongoing activities are expected to be minimal. | Gravel extraction activities not likely to encourage viewpoint development | Viewpoint development could be associated with bank protection projects, but depends on public accessibility. | Viewpoint development could be associated with land reservation from human occupation. | Viewpoint development could be associated with bank protection projects, but depends on public accessibility. |
| Noise | A significant impact is one where the duration, frequency, or level of noise is increased over ambient levels so that human or wildlife uses are measurably changed. | Existing noise levels include air traffic, highway traffic, and existing mining operations. | Some noise associated with construction and operations. Not significant compared to other sources. | Some noise associated with construction. Not significant compared to other sources. | No change from baseline condition. | Some noise associated with construction and operations. Not significant compared to other sources. |
| Recreational Resources | A significant impact is one that results in a measurable shift in the volume or type of recreational use over time, or a measurable change in the quality of the recreational experience for most users. | Little documentation of the amount of recreational floodplain use is available to make comparisons. However, the floodplain is used for recreational purposes. | Long-term gravel extraction activities may interfere with current recreational uses. | Bank protection projects may encourage recreational development or floodplain access. | Good potential to develop recreational use and floodplain access. | Long-term gravel extraction activities may interfere with current recreational uses. Bank protection projects may encourage recreational development or floodplain access. Good potential to develop recreational use and floodplain access on lands reserved from human occupation. |
| Subsistence Use | A significant impact is one that results in a measurable shift in subsistence resources, use or access. | Little documentation of subsistence use in the Matanuska River floodplain is available to make comparisons. | No effect anticipated. | No effect anticipated. | No change from baseline condition. | No effect anticipated. |

Key:

1 – There are no significant impacts to the physical, biological, or human environments from any of the alternatives; however, the character of potential impacts is presented for comparison.

# 5.0 LIST OF PREPARERS

A list of the personnel, companies, and agencies involved in preparing this Design Study Report is provided below.

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(***Bold, italics*** indicates the appendix in this report where the referenced report is located.)


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MWH. 2004b. Bed Material Sampling Program. Technical Memorandum. Prepared by K. Ivarson, MWH, for the NRCS Matanuska River Erosion Project. March 16. (***Appendix C***)

MWH. 2004c. HEC-RAS Modeling: Hydraulic Analysis. Technical Memorandum. Prepared by K. Ivarson, MWH, for the NRCS Matanuska River Erosion Project. October 5. (***Appendix E***)

MWH. 2004d. Matanuska River Hydrology. Technical Memorandum. Prepared by M. Langdon, MWH, for the NRCS Matanuska River Erosion Project. March 16. (***Appendix D***)

MWH. 2004e. Matanuska Survey Data Summary. Technical Memorandum. Prepared by N. Smith, MWH, for the NRCS Matanuska River Erosion Project. October 26. (***Appendix B***)

MWH. 2004f. Permitting, Regulatory, and Environmental Constraints. Technical Memorandum. Prepared by K. Ivarson, MWH, for the NRCS Matanuska River Erosion Project. August 25. (***Appendix G***)

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**nhc.** 2004c. Matanuska River Erosion Assessment – Reconnaissance Report. Prepared for MWH Americas, Inc. for the NRCS Matanuska River Erosion Project. January 13. (***Appendix B***)

**nhc.** 2004d. Matanuska River Erosion Assessment Progress Report – Bank Erosion Mapping. Prepared for MWH Americas, Inc. for the NRCS Matanuska River Erosion Project. March. (***Appendix F***)

**nhc.** 2004e. MIKE-21 Model of the Matanuska River near Palmer, Alaska. Technical Memorandum. Prepared for MWH Americas, Inc. for the NRCS Matanuska River Erosion Project . September 8. (***Appendix E***)

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# MATANUSKA RIVER EROSION ASSESSMENT

## Design Study Report

## VOLUME II: APPENDICES

MWH Job No. 1851040.010107

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# VOLUME II: APPENDICES

**A LITERATURE REVIEW**

**B FIELD INVESTIGATIONS AND SURVEYS**

Matanuska River Erosion Assessment Reconnaissance Report

Matanuska Survey Data Summary Technical Memorandum

**C SEDIMENT ANALYSIS**

Bed Material Sampling Program Technical Memorandum

Geomorphological Investigation of the Matanuska River – Palmer, Alaska, Technical Memorandum

**D HYDROLOGIC ANALYSIS**

Matanuska River Hydrology Technical Memorandum

**E HYDRAULIC ANALYSIS**

MIKE-21 Model of the Matanuska River near Palmer, Alaska, Technical Memorandum

HEC-RAS Modeling: Hydraulic Analysis, Technical Memorandum

**F STABILITY ANALYSIS/SEDIMENT TRANSPORT**

Matanuska River Erosion Assessment Progress Report – Bank Erosion Mapping

Matanuska River Erosion Assessment Gravel Removal and Bank Protection Progress Report

Bank Stabilization Techniques Technical Memorandum

**G PERMITTING, REGULATORY, AND ENVIRONMENTAL CONSTRAINTS**

Permitting, Regulatory, and Environmental Constraints Technical Memorandum

**H LAND USE AND ECONOMICS**

Mat-Su Erosion Land Use Measures Technical Memorandum

Market Analysis of Matanuska Valley Gravel Materials

# APPENDIX A

*Literature Review*

MWH

# MATANUSKA RIVER PROJECT – LITERATURE REVIEW

Alaska Department of Fish and Game (ADF&G). 1983. Susitna Hydro Aquatic Studies. Phase II Data Report.

Compilation of data from winter 1982 to spring 1983 in the Susitna hydroelectric study area. Data included in report: continuous surface and intragravel temperature monitoring, salmon incubation and emergence studies, timing and habitat conditions of burbot spawning in the lower river, and winter progress report of radio telemetry investigations of resident species.

ADF&G. 1984. Fish and Wildlife Resource Element for the Susitna Area Planning Study. ADF&G Habitat Division, Anchorage, Alaska.

Addresses the relationship between the demand for resources and the capacity of the land to meet those demands.

ADF&G. 1985. Susitna Hydro Aquatic Studies. Report series prepared for Alaska Power Authority.

Nine reports on Susitna River fisheries investigations. Reports include data from May 1983 through October 1984. These reports contain an abundance of raw data on the fisheries. Reports include habitat and instream flow investigations, juvenile and adult fish investigations, and an analysis on the availability of invertebrate food sources.

ADF&G. 1986. Cook Inlet Salmon Studies. Federal Aid in Fish Restoration and Anadromous Fish Studies. Vol. 27.

Compilation of nine Cook Inlet Salmon Studies. Studies focus on escapement numbers, sport fishing catches, and fish weight and length statistics. Various authors.

ADF&G. 1995. Fish Habitat Permit Application. Matanuska River Spur Dikes Project.

Request for permit to install four to six additional spur dikes along Matanuska River. Cites previously installed dikes as effective means of erosion control. Estimates that an additional 5,000 feet of bank erosion control could be achieved. Summary discussion on alternatives discussed by the Alaska Task Force: relocation of homes in Circle View/Stampede Subdivisions, Land Swap, Demolition, Armored Revetment, Spur Dikes, and Channelization.

ADF&G. 1996. Escapement and Stock Statistics for Coho Salmon on the Little Susitna River and Selected Matanuska – Susitna Valley, Alaska, Streams during 1994. Bartlett, L. Division of Sport Fish. AFF&G. Fishery Data Series No. 96-16.

Census, escapement, and fish stocking summary.

Alaska Department of Highways (ADOH). 1974. A Report on the Matanuska River Erosion and Overflow in the Vicinity of Bodenburg Butte.

Short discussion on the possible threat of the Matanuska River changing the location of its confluence with the Knik River, causing overflow and threat to homes and land. Summary of watershed size and normal flow ranges. Gives costs and feasibility of training dikes versus overflow dikes. Appendix includes multiple letters and memos referencing the flood threat and homeowner concerns, including a trip report from NRCS evaluating the river condition. References U.S. Army Corp of Engineer studies.

Alaska Department of Natural Resources (ADNR). 1982. Matanuska-Susitna-Beluga Cooperative Planning Program: Land Use Issues and Preliminary Resource Inventory.

Report provides background resource information for the Matanuska-Susitna Borough for: agriculture, forestry, fish and wildlife, recreation, settlement, subsurface resources, and transportation. Plans designate appropriate uses for public lands and guidance for private land use.

ADNR. 1986. Matanuska Valley Moose Range Management Plan.

Resource management plan for the Matanuska Valley Moose Range. Describes the general purpose and organization of the management plan. Provides a description and evaluation of the environmental resources found in the range. The resources described are: fish and wildlife, forestry, subsurface, heritage resources, water, grazing, transportation and access, materials, soils, and engineering geology. Resource maps are provided to clarify the location of the key resource values. Describes the rangewide land management policies that will apply to the Moose Range, and then describes subunit specific land management policies for the three management subunits. Describes the priorities for actions the agencies need to take to manage the Moose Range.

ADNR. 1998. Hydrology, Matanuska River – Draft.

This in-depth report describes the hydraulic and climatic characteristics of the Matanuska River drainage basin, with emphasis on river hydrology and parameters affecting and determining the river's hydraulic properties. Discusses seasonal variation, tributary discharges, suspended and bedload transport, erosion history, and rates. Includes section on fish and wildlife, and geology. Notes the presence of Dolly Varden char, rainbow trout, various species of salmon, Arctic grayling, round whitefish, burbot, three-spine stickleback, nine-spine stickleback, and longnose sucker within the Matanuska Valley Moose Range. Provides the locations of fish along the Matanuska River and its tributaries.

Alaska Department of Transportation (ADOT). Geotechnical Reports for the Glenn Highway.

A series of geotechnical reports.

Alaska Power Authority. 1988. Susitna Hydroelectric Project Document Index. Alphabetical Listing by Author.

Listing of all documents associated with the Susitna Hydroelectric Project. Provides keywords for each document.

Bradley, W.C, R.K Fahnestock, and E.T. Rowecamp. 1972. Coarse Sediment Transport by Flood Flows on the Knik River, Alaska. Geological Society of America Bulletin. Vol. 83(5): 1261-1284.

Summary of sediment changes in the Knik River, a glacial river with a valley train. During its first 16 miles of travel, the coarse fraction of the valley train changes systematically in size and shape. Grain size decreases by 94 percent. At the same time, specimens of quartz and graywacke become progressively more elongated, and foliated specimens show the same change initially, but then deviate to become progressively more platy. Down-valley changes in size decreased by only 8 percent. The sorting processes are the chief cause of changes of gravel shape and size, aided by frost action, which splits foliated particles into platy fragments. During shape-sorting, platy specimens are the most transportable, elongated specimens are intermediate, and compact (equidimensional) specimens are the least transportable.

Collins, W.B. 1992. Harvesting Birch-Spruce Forest to Enhance Moose Habitat in the Matanuska Valley Moose Range. Alaska Department of Fish and Game, Division of Wildlife Conservation. Wildlife Technical Bulletin; 10:ii, 1-37, tables, map.

Presents surveys of variety of timber-harvested sites to determine effect of different cutting and habitat site preparation techniques on hardwood (browse) regeneration and associated moose habitat values.

Collins, W.B. 1996. Wildlife Habitat Enhancement in the Spruce-Hardwood Forest of the Matanuska and Susitna River Valleys. Alaska Department of Fish and Game, Division of Wildlife Conservation.

Study examined various methods used to stimulate early successional hardwood production and enhancing habitat in boreal forests of Southcentral Alaska. Methods tested were timber harvest, scarification, burning, livestock grazing, various mechanical treatments, and a herbicide. Prescribed burning was the most economical and natural means to accomplish this habitat enhancement, but the extent of it's application is limited by concerns of safety, land use, smoke emission, and public perception.

Edmundson, J.A. and J.P. Koenings. 1988. Finger Lake Water Quality: August 1988. Alaska Department Fish and Game; 38 pp. Division Fisheries Rehabilitation, Enhancement and Development (FRED) Report No. 92.

Keywords: Water, Chemical and Physical Properties; Nutrients; Zooplankton, Freshwater; Algae, Freshwater; Limnology; Lakes; Metals; Bacteria; Oxygen; Conductivity; Production; History; Phosphorus; Nitrogen; pH; Alkalinity; Calcium; Fish, Anadromous

Fall, J.A. 1981. Traditional Resource Uses in the Knik Arm Area: Historical and Contemporary Patterns. Alaska Department of Fish and Game, Division of Subsistence. Technical Paper Series; 25 :1-24, map

Provides a brief summary of the traditional resource uses in the Knik Arm drainage area of Alaska. This report discusses the range of wild resources utilized in the variety of environmental settings found in the Knik Arm drainage, and identifies demographic, economic, political, and sociocultural factors that have affected the uses of this resource overtime. It concludes with an overview of contemporary patterns of resources usage within the Dena'ina communities of the area.

Feulner, A.J. 1971. Water-Resources Reconnaissance of a Part of the Matanuska-Susitna Borough, Alaska. Geological Survey Washington, D.C. Geological Survey Hydrologic Investigations Atlas Ha364, I Sheet, 1971. Text, 5 Fig, 3 Map, 2 Tab, 3 Ref.

This one-sheet hydrologic atlas consisting of maps, graphs, tables of data, and a descriptive text summarizes the groundwater and surface water resources of the Matanuska-Susitna Borough, Alaska.

G.N. McDonald & Associates (GNM). 1987. Sutton Erosion Control: A Report for the Matanuska- Susitna Borough Assembly.

Report describes current state of erosion control structures in the area of Sutton. Includes history of site, structure problems, erosion problems and permitting for past work. Provides alternatives for rehabilitation of structures and cost benefit analysis.

Goldsmith, O.S. 1992. South-central Alaska: An Economic Description. University of Alaska Anchorage, Institute of Social and Economic Research, 44pp. III., maps.

Survey of the economic activities (petroleum, fishing, tourism, military, transport, commerce, and state government) of the Anchorage-Kenai Peninsula-Matanuska-Susitna area of Southcentral Alaska.

Havens, A., T. Bradley, and C. Baer. 1995. Lake Stocking Manual for Non-anadromous Fisheries in South-central Alaska. Alaska Department of Fish and Game; 106 pp. Special Publication No. 95-2

An attempt is made to record a summary of Alaska Department of Fish and Game, Division of Sport Fish, Region II stocking history and stocked lake research from the 1960s through the early 1990s. Data are presented on survival and growth of sport fish species stocked in landlocked lakes. Information on physical, chemical, and biological properties of natural lakes in Southcentral Alaska and their relationship to stocked sport fish survival and growth is summarized. Development and use of experimental nets and traps to sample both native and stocked fishes is discussed. Procedures necessary to include a lake in the stocking program are outlined. General recommendations for stocking and sampling sport fish in Southcentral landlocked lakes are included, with specific recommendations for Matanuska- Susitna Valley lakes being listed. A summary of effort, catch, harvest, and related estimated costs is presented for Matanuska-Susitna Valley Lakes from 1986 through 1992. A list of lakes with information on drainages, fish species present, and Fish Transport Permit(s) is also included.

Havens, A.C. 1982. Sport Fish Investigations of Alaska. Lake and Stream Investigations: Population Studies of Game Fish and Evaluation of Managed Lakes in the Upper Cook Inlet Drainage. Alaska Department Fish and Game; 38 pp. Vol. 23.

Annual Performance Report for July 1981. Two stocking sized of Swanson strain rainbow trout (*Saimo gairdneri Richardson*), in six Matanuska- Susitna Valley lakes (some containing three-spine stickleback) were studied to determine survival, growth, and total yield, and limnological conditions affecting survival and growth.

Havens, A.C. 1984. Lake and Stream Investigations: Population Studies of Game Fish and Evaluation of Managed Lakes in the Upper Cook Inlet Drainage. Alaska Department of Fish and Game; 30 pp.

Annual Performance Report for Research Project Segment for July 1983.

Havens, A.C. 1991. Evaluation of Enhancement Efforts for Rainbow Trout in South-central Alaska, 1990. Alaska Department of Fish and Game; 42 pp.

Experiments were conducted to provide information for the development of improved stocking practices for hatchery-reared rainbow trout in landlocked lakes.

Hudson, K. 1992. Comments Regarding the Draft Alaska Task Force Report on Erosion of Matanuska River Basin. Memorandum Prepared by Chief of Code Compliance, Matanuska-Susitna Borough, Department of Planning.

Memorandum notes that the Task Force identifies useful options. Includes comments on organization of report, need for more in-depth discussion, and prioritization of alternatives.

Hulbert, R. 1989. Sedimentation in Lower Matanuska River. Completed as a Portion of Graduate Course CE683, Arctic Hydrology and Hydraulic Engineering, University of Alaska, Anchorage.

The study focuses on the delta of the Matanuska River, from just north of Bodenburg Butte downstream to Knik River. The study examines sedimentation in general and specific historical observations of the lower Matanuska River. Preliminary estimations of sedimentation are given and methods proposed to refine these estimates. Some predictions are made regarding future sedimentation and the effects on existing dikes and structures.

Jokela, J.B., J.A. Munter, and J.G. Evans, et al. 1991. Ground-water Resources of the Palmer-Big Lake Area, Alaska: A Conceptual Model. Alaska Department of Natural Resources. Division of Geological and Geophysical Surveys. Report of investigations, July 1991; 90-4, 38p. + maps; 20 refs.

Provides a conceptual ground water model for this area in order to provide a planning tool for water supply and waste disposal system design, to enhance understanding of ground water resources, and help protect ground water resources and supplies. The model consists of watershed delineation's, a summary of geologic conditions in the area, a regional water-table map, representative cross sections for key areas, and descriptions of ground and surface water interactions in the area. To demonstrate its utility, the model is applied to areas of particular concern.

Komarnitsky, S.J. 2001. "Hungry River." Anchorage Daily News Article. July 9.

Article on erosion occurring near homes.

Knott, J.M. and S.W. Lipscomb. 1983. Sediment Discharge Data for Selected Sites in the Susitna River Basin, Alaska. Alaska Power Authority. U.S. Geological Society Open File Report. 83-870.

Summarizes sediment and hydraulic data collected at five sites in the Susitna River basin in the area between the proposed dam sites and Sunshine. Data was collected during the water years 1981-82 to determine total sediment yield of the Susitna, Chulitna, and Talkeetna Rivers prior to any construction activities.

Kornmuller, J. No Date. Matanuska River Project Report - Summary. Prepared by Palmer Soil and Water Conservation District, Matanuska River Information Office, with Alaska Division of Mining and Water Management. Long, W.E. (editor).

Summary of watershed conditions including hydrology, vegetation, and morphology. Estimates of stream flow and bedload provided, cites State of Alaska and USGS as references. Briefly addresses issue of erosion.

LaSage, D.M. 1992. Ground Water Resources of the Palmer Area, Alaska. Alaska Department of Natural Resources. Division of Geological and Geophysical Surveys. Report of Investigations, No. 92-3.

A summary of the Matanuska-Susitna Borough ground water resource investigation results. The investigation was conducted primarily to improve and expand the current database of well logs, produce a map showing the locations of available well logs, and provide information on ground water occurrence, usage, and quality.

Lipscomb, S.W. 1989. Flow and Hydraulic Characteristics of the Knik-Matanuska River Estuary, Cook Inlet, Southcentral Alaska. U.S. Geological Society, Water Resources Investigations Report 89-4064.

A study of the riverine-estuarine reach of the Knik and Matanuska Rivers provided flow and hydraulic data for use in the design of additional bridges over the rivers. Hydraulic analysis is complicated because: 1) the lower reaches of the rivers merge in a complex system of interconnected channels; and 2) this reach is subject to unsteady flow conditions resulting from a semidiurnal tide wave propagated up the channel through Knik Ann from Cook Inlet, whose tidal range is among the largest in the world. Analysis of flows for the Knik River is further complicated by the historic formation and outburst flooding of glacier-dammed Lake George in the Upper Knik River basin. Peak flows on the Knik River due to breakout floods were as much as seven times greater than peak flows of non-breakout floods. The U.S. Geological Survey's branch-network flow model was used to simulate flows within the study reach. For the Knik River, simulated flows were within 10 percent of measured values in most cases. The model was also used to simulate the flow, stage, and velocity that would be expected in the various channels under different bridge configurations.

Maurer, M. 1998. Hydrologic Data for the Matanuska River Watershed, Southcentral Alaska. Public Data File 98-41. State of Alaska, Department of Natural Resources, Division of Geological and Geophysical Surveys.

Summary of hydrologic and water quality data for the Matanuska River Watershed. Brief description of watershed.

Matanuska-Susitna Borough (Mat-Su Borough). 1987. August 15, 1987, Public Meeting on Erosion in the Matanuska River. Minutes of meeting led by Senator Mike Szymanski.

Discussion on erosion rates, gravel extraction as option for erosion control, potential costs and funding. Need for immediate intervention stressed by attendees.

Mat-Su Borough. 1986. Overall Economic Development Program.

Provides background information on existing conditions within the Mat-Su Borough. Physical conditions addressed are: geology, topography, soils, hydrology, climate, vegetation, fish and wildlife, mineral resources, agricultural resources, and geophysical hazards. Socioeconomic conditions addressed are: population and growth, community services, economic profile, housing and building lots, employment, and sectors of the economy. Gives recommendations based on this information.

Mat-Su Borough, Cultural Resources Division. 1989. Survey of Historic Sites in the Matanuska Coal Field, Alaska. Grants-in-Aid 88254.

The Mat-Su Borough received a historic preservation grant to survey, inventory, and evaluate, historic sites within the Matanuska Coal Field. The report organizes the historic sites within the Matanuska Coal Field into related groups, to facilitate planning.

Meiritt, R.D. 1986. Coal Geology and Resources of the Matanuska Valley, Alaska. Alaska Division of Geological and Geophysical Surveys.

The Matanuska Valley contains relatively small but important reserves of coal. Identified resources amount to about 90 million metric tons, and hypothetical resource estimates range to 450 million metric tons. Most of the potentially mineable resources are concentrated in the Eska-Moose (Wishbone Hill) and Chickaloon fields. The near-term coal-development potential in the Matanuska Valley is high, particularly in the Wishbone Hill district.

Paulsberg, G. 1989a. Recap of Agencies Meeting on Matanuska River Problem. Memorandum prepared by Engineer II, Matanuska-Susitna Borough, Public Works Department. August 15.

Memorandum on Agencies Meeting summarizes discussion and conclusions. Two options discussed for providing authority to control river erosion: land trade and formation of River Management District.

Paulsberg, G. 1989b. Review of Matanuska River Flood Potential. Memorandum prepared by Engineer II, Matanuska-Susitna Borough, Public Works Department. August 2.

Memorandum on field meeting discussing current conditions of Matanuska River. Brief discussion noted on river flood and erosion potential. Includes two options for erosion control (rip rap and gravel fill), with estimated costs for discussed ideas.

Peratrovich, Nottingham & Drage, Inc. (PND). 1991. Matanuska River Erosion Control. Prepared for Matanuska-Susitna Borough, Department of Public Works.

Preliminary report addressing the feasibility of a gravel extraction project to reduce erosion. An attachment “Prototype Erosion Abatement System” documents the decision to proceed with construction of the spur dikes using the PND design.

PND. 1992. Matanuska River Erosion Control Recommendations. Prepared for the Matanuska-Susitna Borough, Department of Public Works.

Review of 1992 spur dike construction project, spur dike performance, and recommendations for maintenance and future erosion control in the Circle View and Stampede Estates area. Recommends additional erosion control using spur dikes as the most cost-effective method available.

PND. 1994. Matanuska River Erosion Study: Field Trip Observations and General Erosion Control Recommendations.

The report documents 1994 Matanuska River flow character, performance of spur dikes, and erosion at two sites. Erosion control measures are recommended.

PND. 1995. Response to Request for Additional Information Regarding DA Permit Modification N-910508, Matanuska River 66. Letter to U.S. Army Corps of Engineers, Regulatory Branch.

Summary of additional alternatives for the site erosion control and their feasibility. These alternatives include: home relocation program, land swap, demolition, armored revetment, channelization, and spur dikes. Additional discussion on spur dikes with an outline of temporary dikes during construction of permanent structures and a schedule of work.

Reckendorf, F. 1989a. Matanuska River Special Report. Soil Conservation Service. West National Technical Center, Portland, OR. 11 p.

Report describes the geomorphology, hydrology, and stream bank stability of the Matanuska River. Summary evaluation of the use of spur dikes as a means of erosion control, including history of existing dikes.

Reckendorf, F. 1989b. Trip Report – Technical Assistance on Erosion and Sedimentation along the Lower Matanuska River, Alaska. Soil Conservation Service. West National Technical Center, Portland, OR.

Letter to B. Clifford, State Conservationist. Brief summary of meeting, including background information. Recommendations include: interagency field evaluation of dike at Bodenburg Loop Road, interagency agreement on long term solution, reactivation of a U.S. Geological Survey stream gage, and that the U.S. Army Corps of Engineers be requested to evaluate sediment transport and conditions.

Rinehart, S. 1983. “Rocks Arrest Erosion, Matanuska River Advance Stopped.” Anchorage Daily News Article. September 8.

Article on placement of rock dike for erosion control

Rulison, T.B. 1989. Preliminary Damage Assessments. Prepared by Civil Engineer, Matanuska-Susitna Borough. September 7.

Field trip assessing damage to flood control dikes in the Bodenburg Butte area. Also includes newspaper clippings of erosion problems in the area. October 13. 1989: Correspondence between Mayor of Mat-Su Borough, Department of Military Affairs, and the U.S. Army Corps of Engineers. Discussions pertaining to a concept plan for a levee system developed by the Corps.

Sharp, L. 1985. Flooding and Bank Erosion on Matanuska River. Memorandum prepared by Borough Attorney, Matanuska-Susitna Borough Attorney's Office.

Memorandum provides opinion on the use of Borough funding for erosion control projects.

Skaugstad, C. and J.H. Clark. 1991. Evaluation of the Stocking of Mixed Species of Game Fish in Small Lakes. Alaska Department of Fish and Game, Division of Sports Fish, 1991 viii, 110 p.: maps ; 28 cm.

Results of stocking game fish in 44 small lakes, ponds, and gravel pits in the Tanana Valley near Fairbanks and Delta Junction, and in three small lakes in the Matanuska and Susitna Valleys near Palmer and Sutton, with recommendations to limit mixed stocking to two species per area.

Skaugstad, C. 1989. Evaluation of Arctic Grayling Enhancement: A Cost per Survivor Estimate. Alaska Department of Fish and Game; Fishery Data Series No. 96, 80 pp.

Purpose was to determine the best size (weight) to stock age-O (young-of-year) grayling based on the cost per survivor at age 1. Grayling were stocked as sac fry and fingerings in lakes near Fairbanks, Glennallen, and Palmer. Information was also collected to determine if species composition and potential lake productivity influenced the survival rate and growth of stocked grayling.

Stirling, D.A. 1981. Historical Uses of the Matanuska River. Alaska Department of Natural Resources.

Overview of the historic uses on or near the Matanuska River, gathered from published and unpublished sources, as well as from questionnaires and oral interviews. Physiography of the river and history of the river's use are presented in sections dealing with Native use prior to white contact, Russian and American exploration, use of the river from World War II to statehood, and use of the river from statehood to the present. The Matanuska River has a history of use as a travel route for hunters and trappers, and is known for its commercial use as a recreational area.

Updike, R.G. 1984. Liquefaction-Susceptibility Analysis for Foundation Soils, Knik River Bridge, Glenn Highway, Alaska. Alaska Division of Geological and Geophysical Surveys. IV, 33p, Report of Investigations, 84-26.

Sediment on which the bridge is founded apparently failed during the 1964 Prince William Sound Earthquake. Four methods of liquefaction-susceptibility analyses were used to study this site: historic observation, examination of borehole and cone-penetration-test logs, standard-penetration-test evaluation, and state-of-the-art quantitative assessment.

Updike, R.G., N. Yamamoto, and P.W. Glaesman. 1984. Moisture Density and Textural Analyses of Modern Tidal Flat Sediments, Upper Knik Arm, Cook Inlet, Alaska. Alaska Division of Geological and Geophysical Surveys.

Substantial growth in both the economy and population has occurred in the upper Cook Inlet region of Alaska during the past 50 years. This growth extends from Anchorage northward along the east side of Knik Arm to Palmer and Wasilla.

Currently, the Alaska Department of Transportation and Public Facilities is examining the feasibility of a bridge or cause-way across Knik Arm. The rapidly expanding infrastructure continues to place greater demands on this region, which includes the tidal flats of Knik and Turnagin Arms. Because these tidal areas may become the site of new port and dock facilities, recreational areas, dredged shipping channels, roads, and bridges, the geotechnical characteristics of the sediments that comprise the flats must be evaluated. These characteristics will dictate future engineering designs of facilities in the tidal-flat areas. This report provides baseline information on the nature of surface sediments exposed on these flats at low tide.

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

Provides a summary of Matanuska and Little Susitna studies performed prior to 1972. Describes the economic development in the area. Climatology, runoff, and stream flow data are given. Discusses various alternatives 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.

USACE. 1989. Emergency Flood Control Measures, State of Alaska Plant Materials Center. Palmer, Alaska. Hydraulics Hydrology. Prepared by USACE – Alaska District.

Provides a conceptual design of a levee for flood protection of the State of Alaska Plant Materials Center. Statement that a levee is the best option for a solution to the flooding. No discussion of alternative solutions is presented. Cost estimates provided for various levee construction options.

USACE. 1991. Erosion Control of the Matanuska River near Bodenburg Butte. Prepared by USACE – Alaska Task Force.

Report outlining flooding and erosion control problem, and discussing the economics and viability of various structural alternatives for erosion control. Concludes that there is no economic justification for structural alternatives, but that non-structural management of the floodplain should be explored.

USACE. 1992. Matanuska River Erosion Task Force Interim Report. Prepared by USACE – Alaska Task Force.

Report investigating the erosion problem along the Matanuska River. The report evaluates various engineering solutions, relocation options, Federal Flood Insurance Programs, and land management alternatives for a long-term solution to erosion threatening property and homes. Solutions were evaluated on the basis of the following: capabilities, cost, potential for success, difficulty of implementation or potential for adverse affects, and legal issues.

USACE. 1996. Planning Assistance to States: Matanuska River at Bodenburg Butte Erosion Study.

Historical erosion patterns and the local erosion rates in the vicinity of Circle View Subdivision and Stampede Estates Subdivision are documented. Major road construction and geologic events are also documented. Available photographs and other data sources were compiled and analyzed to document the erosion patterns. Cross-sections of the river conducted by DOWL in 1995 were obtained to determine the difference in bed elevation between the north and south channels. Concludes that erosion rate along spur dike reach is approximately 20 feet per year, assuming that flow will remain in the south channel. Notes possibility of flood event depositing enough sediment to shift the channel to the north.

USACE. 1999. Matanuska River Reconnaissance Report. General Investigations Report. Section 905(b) (WRDA 86) Analysis.

Study was conducted to determine the problems, needs, and opportunities related to land and water resources of the Matanuska River Watershed. Includes a summary of the River hydrology with bedload transport estimated by the USGS (no specific reference provided) at 267,000 cubic yards of material. The report lists several prior studies with a summary of each. Study evaluates existing conditions, expected future conditions, and a watershed plan alternative for rehabilitation. Discusses Federal interest, possible Federal funding and establishes a basis for a cost sharing agreement and project study plan.

Wenderoff, L.R. 1982. Trophic Competition Between Three-spine Stickleback (*Gasterosteus aculeatus*) and Rainbow Trout (*Saimo gairdneri*) in Three Lakes in the Matanuska Valley South-central Alaska. M.S. thesis, Idaho State University, 76p. FR 37(3)

A study that examines if dietary overlap in food items leads to low growth and survival of rainbow trout, and if varying the time of planting might improve planting success.

Woods, P.P. 1985. Limnology of Nine Small Lakes, Matanuska-Susitna Borough, Alaska, and the Survival and Growth Rates of Rainbow Trout. Geological Survey Anchorage, AK. Water Resources Div. Water Resources Investigations Report 85-4292, 1985. 32p, 12 fig, 8 tab, 24 ref.

The survival and growth rates of rainbow trout (*Saimo gairdneri*) were concurrently measured with selected limnological characteristics in nine small (surface area less than 25 square hectometers) lakes in the Matanuska-Susitna Borough. The project goal was to develop empirical models for predicting rainbow trout growth rates from the following variables: total phosphorus concentration, chlorophyll a concentration, Secchi disc transparency, or the morphoedaphic index-a means of characterizing potential biological productivity. No suitable model could be developed from the data collected during 1982 and 1983.

Williams, G.P., and M.G. Wolman. 1984. Downstream Effects of Dams on Alluvial Rivers. Geological Society Professional Paper 1286. U.S. Geological Survey.

This study describes changes in mean channel-bed elevation, channel width, bed-material sizes, vegetation, water discharges, and sediment loads downstream from 21 dams constructed on alluvial rivers.

Woodward-Clyde Consultants (WCC). 1980. Gravel Removal Studies in Arctic and Subarctic Floodplains in Alaska. Technical Report. FWS/OBS-80/08. U.S. Department of the Interior, Fish and Wildlife Service.

A technical report presenting data analyses and conclusions resulting from a 5-year study of 25 floodplain material sites in Arctic and sub-Arctic Alaska. Provides guidelines to insure minimal environmental degradation when siting, operating, and closing floodplain material sites.

## LITERATURE IDENTIFIED BUT NOT AVAILABLE FOR REVIEW – (SUMMARIES PROVIDED BY OTHERS)

Barber, W.F. 1995. Evaluation of Alternatives for the Bodenburg Loop Road Erosion Problem near Circle View Subdivision. Alaska Department of Transportation and Public Facilities, Central Region.

Gatto, L.W., D.J. Calkins, E.F. Chacho, Jr., D.E. Lawson, and R.A. Melloh, et al. 1992. Applications of ERS-I SAR Data for Analyzing Riverine and Coastal Processes and Geomorphology. p.873-878, ERS-I Symposium, Cannes, France, Nov. 4-6. Proceedings, Vol.2. Space at the service of our environment. Edited by B. Kaldeich: Paris, European Space Agency, 1993; 7 refs.

An objective in analyzing European Space Agency ERS-I SAR images was to determine their utility in monitoring environmental conditions and processes important for managing water resources. This paper summarizes the initial analyses of such SAR images of various geomorphic features around Alaska. Patterns on SAR images are compared to those on Landsat images, and data from ground-penetrating radar and field observations is used to interpret the SAR images. These comparisons show that the ERS-I SAR can locate unfrozen water beneath river and lake ice on the Sagavanirktok River floodplain; determine the general ice, snow, and sediment conditions along the Matanuska Glacier; show general near-shore ice conditions and coastal geomorphology along Alaska's north shore; and delineate coastal wetlands vegetation along Knik Arm.

Havens, A.C. 1983. Sport Fish Investigations of Alaska. Lake and Stream Investigations: Population Studies of Game Fish and Evaluation of Managed Lakes in the Upper Cook Inlet Drainage. Alaska Department Fish and Game; 29 pp. Vol. 24.

Annual Performance Report. Period Covered: I July 1982. Swanson strain rainbow trout (*Saimo gairdneri Richardson*) populations stocked in nine lakes were investigated.

Helm, D.J. 1992. Of Moose and Mines. Agroborealis; 24(1): 41-48, ill.

Reports studies carried out by staff of Agricultural and Forestry Experiment Station, University of Alaska Fairbanks, into moose browse as one of the planned objectives of a proposed reclamation project of land used in former coal mining in Matanuska Valley. Seeks to determine woody plant species survival and growth rates on area's soils and investigates seed mixes appropriate for different goals.

Idemitsu Alaska, Inc. (IAI). 1989. Wishbone Hill Coal Mine. Surface Coal Mining Permit Application. Submitted to Alaska Department of Natural Resources, Division of Mining, Anchorage, Alaska.

Lawson, D.E. 1982. Mobilization, Movement and Deposition of Active Subaerial Sediment Flows, Matanuska Glacier, Alaska. Cold Regions Research and Engineering Lab. Hanover, NH. Journal of Geology, Vol. 90(3): 279-300.

Subaerial sediment flows, which deposit diamictons at the terminus of Matanuska Glacier, Alaska, were investigated during 1974-79. The flows originate where sediments overlie glacier ice. Ablation of ice on slopes releases the sediment and mixes it with melt water and debris. Sediment begins to flow as a result of excess pore and seepage pressures produced by melt water. Sediment flows vary widely in dimensions, texture, flow rates, density, erosional action, grain support, and transport mechanisms which depend on changes in water content of the material. At low water content, flows support grains by their strength and move through shear in a thin zone at their base. Increased water content increases the thickness of the shear zone and produces deformations such as grain interference and collisions, localized liquefaction and fluidization, transient turbulence, and bedload traction. Flows with maximum water content are fully liquified and well-mixed. Mobilization of a sediment flow changes the glacial sedimentary properties of its source. Therefore, the diamicton deposited by sediment flow should not be called till.

Liepitz, G. 1988. Memo from ADF&G Habitat Biologist regarding Sutton erosion control. December 9.

Meeting held at Ed Musial's residence. Mr. Musial voiced concerns that previous flood control efforts constructed just downstream of his property were causing flooding of a small anadromous fish stream (Yellow Creek) and erosion of his property. He requested that the U.S. Army Corps of Engineers and ADF&G issue the necessary approvals to remove the previously built dike and to place fill in the high water channel that was diverting flows into Yellow Creek. Stated that the dikes were in poor condition and not serving their original purpose.

Lipscomb, S.W. 1987. Calibration and Verification of a One-dimensional Flow Model to the Knik and Matanuska Rivers; South-Central Alaska. In Huntsinger, R.G. (Technical Chairman), Water Quality in the Great Land – Alaska's Challenge. Proceedings, American Water Resources Association, Water Research Center – Institute of Northern Engineering. University of Alaska, Fairbanks. Report IWR-109, p. 43-54.

Lipscomb, S.W. 1989a. Branch Flow Model of the Knik and Matanuska Rivers, Alaska. Proceedings of the Advanced Seminar on the One-dimensional, Open Channel Flow and Transport Modeling. June 15-18, 1987. National Space Technology Laboratory, Bay St. Louis, Mississippi. USGS Water Resources Investigations Report 89-4061, p. 62-64. Pace Technology L4 ref.

A study of the combination riverine-estuarine reach of the Knik and Matanuska Rivers has been conducted by the U.S. Geological Survey, to provide hydrologic and hydraulic data for use in the design of additional bridge crossings of the two rivers. Both rivers originate at large glaciers in the Chugach Mountains, empty into Cook Inlet, and are characterized by a complex system of interconnected channels that meander across a wide floodplain. The branch-network (BRANCH) unsteady-flow model has been used to evaluate the hydraulic characteristics of the Knik-Matanuska river system. Implementation of the model required input of cross-sectional geometry data at critical locations throughout the network of channels, as well as time series of boundary-value stage and/or discharge data at the upstream and downstream extremities of the study reaches. Three sets of discharge data were collected for calibration and verification purposes.

Intermittent flow in overflow channels posed a problem in model implementation. Accommodating this problem created difficulties in calibrating the model at low flows; because the objective of the study is to develop tools for analyzing flood flows, calibration of the model in the high discharge range is more critical.

Simulations were run that synthesized different bridge configurations and were found to aid in optimizing the bridge design.

Long, W.E. 1998. Channel Shifting and Bank Erosion of the Matanuska River near Palmer.

Defines historical bank locations through analysis of available aerial photography. Relates historical erosion and channel shifting to major flooding events. Discusses causes of channel shifting and erosion and theoretical extent of future erosion.

Mayo, L.R. 1986. Annual Runoff Rate from Glaciers in Alaska: A Model Using the Altitude of Glacier Mass Balance Equilibrium. Proceedings of the Symposium: Cold Regions Hydrology, University of Alaska, Fairbanks. American Water Resources Association, Bethesda, Maryland. p. 506-517.

Glaciers in Alaska occur in high precipitation areas where the runoff is difficult to measure. The spatial variability of glacier runoffs poorly understood. The equilibrium line altitude (ELA) of glaciers is related inversely to the average precipitation rate. Therefore, information about the average runoff from individual glaciers is contained in ELA data. Newly evaluated information about runoffs is available from topographic maps, and a proposed ELA runoff model determines average annual runoff from glacial basins in Alaska. The runoff rate was calculated for the Knik River Basin, Alaska, using the model. The test data indicated a 2.0-meter per year runoff, which compares with the average runoff rate of 2.03 meters per year as measured from 1959-1985. The ELA model was also applied to an ungaged site in Alaska – the Bering Glacier drainage basin. Data indicated that 34 cubic kilometers of water is produced annually from this basin. The Bering Glacier is the largest glacier in Alaska, and the source of 76 percent of the discharge from the basin, with an average drainage into the Gulf of Alaska of approximately 1,080 cubic meters per second.

Menzies. J. 1995. Hydrology of Glaciers. P. 197-239, Modern Glacial Environments: processes, Dynamics, and Sediments. Butterworth-Heinemann Ltd., Oxford , England.

Reichmuth, D.R. 1987. Living with Fluvial Systems, a Short Course on River Mechanics. Geomax, P.C.

Provides an outline designed to analyze natural river behavior and man's use and abuse of stream systems. Emphasis is placed on non-mathematical approaches, which describe the effects of geology, runoff, sediment transport and man's activities on stream stability. Stream systems are analyzed using an interdisciplinary approach that combines hydrologic, geologic, and biologic interactions. Numerous illustrations provided.

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# APPENDIX B

*Field Investigations and Surveys*

# Matanuska River Erosion Assessment
# Reconnaissance Report

**Prepared For:**

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**November 11 to 13, 2003**
**Revised January 13, 2004**

2-1246

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# Table of Contents

# 1. INTRODUCTION

As stated in the background to the statement of work:

> "For over fifty years, the Matanuska River Erosion problem has been a major concern for the citizens of the Wasilla and Palmer area of Alaska. During this period, Palmer has developed and continues to grow around the river. Erosion now may threaten homes, roads and other surrounding infrastructure. The Natural Resources Conservation Service, an agency of the United States Department of Agriculture, needs assistance to defend against the processes causing erosion, the rates of erosion, possible solutions to the erosion problem, and the regulatory constraints on their solutions. In addition, citizens are interested in gravel extraction as a means of controlling the erosion".

At this early stage of the project, staff from Northwest Hydraulic Consultants, namely Mr. Brad Hall and Dr. Vic Galay traveled to Anchorage, Alaska in order to gain knowledge of the river system and the extent of ongoing erosion, to review the available literature and data base, and to prepare a survey program as well as a bed material sampling program. Meetings were held with individuals from Montgomery Watson Harza and other relevant agencies:

i) MWH staff:

J. Brett Jokela PE, Project Manager

K. Ivarson, Hydrogeologist

Mel Langdon, PE, Environmental and Permitting

Mary Loise Keefe Ph.D., Regulatory and Environmental Sc. Manager

ii) NRCS

Rob Sampson, PE, State Conservation Eng.

Mike Knudsen, PE, Conservation Eng.

iii) Northern Economics Inc.
Caren L. Mathis, MCP, Planning Services
Calvin Kerr, MBA, Analyst

iv) Bill Long, former chief, ADNR Div. of Water

v) Matanuska – Susitna Borough, Palmer, Alaska
Don Shiesl, Director of Public Works
Jim Rowland, Engineer.

An overflight was conducted over the river system from Cook Inlet to the Matanuska Glacier on November 11, 2003 and oblique photos of various geomorphic features were taken.

This brief reconnaissance report presents a summary of the literature and data that was reviewed, discusses potential methods for reducing erosion by thalweg diversions and presents a survey program and bed material sampling program.

A list of the reviewed literature is presented in Appendix 1 along with other references to gravel excavation cases and guidelines in Alaska and elsewhere.

# 2. GEOMORPHIC PROCESSES ALONG MATANUSKA RIVER

## 2.1 Geomorphic Description

The Matanuska River has a watershed area of about 2,070 sq. miles with about 10 percent, some 200 sq. miles, taken up by the Matanuska Glacier (see Figure 2.1). The river valley is bounded by the Chugach Mountains to the south and the Talkeetna Mountains to the north. The river empties into Cook Inlet where it is joined by the Knik River from the east. Large tributaries such as Gravel Ck, Chickaloon River and Granite Ck enter the Matanuska bringing large quantities of sediment. The river itself has developed a series of confined alluvial fans which are separated by glacial debris or bedrock gorges such as at the highway bridge at Palmer (see Photo 2.1). This gorge is relatively narrow resulting in a high velocity jet during high flows carrying sediment which drops out as a central bar/island in the wide downstream river (see Photo 2.2). This deposition process results in the development of a confined alluvial fan with the highest part of the fan being in the middle of the cross-section and active flow channels being pushed to each side, thereby eroding the channel banks. The detailed behavior of the deposition process will be discussed in more detail for several confined fans that are shown in Figure 2.1.

The river slope averages approximately 0.005 (from Fahnestock and Bradley, 1973). The slope varies between the gorges and the confined fan reaches as depicted in Figure 2.2.

Upstream from several gorges, the internal confined alluvial fans exhibit braided channel patterns which extend from valley wall to valley wall. Sometimes there exists a single dominant flow channel which shifts frequently across the gravel bed as shown in Photo 2.3. Fahnestock and Bradley (1973) describes the lateral shifting of the Matanuska deposition zones as follows:

> "The Matanuska at normal summer high flows is actively changing the details of its complex pattern, vigorously attacking and undercutting a tree laden bank or island, depositing bars and levees across channel mouths, blocking flow from active channels or raising the local bed elevation to cause the reactivation of abandoned channels. Even at the gaging station at the bedrock narrows, the rattle and hiss of gravel bed load movement can be heard and discharge measurements on successive days show the changes in channel cross-section."

The river indeed is actively transporting gravel during high flows. The source of the gravel, sand and silt is from landslides (Photo 2.4), from tributaries which form alluvial fans where they enter the Matanuska (Photo 2.5), from erosion of river terraces (Photo 2.6), from exposure of sediment at the base of the receding Matanuska Glacier (Photo 2.7) and from surface erosion within the watershed. Several constricted reaches serve as vertical controls and cause accumulations of gravel upstream. The constriction downstream from the Chickaloon River appears to be a glacial deposit such as a terminal moraine as shown on the map sheet of Figure 2.3. The river has cut through this deposit where it flows as an incised single channel.

Farther downstream, the river has constructed three wide alluvial fan reaches, the Moose Creek fan, the Palmer fan and the Bodenburg fan as shown on the map of Figure 2.4. Also, Photos 2.8, 2.9 and 2.10 show aerial views taken on November 11, 2003. The annual suspended sediment yield has been estimated from periodic sampling by the USGS to be about 5 million tons at Palmer. The bedload portion (gravel) was assumed to be equal to eight (8) percent of this total, or 400,000 tons (Reckendorf, 1989) but this preliminary figure is based on very limited bedload sampling. More discussion regarding the sediment yield, gravel loads and sediment budget are presented in the following sections with more descriptions of each specific geomorphic reach.

## 2.2 Gravel Budget

In order to assess the viability of reducing bank erosion by gravel excavation, it is essential that the gravel budget be clarified in terms of movement of gravel into a gravel excavated reach and the rate at which gravel is being supplied. A total sediment budget is the volume of sediment moving past several locations, or gaging stations, along the mainstem of a river system. The total sediment volume is generally made up of suspended load (silt and clay and sand) which does not deposit on the bed of the river and is also called the wash load, plus a portion of the sand load plus the gravel load which is frequently referred to as bed load. It should be noted that the sand load moves both as suspended load and bed load, but is predominantly moving as suspended load. In gravel rivers, sediment measurements represent the suspended load, and researchers estimate the gravel (bedload) to range from 0 to 20 percent depending on river characteristics.

In order to develop a first approximation of a sediment budget for the Matanuska River, we can represent the suspended load budget by starting at Palmer with an annual load of 5,000,000 tons and a bedload of 400,000 tons. We can then add upstream suspended load starting from the glacier by assuming inputs from tributaries (see Figure 2.1) until the total input at Palmer is accumulated. We will also assume that this material does not drop out until it reaches the delta reach as shown in Figure 2.1. The contributions from the major tributaries is based on an approximate specific sediment yield value of 2500 tons/mi$^2$/year and a higher value was used for the glacier reach. The result is an approximate suspended sediment budget as shown by the upper line in Figure 2.5, and it can be seen that the load continues to increase until it reaches the wide Palmer Reach, then declines towards the delta.

A preliminary approximation of the gravel budget is also presented (lower line). Further studies and analysis will be carried out to improve these estimates. The plot indicates a loss of gravel into each wide alluvial fan reach. A large portion of the gravel generated from several large tributaries is trapped, but serves as a future source of gravel load. Of interest is the last 15 miles – from the last constriction near Moose Creek, the approximate gravel load continuously reduces from the estimated one (1) million tons per year to zero at mile zero. At the new Glenn Highway Bridge, the gravel load is tentatively estimated to be about 400,000 tons per year. If a gravel excavation program is established then the annual excavation is expected to be of similar magnitude. However, if a gravel trap is established near the bridge, then, as shown in the conceptual gravel budget (Figure 2.6), the load downstream from the trap can be significantly reduced. As well, the downstream diversion channel will tend to downcut during the trap-filling years resulting in increased lateral stability to the diversion channel. Annual maintenance would be required to clean out the trap, but this would be over a localized reach.

Additional sediment transport calculations and morphological analysis will be made to assess the feasibility of utilizing gravel traps upstream from the diversion channel. The computations will provide rates of filling of traps and excavated channels. Of significance also is the impact of a large flood or a glacier lake outburst flood such as occurred on Granite Creek in 1971 – a conceptual gravel budget shows that the single-day event produces a gravel load equivalent to an annual load and that the annual gravel load could be double (Figure 2.7). This means that all traps and diversion channels would fill with gravel. The risk of this combination of a glacier lake outburst flood with an annual input of gravel should be examined.

# 3. REDUCING BANK EROSION BY RIVER WORKS AND THALWEG DIVERSION

## 3.1 Introduction

Over the years, engineers have developed many types of river bank protective works as well as channel diversion works, or thalweg diversion works, in order to reduce bank erosion. Manuals, guidebooks and papers have been produced on the topic and a brief list of the more prominent literature is presented below:

- “Bank and Shore Protection in California Highway Practice” by the California Division of Highways, 1960;
- “Highways in the River Environment” by Colorado State University, 1974;
- “River, Coastal and Shoreline Protection” by Thorne, et al (1995);
- “Guide to Bridge Hydraulics” by Transportation Association of Canada (2001); and
- “River Control and Drainage in New Zealand” by Acheson, A.R. (1968).

More references are presented in Appendix 1. The references include many types of river works that can reduce bank erosion and some of these that may be appropriate for the Matanuska will be discussed after we deal with the observed works already constructed along the river banks.

## 3.2 Bank Erosion Protective Works on the Matanuska River

From the brief reconnaissance and review of the literature and data, the following river works have been constructed along the Palmer Reach and the Bodenburg Reach (approximate locations shown on Figure 2.4):

Site A) Four Riprap Spurs Along Left Bank (looking downstream) at Mile 5.5 from Railway Bridge. These spurs were constructed during the summer of 1992 and Photo 3.1 shows spurs during construction on June 8, 1992 and Figure 3.1 shows the layout. Flow conditions in midsummer 1994 are shown in Photo 3.2 which clearly shows accumulation of sediment between the spurs.

During the field trip in November, 2003, the spurs were inspected and found to be performing well (see Photo 3.3).

A proposal was presented in 1995 to construct an additional four spurs upstream of these existing spurs but this was not completed.

Site B) Riprap Protection of Right Bridge Abutment for New Bridge on Allen Highway (Photo 3.4). The protection results in a drastic constriction of the wide alluvial braided system to a deep single channel.

Site C) Revetment Protection of Left Bank Near Mile 8.
A revetment, that is, a lining of riprap (rock) protects the left bank of the river for a length of about 2 miles (Photo 3.5). The condition of the revetment is unknown but portions appear adequate because of protection of protruding parts of the bank.

Site D) Railway and Highway Crossing Protection of Abutments (Delta)
Along with the main channel crossing in the delta reach, there are a number of secondary channels that are also bridged by the railway and highway as shown in Photo 3.6 and several of the bridge abutments are protected by riprap. The alluvial fan transforms to a delta but the channels have not been blocked allowing for deposition over a wide zone.

Site E) Revetment and Spur near Granite Creek
A short rock spur has been added to the end of a rock (riprap) revetment as shown in Photo 3.7. The spur deflects the deep channel away from the highway and appears to be a recent addition to the revetment.

### 3.3 Possible Types of Bank Protection Along the Matanuska Downstream of the New Glenn Highway Bridge

In order to compare options for reducing bank erosion, we will consider several appropriate preliminary designs such as:

i. Timber crib spurs could be constructed from logs and stones that are readily available along the Matanuska – an example is shown in Photo 3.8 of a bridge abutment.

ii. Short rock spurs such as constructed along the Fraser River in Photo 3.9.

iii. Long spurs constructed from gravel and protected by rock as was done for the four spurs at mile 5.5 (called Circle View – this design is rather expensive but does provide good protection against erosion.

iv. Continuous bank protection by a rock revetment – this is a more expensive method generally costing from $200 to $300 per running foot which comes to $110,000 to $160,000 per mile.

Consideration will also be given to use of alternative materials, such as concrete dolos units (Photo 3.10), in the construction of spurs and revetments.

## 3.4 Extent of Bank Erosion

A study by U.S. Army Corps of Engineers measured the change in bank position from a reference line and concluded that the maximum erosion was along the east bank. In contrast, Hulbert (1989) reported a filling of a network of channels upstream from the Matanuska Dike. LIDAR mapping and historic airphotos will be used in the present study to prepare a bankline erosion map. We have received 1980 stereopairs and are presently preparing maps from these photos.

## 3.5 Thalweg Diversions

Another method for reducing bank erosion is to divert the deep channel (thalweg) away from eroding banks. This method has not been used extensively as gravel excavations in Alaska have been primarily for commercial purposes, such as for concrete products or road fill (Germanoski, 2001). A study of gravel excavations was completed in 1980 by the U.S. Army Corps of Engineers and dealt with six (6) case histories. Subsequently a manual for gravel excavations was prepared by the Fish and Wildlife Service (1980). An example of gravel excavation for the purpose of diverting the thalweg was the excavation of a pilot channel on the Tanana River. About 263,000 cubic yards of material was excavated to divert the main deep channel away from the toe of groins (spurs) and this history is documented by the U.S. Army Corps of Engineers (1984). This pilot channel re-filled quickly and was not re-excavated. However, much more gravel was excavated for dikes and levees – about 1,500,000 cubic yards between 1969 and 1976 and just over one (1) million cubic yards between 1977 and 1981. The studies on the Tanana indicated that the annual bed-load averaged 360,000 tons and the rate of travel of the bed load was about one (1) mile per year.

The diversion of high velocity thalweg channels away from eroding banks is often done in conjunction with the construction of flood dikes such as noted by

Whitehouse and McSaveney (1990) where a large deposit on an alluvial fan was bulldozed to create a dike and a low-level thalweg diversion. Another example of thalweg diversion is on the Vedder River where channels are excavated through bars and, at some locations gravel traps have been constructed so as to reduce the downstream rate of bed rise and subsequent flooding (Northwest Hydraulic Consultants, 1997). An example of the gravel traps on the Vedder is shown in Photo 3.11 which shows a series of traps separated by low berms. The traps were re-filled over a period of about six months but they significantly reduced the amount of gravel entering the lower reaches and therefore reduced the excavation requirements along the lower reaches. In some instances, the combination of gravel traps upstream from a thalweg diversion results in a reduced rate of gravel filling of the diversion and, therefore, less tendency for the channel to shift laterally. This topic will be discussed more in the next section.

# 4. THALWEG DIVERSIONS

## 4.1 Types of Thalweg Diversions

As briefly presented in Section 3, one method to reduce erosion along river banks is to divert the main flow channels away from the eroding banks (thalweg diversions). There are several methods by which deep thalweg channels along braided rivers might be diverted:

i. secondary - channel plugs plus thalweg diversion;
ii. two thalweg diversions having alternate year excavations; and
iii. upstream gravel trap plus channel diversion.

We shall briefly discuss each of the above methods and will expand on the analysis in more detail after receiving the survey data for the river reach below the new Glenn Highway bridge, that is, for the Palmer Reach and the Bodenburg Reach. On some wide, braided rivers, secondary channels have been plugged and main thalweg channels have been excavated in order to lower flood levels. An example is from Norrish Creek where a railway crossing severely constricted an alluvial fan resulting in blockage of historical secondary channels as shown in Photo 4.1. However, since secondary channels provide habitat for fish, this method should not be pursued further.

Another method of keeping thalweg diversions functioning is to construct two diversions through the large central bar and establish alternate excavation programs where one channel is flowing while the entrance to the other is blocked and excavation can proceed in the dry. This method has been practiced in northern Pakistan and India where parallel irrigation canals have been constructed and alternate canals flow with water every year allowing for excavation of silted canals without interfering with the supply of irrigation water

(Central Board of Irrigation and Power, 1965). This method should be investigated further.

A thalweg diversion coupled with an upstream gravel trap may prove to be effective because the trap will delay the filling of the diversion such that the thalweg channel will remain stable for a longer time. This approach can be investigated further with the sediment transport model which will be used to establish an annual maintenance program. A version of this option was proposed by PND (1995) and is shown in Figure 4.1. The gravel trap plus thalweg diversion option should be studied in more detail.

Assuming a simple long excavation through a high mid-channel deposit, the dimensions of the diversion will partially establish the flow quantity down the diversion. For discussion purposes we assume a diversion channel to have the following hydraulic dimensions:

| | | |
|---|---|---|
| - diversion flow | = | 30,000 cfs (5 yr flood) |
| - average width | = | 400 feet |
| - average depth | = | 12 feet |
| - diversion slope | = | 0.005 |
| - approximate velocity | = | 17 ft/s |
| - approximate gravel transport at the above discharge | = | 800,000 tons/year |

Also, the above diversion channel should be located just downstream from the Glenn Highway Bridge. There are, however, a number of questions that will need to be examined in preparation of a feasibility level design for a thalweg diversion:

i. Will there be a headcut of the upper portion of the diversion channel, or will the incoming gravel load partially fill the excavated channel? Sediment transport modeling may be used to answer this question. The entrance to the diversion channel should be aligned with the bridge opening which also has a 400 ft opening.

ii. If the thalweg diversion is capable of transporting a large amount of gravel and if it doesn't fill, then the gravel will be transported to the end of the channel where a new alluvial fan type deposit will begin to develop. This new deposit may cause buildup of gravel in an upstream direction and eventually fill the channel.

Experience from alluvial fan crossings by highway and railway bridges indicates that gravel needs to be frequently excavated through the bridge opening because of deposition which is caused by channel blockage downstream from the bridge. An assessment of the filling process of this channel excavation will be made from experience on other braided river systems as well as by using the sediment transport modeling.

iii. How long should the excavated channel be and should the channel be excavated with partial plugs at regular intervals, say at 1000 ft spacings? In some gravel excavations, long pools are constructed with low berms in between in order to develop short-term pools that would serve as fish habitat. An example is shown for the Vedder River where five pools were constructed for the purpose of trapping gravel thereby reducing the rate of rise of downstream river bed and subsequent flooding (see Photo 3.11). The use of the water level model (HEC-RAS) will provide information about the design of the thalweg diversion.

iv. Will the generally straight excavated channel erode its banks and develop a flow path that deviates from the constructed alignment? Frequently an excavated channel having a straight alignment will erode its banks, especially when velocities are high, and will take on an irregular pattern. Logs and log jams can quickly initiate a change in flow direction which leads to a new path, and there appear to be many logs on the active floodplain of the Palmer fan.

These questions and the options for thalweg diversions will be addressed in subsequent phases of the study once more data is obtained.

# 5. SURVEY AND BED-MATERIAL SAMPLING PROGRAM

## 5.1 Site Survey

During the initial meetings in Anchorage, a quote was received from Aeromap to undertake a site survey by LIDAR which is to have 15cm resolution. The survey is to cover the reach from Palmer to the Matanuska Dike (near the confluence with the Knik River). The results from the survey should be available in 45 days from November 19, 2003. Cross-sections can be obtained at any exposed (above water) location from the LIDAR mapping.

## 5.2 Bed-Material Sampling

The following notes are taken directly from a MWH memo by Brett Jokela to Kris Ivarson (Nov. 19, 2003).

A.) Bulk samples of bed material.

Take six samples of approximately five gallons each of material from below the armored layer of the river bed (below 6 inches depth). These samples can be collected by shovel, and should be accessible by breaking the frost crust with a torch or digging bar. The sample material should be at least 6 inches below the surface. Approximate locations of the samples should be:

1) Central portion of river left braidplain, 0.6 mile southeast of Old Glenn Bridge;
2) Head of upper mid-channel island, 0.6 mile south-southeast of Old Glenn Bridge;
3) Central portion of river right braidplain, 0.6 mile due south of Old Glenn Bridge;
4) Central portion of river left braidplain near lower mid-channel island, 0.75 mile south-southwest of “pinch point”, near spurs;

5) Head of lower mid-channel island, 0.5 mile southwest of pinchpoint; and
6) Central portion of river right braidplain, 0.75 mile west-southwest of pinchpoint.

These samples should be run for sieve gradation. It is probably not necessary to characterize any material finer than %passing 200 sieve (~72 um). We also need to characterize the lithology in a general way – such as % gneiss, % graywacke, % granite. A citable standard approach to this would be useful. The intent is to use the lithology findings to represent the hardness and durability of marketable materials.

B) Armor layer material classification.

We need a statistical classification of bed surface material sizes for different channel features. This can be done by exposing a standard area of the bed and photographing the bed with a reference scale in the photograph. A one-meter grid overlain on the stream bed may facilitate scaling. A visual description of each site will be useful as well.

Locations for visual classifications should be at 4 cross sections from bank to bank as follows:

1) Across upper mid-channel island, approximately 1 mile downstream from bridge.
2) "Waist" below upper mid-channel island, approximately 2.5 downstream from bridge
3) "Pinchpoint" 4 miles below bridge
4) Under power transmission lines, 5 miles below bridge.

At each cross section, take up to 6 measurements/photographs of bed materials, including a description of the morphologic feature represented, such as toe of bank, top of bar, dry channel, deep side channel, etc.  Its would also be helpful to get a representative cross section of different types of channel features.

# APPENDIX A

1. References
2. Reference materials

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Meeting minutes with Senator, representatives from various Government agencies and members of the public. Provides a discussion / review of past erosion and flooding problems to introduce potential long-term remedial actions. 24 p.

3. ADFG Fish Hab Permit Appl. (1995). Alaska Department of Fish and Game, Habitat and Restoration Department, fish habitat permit application.

Project description for Matanuska River spur dykes. Notes that an existing project in which 4 spur dykes were contructed was successful in halting riverbank erosion, but recent erosion occurred up- and downstream. Permit application seeks to build 6 additional dykes in spring 1995 to protect 3000 ft of bank and presents review information and design specs in support of permit. 8 p.

4. ADN 9 93 Article (1993). Rocks arrest erosion.

Alaska Daily News article on using placed rock to stop local erosion along Matanuska River away from the Glenn Highway east of Sutton. 1 p.

5. ADN Article (2001). Hungry River.

Alaska Daily News article (online) on river erosion destroying a house and property. Also refers to other recent events despite the large number of dollars spent on projects to prevent erosion problems. Also notes that the constructed wing dykes were never a permanent solution and have been failing. 5p.

6. AERG Sed letter (1989). Alaska Energy Research Group.

Letter sent to Soil Conservation Service (Palmer, AK) on sedimentation in Matanuska river. Attached is Hulbert report (grad course term paper) on

sedimentation in the lower Matanuska River. Report is described elsewhere in this listing. 1 p (letter) + 26 p (report).

7. Alaska task force doc (1991). Alaska Task force Erosion Control of Matanuska River.

   Summarizes Corps of Engineers and DOT findings on possible engineering solutions and their practicality w/r erosion control on Matanuska River. COE report provides overview of nature of problem, local requests, improvements considered and cost / benefit summary; DOT report examines possible mitigation measures and provides costs. Findings indicate that erosion below Bodenburg butte needs to be addressed by non-structural alternatives because economics do not support training structures for flooding and erosion protection, as the region is not well developed. 16 p.

8. Coarse sed trans (1972). Coarse Sediment Transport by Flood Flows on Knik River, Alaska.

   Bradley, W.C., Fahnestock, R.K. and Rowekamp, E.T. (1972). Coarse Sediment Transport by Flood Flows on Knik River, Alaska. Geological Society of America Bulletin, V. 83, pp 1261-1284. Paper is reviewed elsewhere in this listing.

9. Dept of Army 6 99 (1999). Cover letter and report, Department of the Army.

   Cover letter to Matasuska-Susitna Borough outlining need to create a project study plan for a watershed study. Attached is a reconnaissance report by the Army Corps to the borough related to problems, needs and opportunities for development of water and land resources in the watershed, including potential for Federal participation and assistance. Includes short review of prior reports and existing projects, identifies problem areas, summarizes alternative strategies. Report recommends project proceed with 50% Fed cost share. 23 p.

10. Draft Alaska task force (1991). Draft Alaska Task Force – erosion of Matanuska River basin.

Draft report to State Governor on ability of state to react to or address erosion and flooding problems in watershed to aid in developing programs and policies that reduce or eliminate the erosion problem. Provides list of 16 summary recommendations.

11. Mat River Bondenburg Butte: 1996 US army corps report that documents historic erosion patterns and rates near Palmer. Includes historic discussion, lists photos, and notes that cross-sections were collected, but no figures attached.

Mat River erosion overflow report: 1974 highways report on erosion and flooding near Bodenburg Butte – largely reviews army corps reports

Mat River erosion control recommend: 1992 report prepared by PN&D for Dept Public Works report on effectiveness of spur dykes and additional recommendations for new erosion control

Mat River erosion control: 1991 report prepared by PN&D for borough on gravel mining feasibility as erosion control

Mat River Proj rpt: report prepared by Palmer soil and water conservation district – rough overview of morphology and problems

Mat River watershed 2 of 3: list of references prepared by Palmer soil and water conservation district on material that might be useful for various studies in the watershed

Mat River watershed 3 of 3

Mat River watershed hydrology

MRE task force interim report

MRE task force Rpt att 5 to end

MSB 1 92 letter

MSB 7 85 letter

MSB 8 15 89 letter

MSB 8 89 letter

PN & D 2 95 Doc

Prelim Damage assess 9 89

Reconn Mtg Mat River erosion

Sediment in lower Mat River

SOA DMVA 10 89 letter

Sutton erosion control

Table of photos

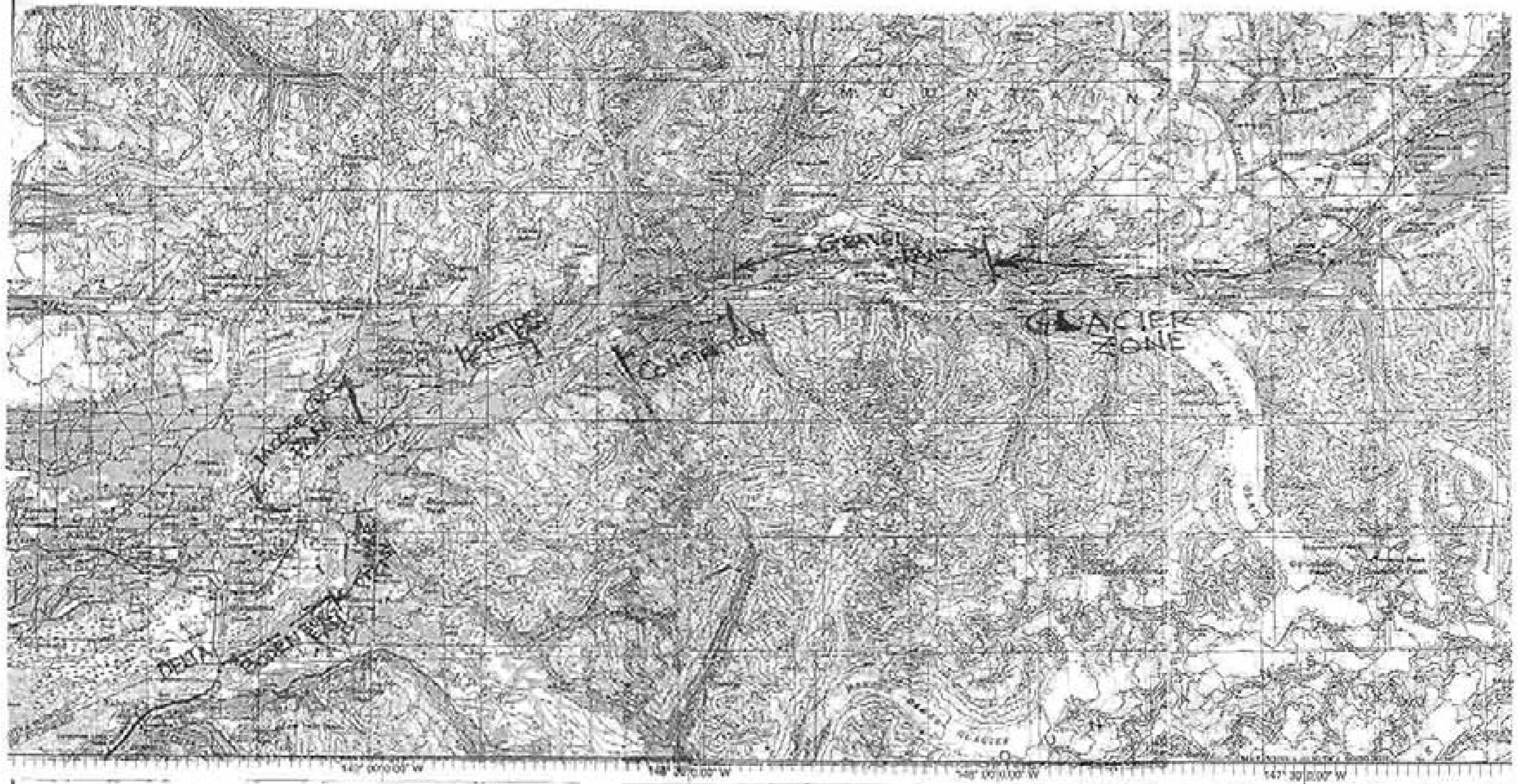
USACE review of reports

USDA SCS 6 89 letter

Watershed Recon study

Germanoski, D. (2001). Bar forming processes in gravel-bed braided rivers, with implications for small-scale gravel mining. In *Applying Geomorphology to Environmental Management*, D.J. Anthony, M.D. Harvey, J.B. Laronne and M.P. Mosley [eds]. Water Resources Publications, LLC, pp. 3-32.

Study of braiding and braid-bar formation along 3 Alaska Rivers. Shows how a consideration of these dynamics can be used to rehabilitate gravel mining sites and how the natural appearance of channels can be maintained provided certain conditions are followed.

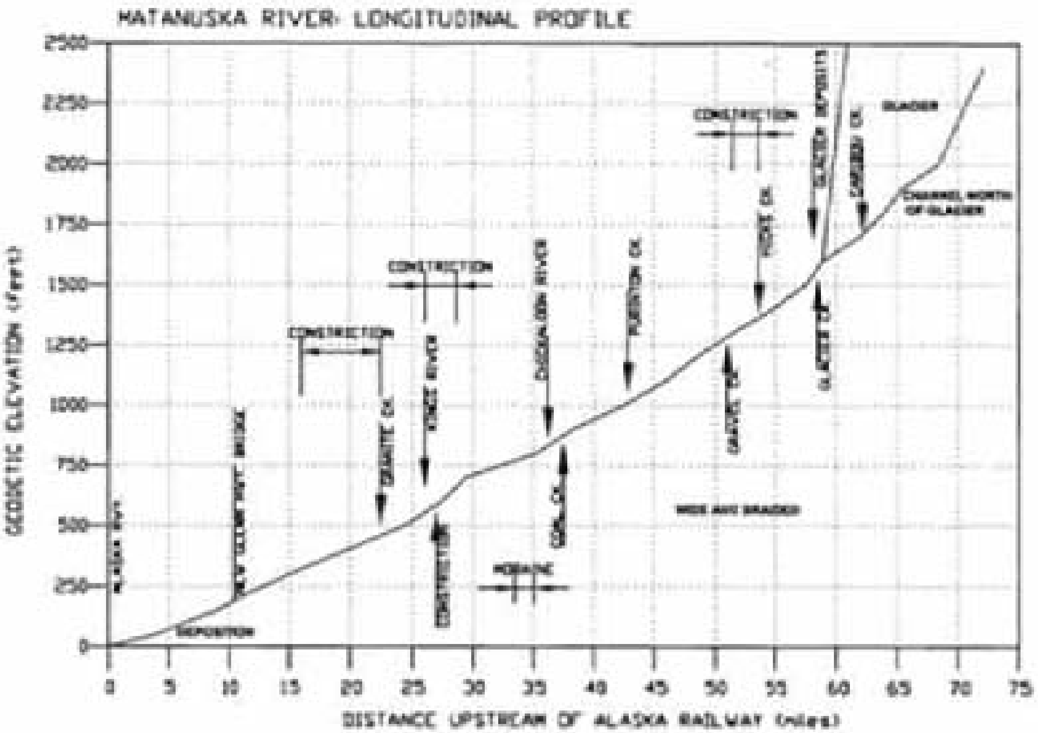



MATANUSKA RIVER

Matanuska Basin
Location Map

northwest hydraulic consultants

FIGURE 2.1




NOTES:
DATA SOURCE IS 1:50,000 USGS TOPOGRAPHIC MAPS
EXAGGERATION 50H:V

| MATANUSKA RIVER |
|---|
| Matanuska River<br>Longitudinal Profile |
| northwest hydraulic consultants |

FIGURE 2.2

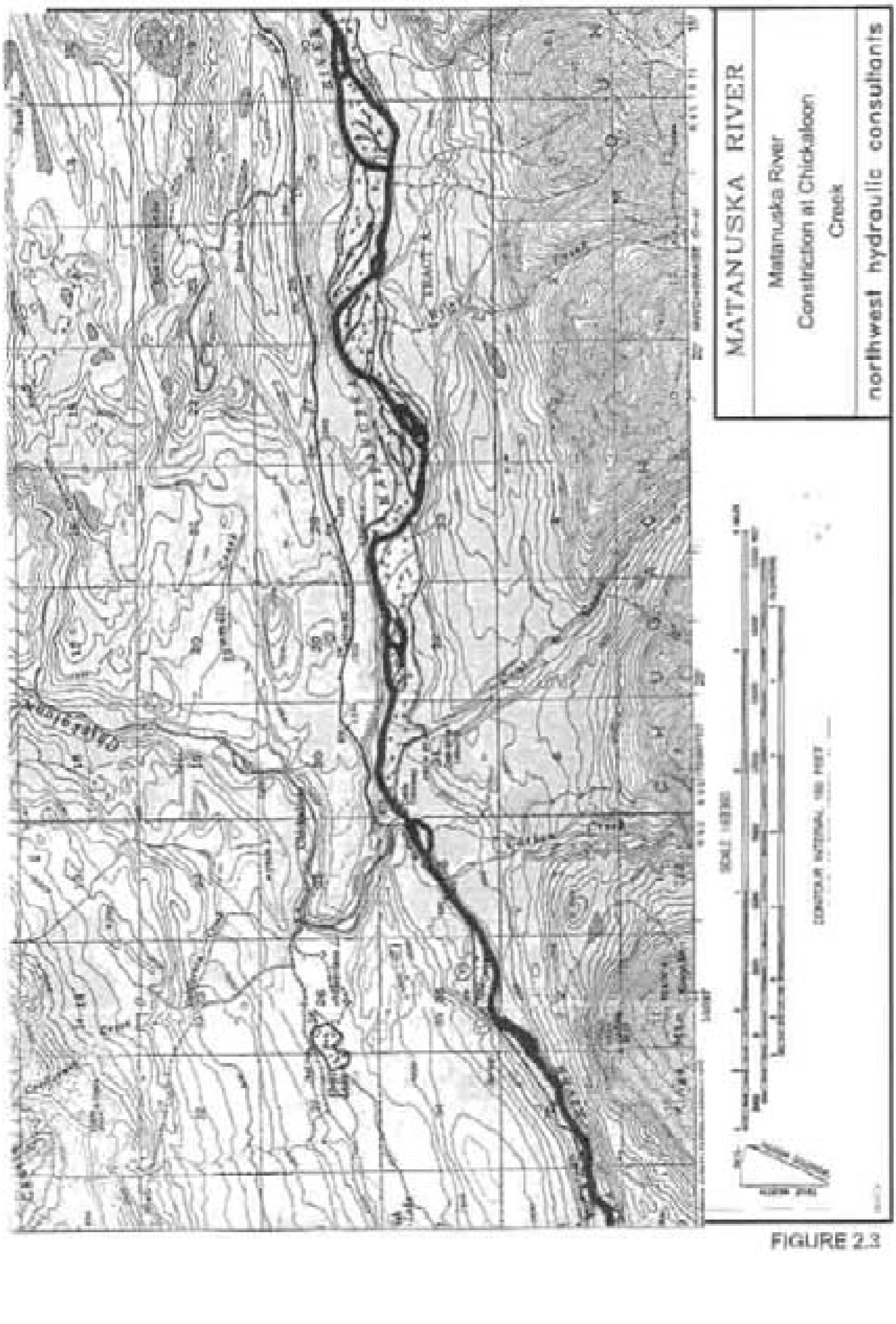
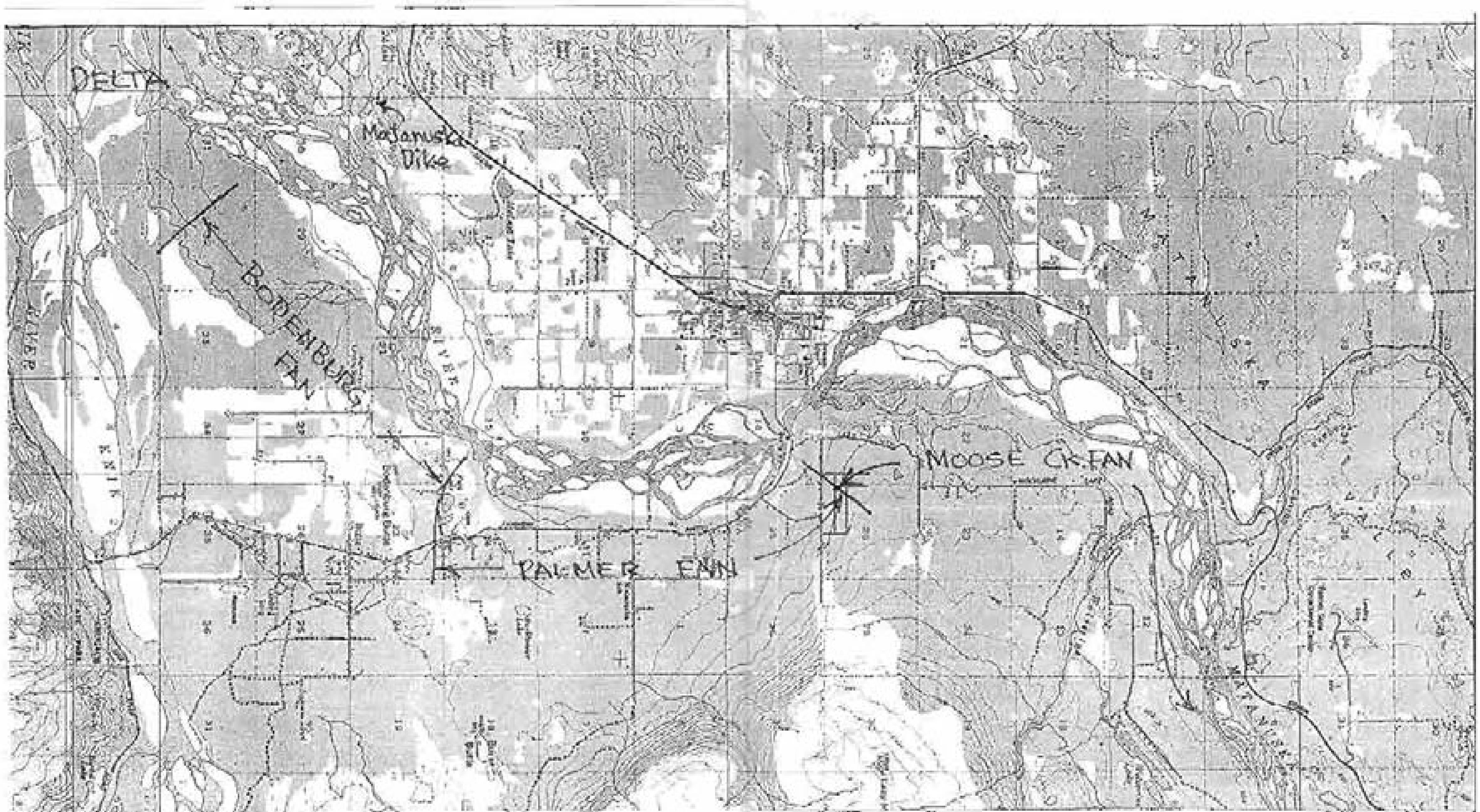

MATANUSKA RIVER
Matanuska River
Constriction at Chickaloon
Creek
northwest hydraulic consultants

FIGURE 2.3

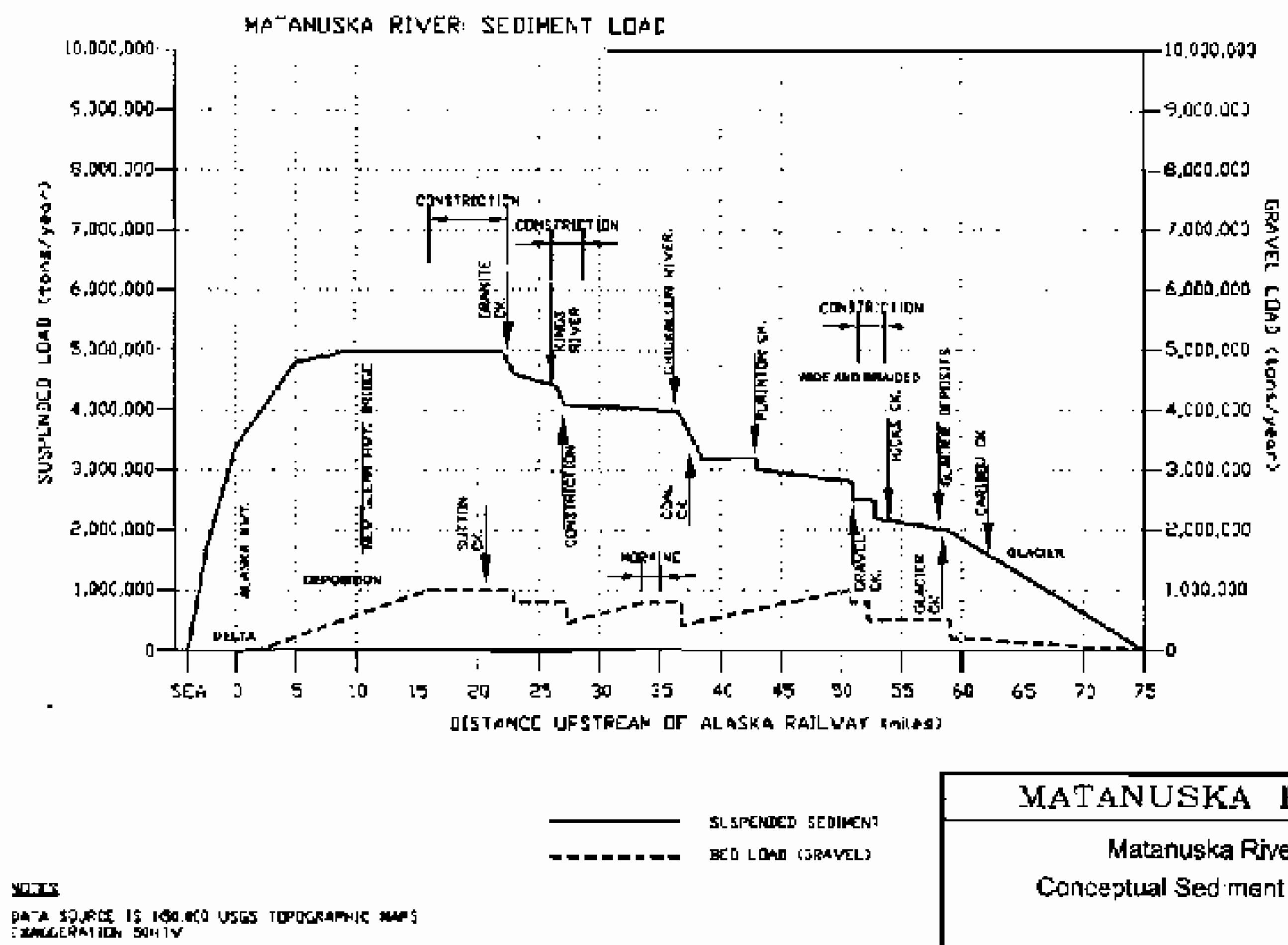



MATANUSKA RIVER

Matanuska River
Lower Reaches

northwest hydraulic consultants

FIGURE 2.4



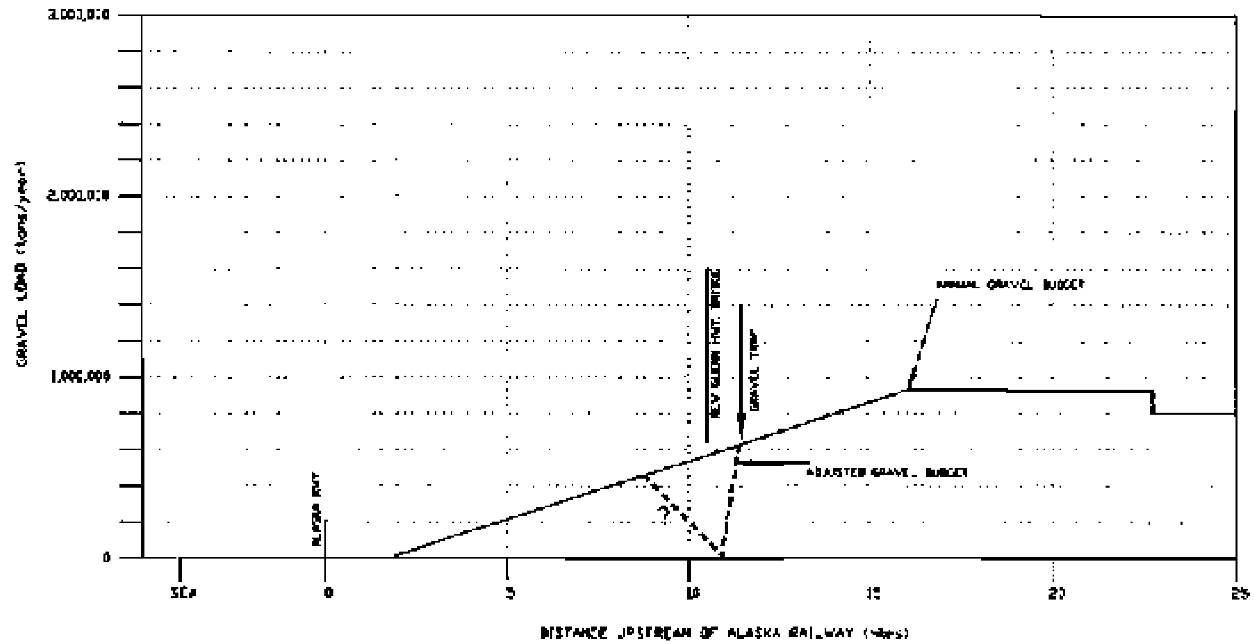

MATANUSKA RIVER

Matanuska River

Conceptual Sediment Budget

northwest hydraulic consultants

FIGURE 2.5




NOTES:
DATA SOURCE IS 1:63,000 USGS TOPOGRAPHIC MAPS
EXAGGERATION 50H:1V

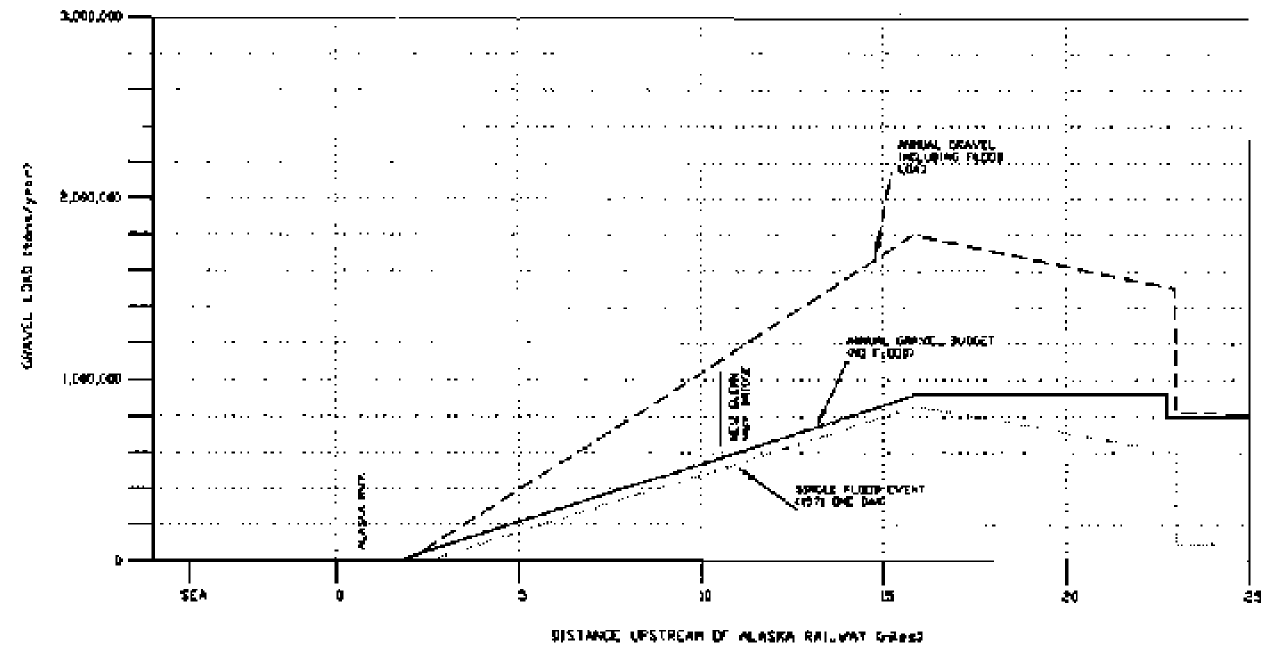
# MATANUSKA RIVER

Matanuska River
Conceptual Gravel Budget
with Gravel Trap

northwest hydraulic consultants

NHCV

FIGURE 2.6




NOTES:
DATA SOURCE IS 1:50,000 USGS TOPOGRAPHIC MAPS
EXAGGERATION 50H:V

NHCV

# MATANUSKA RIVER

Matanuska River
Conceptual Gravel Budget
with 1971 Flood Event

northwest hydraulic consultants

FIGURE 2.7

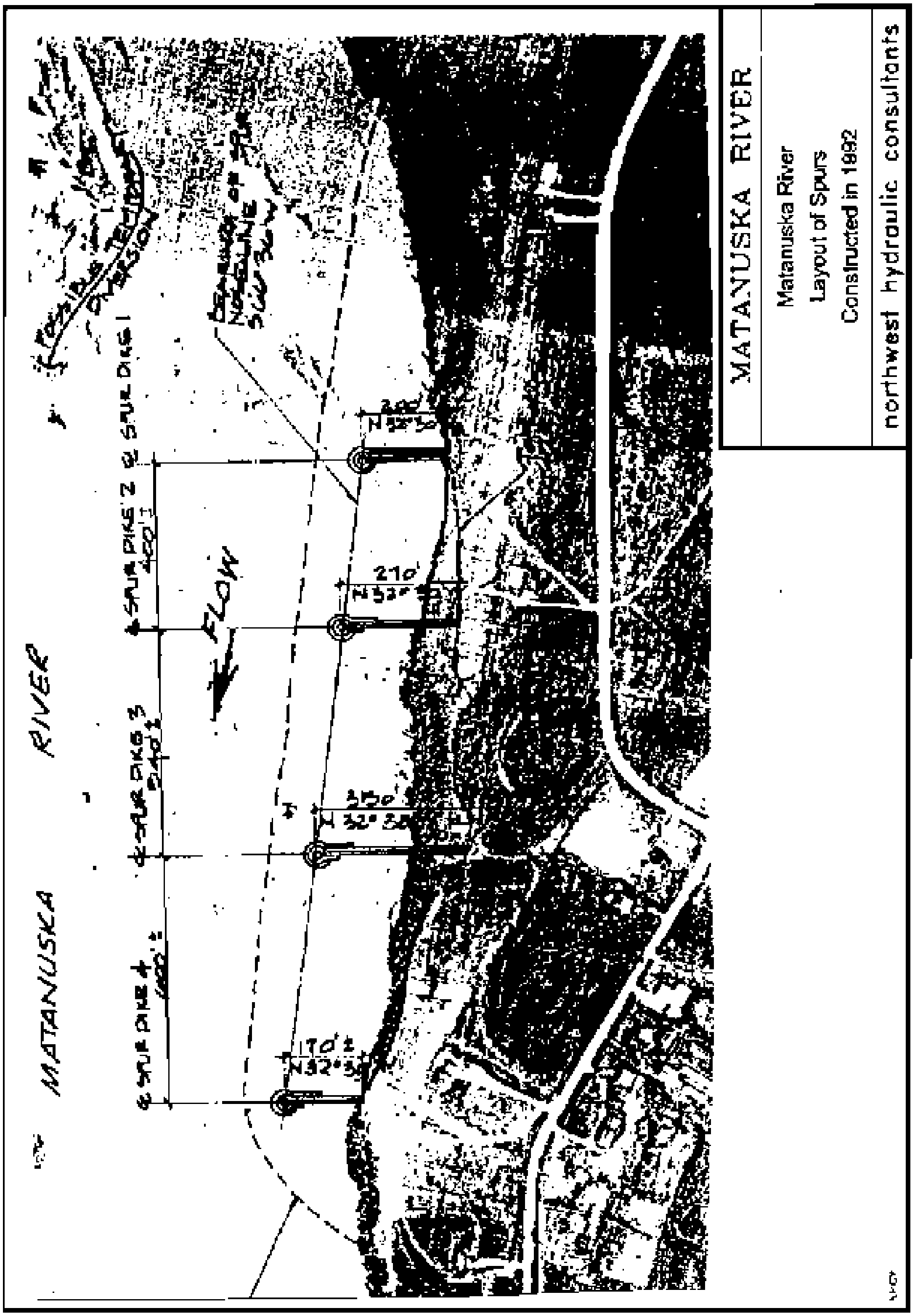

MATANUSKA RIVER
Matanuska River
Layout of Spurs
Constructed in 1992
northwest hydraulic consultants
MATANUSKA RIVER
FLOW
SPUR DIKE 1
SPUR DIKE 2
400'±
SPUR DIKE 3
240'±
SPUR DIKE 4
160'±
200'
210'
350'
70'±

FIGURE 3.1

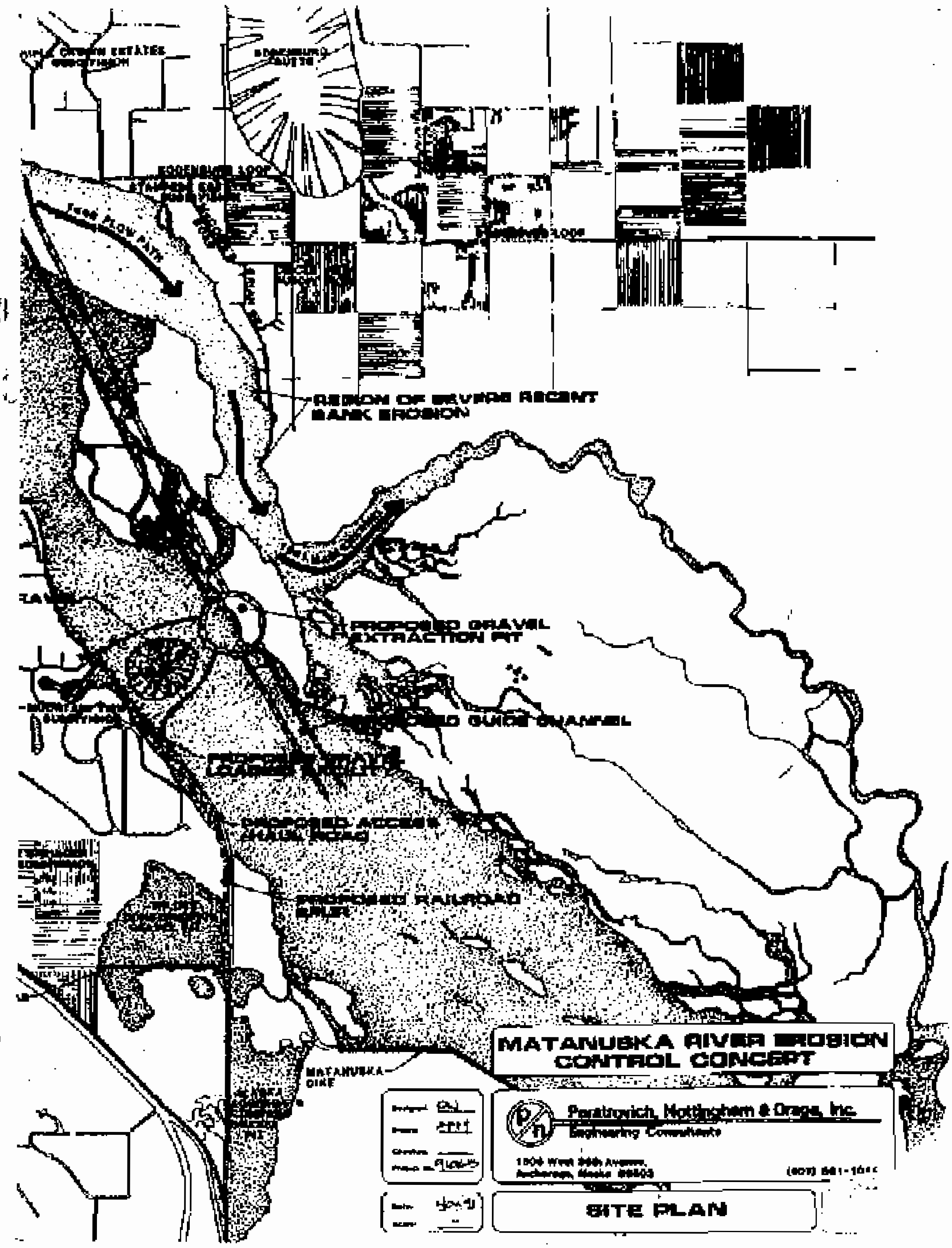

REGION OF SEVERE RECENT BANK EROSION
PROPOSED GRAVEL EXTRACTION PIT
PROPOSED ACCESS (HAUL ROAD)
PROPOSED RAILROAD SPUR
MATANUSKA DIKE
MATANUSKA RIVER EROSION CONTROL CONCEPT
Peratrovich, Nottingham & Drage, Inc.
Engineering Consultants
SITE PLAN

FIGURE 4.1

PHOTO 2.1

Matanuska River

New highway crossing near Palmer
showing bedrock cliff along the
left bank just upstream
from the old bridge.

Flow is left to right.

November 11, 2003
(Neg. # 1-2)

**PHOTO 2.2**

**Matanuska River**

**Constriction at the new Palmer Bridge which coincides with high bedrock banks. The deposition of sand and gravel downstream creates a mid-channel island/bar system and the feature is typical of a confined alluvial fan.**

**View is downstream.**

**November 11, 2003**
**(Neg. # 8-19)**

**PHOTO 2.3**

**Matanuska River**

River expands into a large confined
alluvial fan after emerging from
a narrow gorge near the confluence
with Kings River entering from
the north (left of photo).
The river pattern changes from
braided at high flow to a
single meandering channel
at low flow.

View is upstream.

November 11, 2003
(Neg. # 3-16)

PHOTO 2.4

Matanuska River

Landslides of valley wall contributing sediment to the river. The sediment supply is higher than the transport capacity resulting in long term deposition and slow rising (aggradation) of the river bed.

View is upstream.

November 11, 2003
(Neg. # 7-9)

**PHOTO 2.5**

**Matanuska River**

Gravel and sand source from
Granite Creek entering from the
north side of the river.
An alluvial fan has developed at the
confluence where sediment is stored
and becomes a source of supply
when the Matanuska flows
are high.

Flow is left to right.

November 11, 2003
(Neg. # 8-13)

**PHOTO 2.6**

**Matanuska River**

Bank erosion along terraces on the south side of the river upstream from Sutton.

Flow is left to right.

November 11, 2003
(Neg. # 3-2, 1)

**PHOTO 2.7**

**Matanuska River**

**Looking upstream to Matanuska Glacier which is slowly receding and exposing loose sediments at the toe. These sediments are a major source of sediment supply to the Matanuska River.**

**November 11, 2003**
**(Neg. #4-9)**

**PHOTO 2.8**

**Matanuska River**

**Downstream view of wide confined reach called Moose Creek fan. The constriction at the Glenn Highway is shown in the background.**

**November 11, 2003**
**(Neg. #11-10)**

**PHOTO 2.9**

**Matanuska River**

**Downstream view of Palmer Alluvial Fan.**
**November 11, 2003 (Neg. #10-14 to 17)**

PHOTO 2.10

Matanuska River

Upstream view of Bodenburg confined fan reach. The reach begins at the contraction at the left of the photo. The right arm of the river flowing near the sewage disposal plant is slowly being silted with sand and silt – the main flow channels are along the left channel system.

November 11, 2003
(Neg. #11-13)

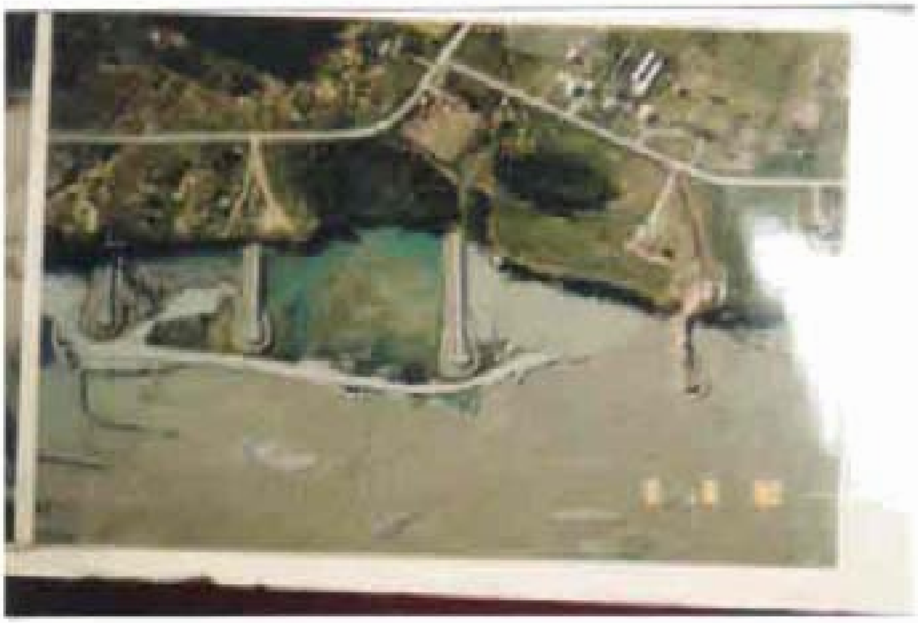


**PHOTO 3.1**

**Matanuska River**

**Air view of four (4) spurs under construction. Access roads are still in place at the ends of the spurs.**

**Flow is left to right.**
**Date of photo - June 8, 1992**
**Photo source – Matanuska-Susitna Borough (Neg. #13-21)**

PHOTO 3.2

Matanuska River

Air view of four (4) spurs during
flow in midsummer 1994.

View is upstream
Photo source – Matanuska-Susitna Borough
(Neg. #13-23)

PHOTO 3.3

Matanuska River

Spur dike #3 with scour hole
at the end of the spur. The riprap
appears to be in place with some
stone rolling down into the
scour hole.

View is downstream.
November 11, 2003
(Neg. #12-15)

**PHOTO 3.4**

**Matanuska River at New Allan Road Bridge**

**The flow is right to left and the right abutment is protected with riprap. The left abutment (right of photo) is founded on bedrock.**

**November 11, 2003**
**(Neg. #13-32,33,34)**

**PHOTO 3.5**

**Matanuska River**

Revetment protection of the
left river bank near mile 8.
The riprap protection covers
a length of approximately 3 miles
and several bank protrusions are
protected as in the above photo.

Flow is right to left.
November 11, 2003
(Neg. #10-21)

**PHOTO 3.6**

**Matanuska River**

Railway and Highway Crossing
of the Matanuska at the upstream
end of the delta reach.

Flow is left to right.
November 11, 2003
(Neg. #9-6 to 10)

**PHOTO 3.7**

**Matanuska River**

**Revetment and spur to protect north bank of Matanuska near Granite Creek.**

**Flow is left to right.**
**November 11, 2003**
**(Neg. #1-24, 25)**

PHOTO 3.8

Zetu Creek, British Columbia

Bridge abutment constructed from timber crib fill with river stone. This type of crib could also be used as bank protection spurs.

View is upstream.
(1984)
(Neg. #2-2)

PHOTO 3.9

Fraser River

Downstream view to a
series of 20 short rock
spurs constructed as
temporary bank protection.

September, 1998

**PHOTO 3.10**

**Nooksack River**

Dolos concrete units used
to construct short spurs.
Each unit cost about $1000
and provided spaces for fish.
The performance of these
units is till being monitored.

(April, 1997)

PHOTO 3.11

Vedder River

Series of Excavated Gravel Traps
Trap 1, 2, 3, 4 and 5 were excavated
in 1996 to lower gravel load downstream.

Flow is left to right.
(October 10, 1996)

PHOTO 4.1

Norrish Creek

Constriction of secondary
channels by bridge on alluvial fan.

View is upstream.
(September, 2003)

# TECHNICAL MEMORANDUM

MWH

**To:** File **Date:** October 26, 2004

**From:** Nick Smith **Reference:** 1851040.010107/6.1

**Subject:** **Matanuska River Erosion Project – Matanuska Survey Data Summary**

## INTRODUCTION

Homes, land, and utilities are being endangered due to riverbank erosion along the Matanuska River near the city of Palmer, Alaska. NRCS has retained MWH to evaluate methods to protect the riverbank from further erosion. Protection methods under consideration include bank stabilization, excavation in order to reroute the river and use the gravel as a revenue source to offset the costs, and/or conservation efforts, which alter public land use practices. Relatively accurate survey information was needed to analyze these options. The survey data was used for development of river transport models and evaluation of historical information to draw practical conclusions.

Two sources of survey data have been obtained. First, Aeromap collected aerial photography and gathered aerial photographs and Light Detection and Ranging (LiDAR) data. Secondly, DOWL Engineering surveyed two cross sections of the Matanuska River. These surveys were conducted in response to a request from the USACE for updated information regarding erosion to compare to the September 19, 1991, *Erosion Control of the Matanuska River near Bodenburg Butte* report. This survey information has been compiled to use with various modeling techniques.

## LiDAR DATA

LiDAR uses the same principle as RADAR. The LiDAR instrument transmits laser light out to a target. Laser transmitters are used that fire thousands of pulses per second. By scanning the laser pulses across the terrain using a rotating mirror, a dense set of distances to the surface is measured along a narrow corridor. Some of this is reflected / scattered back to the instrument where it is analyzed. The distance measurements are converted to map coordinates and elevations for each laser pulse by combining the distance data with information on the position of the airplane (using GPS) at the time the laser pulse was fired and the direction in which the pulse was fired. The change in the properties of the beam enables some property of the target to be determined. The time for the beams to travel out to the target and back to the LiDAR is used to determine the range to the target.

There are three basic generic types of LiDAR:

- Differential Absorbtion LiDAR (DIAL)

- Doppler LiDAR
- Range Finders (used in the Matanuska River analysis)

**DIAL** is used to measure chemical concentrations (such as ozone, water vapor, and pollutants) in the atmosphere. This method of data collection was not used for the Matanuska River project.

**Doppler LiDAR** is used to measure the velocity of a target. When the light transmitted from the LiDAR hits a target moving towards or away from the LiDAR, the wavelength of the light reflected/scattered off the target will be changed slightly. This is known as a Doppler shift – hence Doppler LiDAR. This method of data collection was not used for the Matanuska River project.

**Range Finder LiDAR** is what was used on the Matanuska River project. Range finder LiDAR are used to measure the distance from the LiDAR instrument to a solid or hard target. It was the method used on the Matanuska River, since only topographical information was needed.

**Limitations to LIDAR**

There are several limitations to LiDAR data. These limitations include:

- **Vegetation –** When the laser beam is pointing straight down, a hole in the canopy allows the system to receive a return a signal from the ground surface. In a forested area, there is a wider angle of scan. The further the beam is off vertical, the greater the chance of hitting other objects (tree trunks and branches) besides the surface. In densely forested areas, the laser tends to hit more tree trunks – producing a scattering effect and making a noisy return. It is then more difficult to determine what is giving returns: some foliage, some branches and tree trunks, and some ground returns. (http://www.lasermap.com/laserM/english/lidarRadar.asp). This appears to be only a minor concern for the Matanuska River, since most of the area of concern is sparsely vegetated.
- **Accuracy –** Although more accurate than Radar, LiDAR has limitations to its inherent accuracy typically from the inertial system and the GPS due to plane movement, equipment inaccuracies, or other imperfections.
- **Water Surfaces –** When the laser light beam hits a column of water, part of the energy is reflected off the surface and the rest travels through the water column and reflects off the water body bottom. The water surface reflects energy from the infrared pulse, while the blue-green pulse is the one that penetrates the water column and is reflected off the bottom. The system records the time it takes for the reflected signals from the surface (infrared) and water body bottom (blue-green) to return to the aircraft. The water depth is calculated from the time difference between the return pulses. LiDAR was chosen despite these limitations, since water depth in the Matanuska River is relatively shallow.

  Hydrographic LiDAR is extremely useful for regional coastal mapping. LiDAR systems can provide uniform and dense data in extremely shallow water. It is a good complement to acoustical surveys, which are less effective in depths less than about 5 meters. The biggest limitation of LiDAR, as with other airborne techniques, is its dependency on water clarity. In clear waters it can be used to depths of over 50 meters (over 150 feet), but in turbid water it is only successful to depths of two to three times the visible depth. LiDAR is cost effective for surveying large, shallow water body areas with generally good water clarity (http://www.csc.noaa.gov/ benthic/mapping/techniques/sensors/lidar.htm). Unfortunately, the Matanuska River has a high silt content and low clarity.

**CROSS SECTION SURVEY**

DOWL Engineering performed a cross section survey of the Matanuska River in 2003 at two locations (A and B). The older cross section data did not match well with the LiDAR data in terms of elevations reported.

At a meeting with Aeromap and DOWL survey staff, it was determined that a control survey could be used to measure the differences between the ellipsoid approximation of elevations used by the LiDAR data processing and orthometric heights common to conventional surveying. The 1995 survey used conventional surveying techniques, but did not adjust elevations to NAVD88 benchmarks. In July 2004, DOWL connected LiDAR ground control points to orthometric features, as well as control points to orthometric features, and recovered the ground based control for the 1995 cross sections. These data were tied to network of well documented orthographic control.

The cross sections were controlled off a monument on the S. Bodenburg Loop Road and then tied together. This cross section survey information was taken and compared to the LiDAR data as a quality check on the LiDAR. The comparison showed a discrepancy between the points (GEOID99 Orthometric Heights compared to the NAVD88 leveled elevations) of slightly greater than 2 meters (2.017 meters average). After rectifying the sets of data by this height, the data varied by no greater than 25 mm (nearly 1 inch). This verifies that the two data sets had an overall vertical shift rather than a warping or tilted data. The correlation provides confidence to the accuracy of the LiDAR data.

**CONCLUSION**

The LiDAR and survey information do not rectify perfectly; however, vertical adjustments validate the LiDAR data and enable the data to be used with confidence for the purpose of the study.

Nick Smith
Engineer

# APPENDIX C

*Sediment Analysis*

**TECHNICAL MEMORANDUM**

MWH

| | | | |
|---|---|---|---|
| **To:** | File | **Date:** | March 16, 2004 |
| **From:** | Kris Ivarson | **Reference:** | 1851040.010101 |
| **Subject:** | Bed Material Sampling Program | | |

# 1.0 INTRODUCTION

## 1.1 PURPOSE AND SCOPE

Sampling of the bed material was conducted to provide information on three principal characteristics of the Matanuska River bedload within the study area. These characteristics are:

- The affect of bed material on stream hydraulics
- The character of material being moved by the river and how the streambed responds to various flow stages
- The character of material that would be encountered should mining be determined as a feasible and desirable option to control erosion

Bulk samples of bed material were collected from two cross sections along the river. Locations of the samples are shown on Figure 1. Armor layer material was also classified in these areas, using a pebble count to determine the surface sediment size.

## 1.2 PROJECT ORGANIZATION

The project organization is as follows:

- Fieldwork – conducted by Kris Ivarson, Hydrogeologist, and Nick Smith, Associate Engineer, both with MWH.
- Project Manager – Brett Jokela, P.E. with MWH
- Flight Services – Prism Helicopters, Wasilla, Alaska
- Laboratory Testing – Alaska Test Lab, Anchorage, Alaska

## 2.0 FIELD TECHNIQUES

Fieldwork was conducted on December 9, 2003. River conditions at the time of fieldwork limited access due to sections of open water and thin ice (see photo to right). Samples were located in areas accessible by helicopter, which consisted of exposed river bars.

Aerial view of Matanuska River downstream of first cross-section.

### 2.1 SEDIMENT SAMPLING PROCEDURES

Seven samples were collected from the exposed river bars in the locations shown on Figures 1 and 2. Three locations were selected for sample collection from each cross-section, with two samples collected at the first sample location. The first cross-section consists of sample locations #1, #1A, #2 and #3. The second cross-section consists of sample locations #4, #5 and #6.

The majority of samples were collected from below the armored layer, on the top of the river bars where the material appeared to represent the sample area. Sample #1A was collected from an area closer to the active channel and exposed water. Sample #6 was collected from the center high bar of the second cross-section. This area was well vegetated and should be considered representative of the center high bar of the first cross section as well, which is located near Sample #2. Photos for each sample location are included in Appendix A.

A propane-fueled weed-burner and digging bar were used to soften the frozen soil prior to excavation of the sample. The top 6-inches of material was removed prior to sample collection. This top material comprises the armored portion of the streambed. Representative samples of the underlying material were then shoveled into sandbags for later analysis. Sediment was collected from a depth of approximately 0.5 feet to 1.5 feet below ground surface. Each sample weighed approximately 20 lbs. Larger samples were not feasible for collection due to frozen conditions, time constraints and helicopter weight limits.

### 2.2 SAMPLE COORDINATES

Global Positioning System (GPS) coordinates were collected at each sample location. These coordinates were converted into Alaska State Plane Zone 4, North American Datum for 1927 (NAD27) and sample locations were then placed on the base figure (Figure 1). Coordinates for these sample locations are presented in Table 1. The coordinate system NAD83 was confirmed prior to conversion into State Plane coordinates.

**Table 1 Sample Coordinates**

| Sample Identifier | Latitude North | Longitude West | UTM Coordinates Northing | UTM Coordinates Easting |
|---|---|---|---|---|
| #1 and #1A | 61º 35.900' | 149º 4.690' | 2777517.41411 | 660923.22570 |
| #2 | 61º 36.056' | 149º 4.124' | 2778491.00982 | 662552.33538 |
| #3 | 61º 36.188' | 149º 3.477' | 2779321.98524 | 664418.33645 |
| #4 | 61º 33.568' | 149º 5.377' | 2763282.04500 | 659128.31171 |
| #5 | 61º 33.281' | 149º 5.760' | 2761518.08755 | 658039.62637 |
| #6 | 61º 33.065' | 149º 5.267' | 2760222.01944 | 659490.97290 |

## 3.0 SIEVE ANALYSIS RESULTS

Sediment samples were taken to Alaska Test Lab for sieve gradation analysis. Gradation was conducted down to a Number 200 sieve, approximately 72 µm in size. Sieve result reports are included in Appendix B. A summary of the grain size distribution is presented in Table 2, where the $D_{90}$ represents the grain size at which 90% of the sample (by weight) that passes the given size, in millimeters.

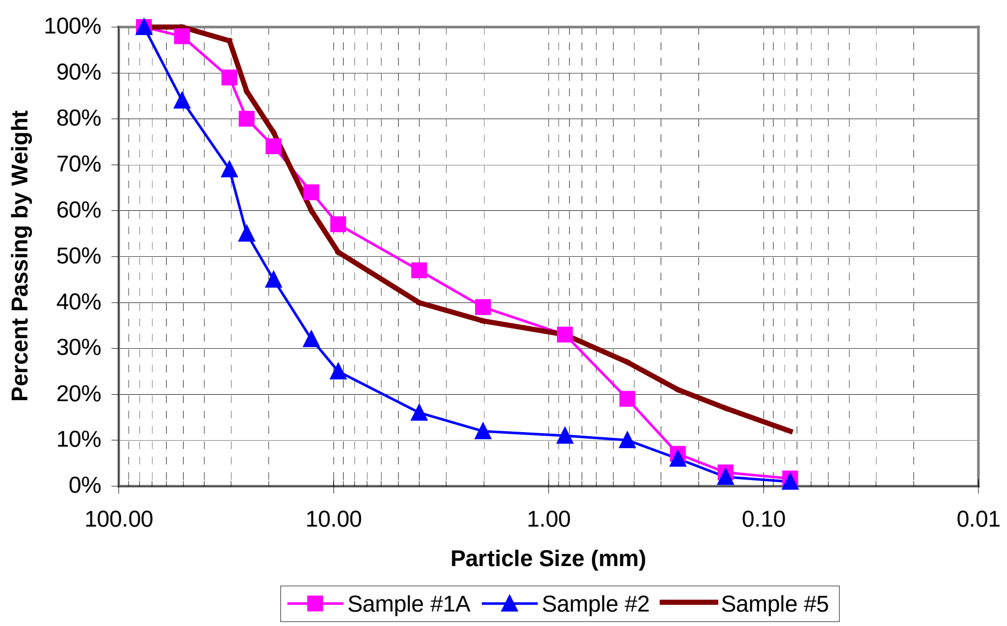
**Table 2 Grain Size Distribution**

| Sample ID | Grain Distribution Size in millimeters (mm) | | | |
|---|---|---|---|---|
| | $D_{90}$ | $D_{84}$ | $D_{50}$ | $D_{16}$ |
| #1 | 42 | 35 | 15.0 | 0.60 |
| #1A | 39 | 30 | 6.0 | 0.38 |
| #2 | 60 | 50 | 22.0 | 4.00 |
| #3 | 42 | 33 | 13.0 | 0.28 |
| #4 | 39 | 30 | 13.0 | 0.41 |
| #5 | 30 | 25 | 8.9 | 0.14 |
| #6 | 45 | 40 | 15.8 | 1.20 |
| Average Values | 37.13 | 30.38 | 11.71 | 0.88 |

The subsurface material appeared to be relatively uniform at both cross-section locations, as shown in Table 2. Sample #2 had somewhat higher grain sizes. This may be attributed to a single large cobble, which would skew the results of the distribution since the distribution is based on percentage passing by weight. As shown in Graph 1, a comparison of the sieve analysis curves for Sample #2 and Sample #5 indicates a higher percentage of material less than 1.00 mm are present in Sample #5.

Overall, the sampled material consists of sandy gravel to gravelly sand. Large gravel material was primarily identified on the armor layer. Smaller gravel, of 1 to 2 inches in size, was intermixed within the sand. Several predominantly sandy areas were noted along the cross-section transect, which appeared to be related to channel shifting during high flows. The sand consisted of uniform, fine tan material with few or no fines observed. Finer material, such as fine sand and silt, is likely deposited farther downstream in areas of slow water, or transported to the inlet. Silt was limited to the vegetated bars, as represented by Sample #5. A silt lens of approximately 2-inches in thickness was observed at the down-river vegetated gravel bar, at the ground surface at Sample #5. This material was not collected for sieve analysis and was removed prior to sample collection. The underlying material was consistent with the previous samples, with the exception of a higher percentage of fine material than other samples (Graph 1).

**Graph 1 - Sieve Analysis Result Comparison**




## 4.0 ARMOR LAYER MATERIAL CLASSIFICATION

After the sediment samples were collected, several sites were chosen for pebble counts. Pebble counts were conducted to provide information on the armoring material of the riverbed. Kris Ivarson conducted the pebble counts. Photos were taken at each count location and are included in Appendix C.

Pebble counts were conducted along two distinct areas. The first area was along a cross-section of the channel, located near Samples #4, #5, and #6. An overhead electric power line crosses the Matanuska River near the transect location.

The second pebble count area was down-river of Sample #4 and the City of Palmer WasteWater Treatment Plant. This area is classified as river bar, and is located adjacent to the active channel (photo below). This transect was conducted from upriver to downriver.

As discussed in the United States Department of Agriculture (USDA) Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR 74 (Bunte and Abt, 2001), pebble counts are biased towards larger particle sizes and can be easily biased by the sampler. This tendency makes pebble counts more accurate when the material consists primarily of larger particles, such as gravel and cobbles. In this case, a gravel and cobble size armored material was anticipated.


River bar near active channel, facing downstream

## 4.1 PEBBLE COUNT METHODOLOGY AND RESULTS

Pebble counts were conducted based on a modified Wolman (1954) method, which calls for 100 grid points. Wolman's methodology is typically described as traversing a sampling area with heel-to-toe steps, paces, strides, or several steps at a time. The first particle that is touched by a pointed finger, eyes averted, at the tip of the boot is picked up and measured along the median axis (e.g., Leopold 1970; Hey and Thorne 1983; Fripp and Diplas 1993; Bevenger and King 1995).

For our purposes, this method was modified to be more systematic and to take into account the site-specific problems in sampling. These site problems included open water, thin ice, ice flows, extensive snow cover and frozen particles, in addition to a flood plain nearly a mile in width. Due to this difficulty, particle counts were made along the accessible flood plain width and an accessible channel bar near the active channel.

In order to collect a reasonable sample of the armored layer both areas, two separate transects were traversed. Fifty pebbles were counted along the first cross-section, and approximately 50 were counted along the active channel bar. Sample areas were paced off and cleared of snow to the extent practical, in order to conduct sampling. A measuring tape was laid out along this exposed area. Particles were selected at intersections with even-spaced intervals of ½-foot along the edge of the tape (e.g., Wohl et al. 1996).

The first transect was conducted as a cross-section of the river. To the extent possible, a wide area of the flood plain was traversed and a particle count was conducted in selected areas. The second transect was conducted along the river bar, adjacent to an active channel riffle reach. This area was traversed from up river to down river along this single river bar. The bar was selected due to its proximity to the open water and length of visible sediment.

## 4.2 PEBBLE COUNT RESULTS

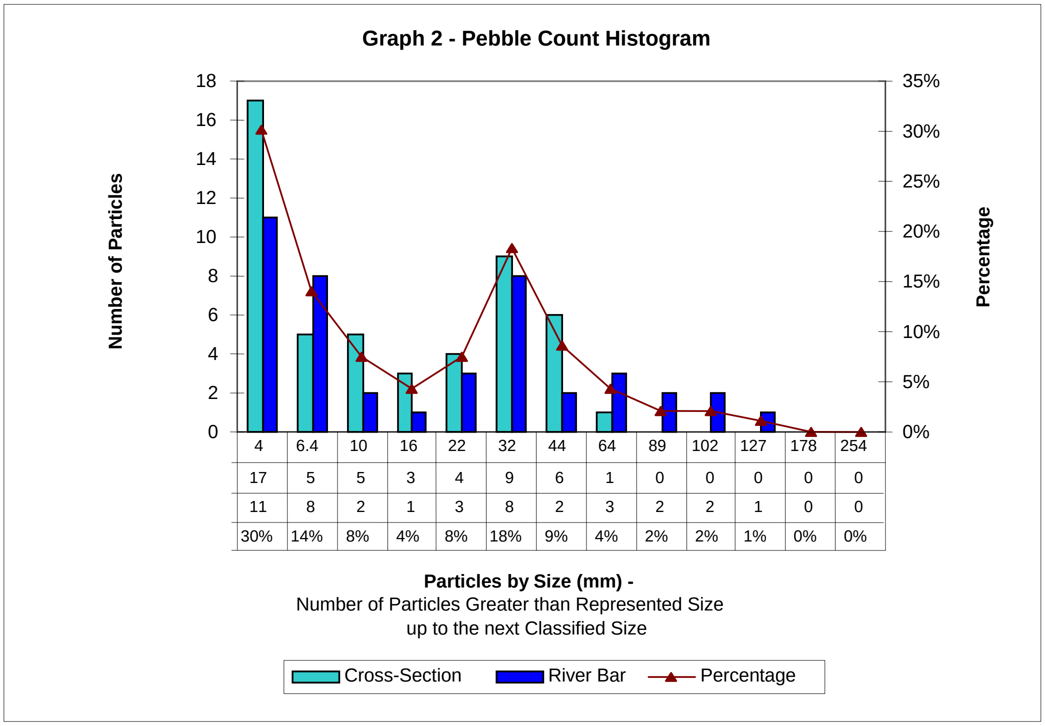
Particle classification was conducted using the Unified Soil Classification System (USCS), with broad particle size divisions, as shown in Table 3. Pebble count results indicated some cobbles (ranging from 75 mm to 150 mm) present along the river bar, with none found along the cross-section transect. Coarse gravel was identified in both transects, with 40% found along the cross-

**Table 3 Unified Soil Classification System (USCS) Particle Size Definitions**

| Particle Size (mm) | USCS Classification |
|---|---|
| 75 to 300 | Cobbles |
| 19 to 75 | Coarse Gravel |
| 4.8 to 19 | Fine Gravel |
| 2.0 to 4.8 | Coarse Sand |
| < 2.0 | Fine Sand to Silt |

section and 38% along the river bar. This size class represents the majority of the identified material.

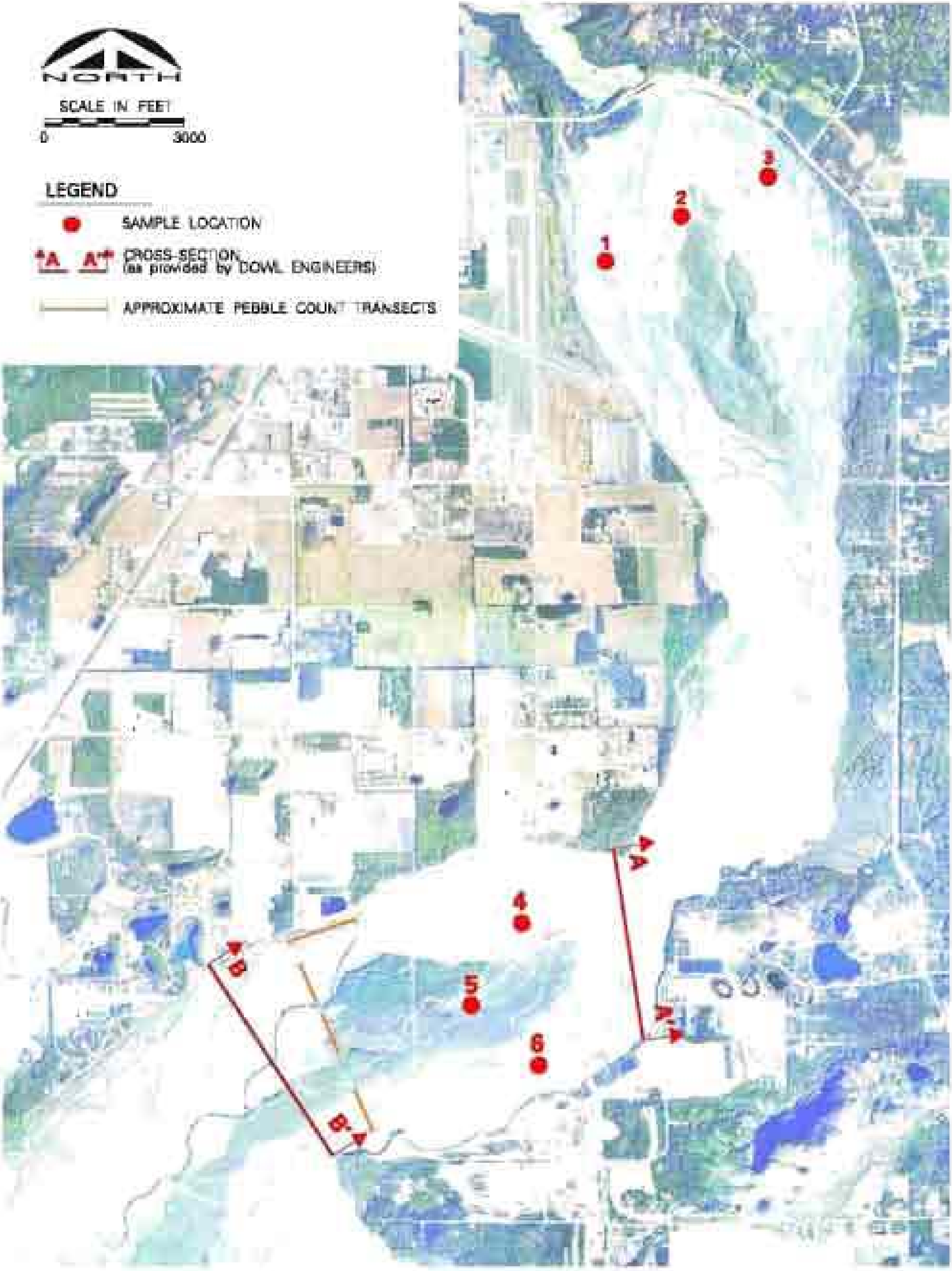
Fine gravel was present in nearly equal amounts along both transects, with an even distribution along the cross-section transect. The amount of fine gravel along the river bar transect was weighted towards finer material of 6 to 10 mm in size, as presented in Graph 2. A notable amount of coarse to medium sand was present and easily visible between the gravel and cobble particles at both transects. One portion of the transect along the cross-section transect consisted completely of coarse sand over a distance of approximately 20 feet. This situation did not occur along the river bar. Little silt was identified in either transect.




## 4.3 GENERAL LITHOLOGY AND REGIONAL GEOLOGY

Gravel and cobble size material appeared to consist primarily of quartz and granite. This rock type makes up approximately 80 to 90 percent of the overall sediment material. Some feldspar and conglomerate rock was also identified during sampling, however this was a secondary component of the material. Materials such as schist, slate, shale or sedimentary rocks were not apparent. Classification of sediment material was based on visual observation.

## FIGURES




MWH
Anchorage, Alaska

FIGURE 1

USNRCS
MATANUSKA RIVER – BED MATERIAL TECHNICAL MEMO

**SAMPLE LOCATIONS, CROSS–SECTIONS AND TRANSECTS**

# APPENDIX A

*Sample Locations - Photos*

Sediment Sample Location #1.

Sediment Sample Location #1A, shows greater amount of sand present within approximately 10 feet of Location #1.

Sediment Sample Location #2, aerial view showing vegetated high bar.

Sediment Sample Location #3.

Sediment Sample Location #4.

Sediment Sample Location #5
Aerial view showing vegetated high bar with spur dikes in background.

Sediment Sample Location #5
Showing vegetated high bar.

Sediment Sample Location #6
Sample collected at location shown near bottom of photograph, spur dikes in background.

Sediment Sample Location #5
Silt lens at ground surface.

# APPENDIX B

*Sieve Analysis Reports*

ALASKA TESTLAB
A Division of DOWL LLC

Client: MWH

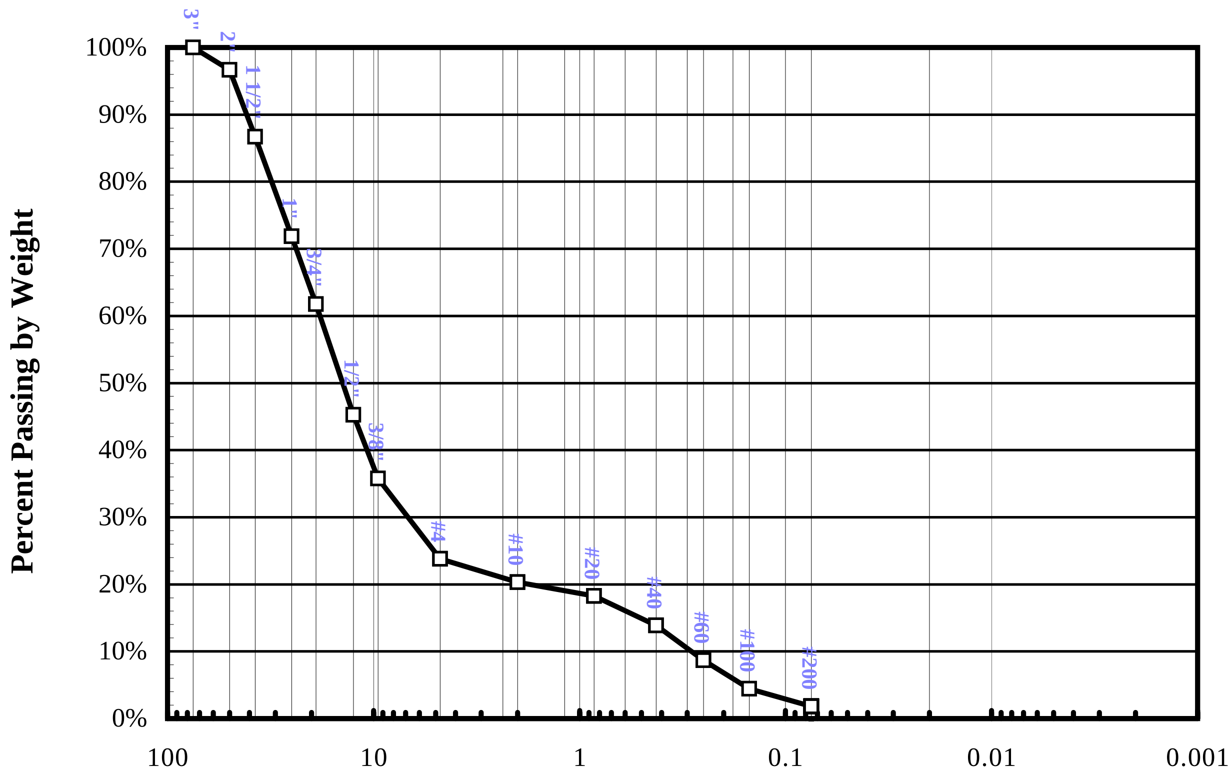
Project: Mat-Su River

Location: By Client,

Sample #1

Engineering Classification: Poorly Graded GRAVEL with Sand, GP

Frost Classification: NFS MOA






**PARTICLE-SIZE DIST. ASTM D422**

W.O. A30572

Lab No. 2921

Received: 12/10/03

Reported: 12/17/03

| SIZE | PASSING | SPECIFICATION |
|---|---|---|
| +3 in Not Included in Test = ~0% | | |
| 3" | 100% | |
| 2" | 97% | |
| 1 1/2" | 87% | |
| 1" | 72% | |
| 3/4" | 62% | |
| 1/2" | 45% | |
| 3/8" | 36% | |
| No. 4 | 24% | |
| Total Wt. = 10787g | | |
| No. 8 | | |
| No. 10 | 20% | |
| No. 16 | | |
| No. 20 | 18% | |
| No. 30 | | |
| No. 40 | 14% | |
| No. 50 | | |
| No. 60 | 9% | |
| No. 80 | | |
| No. 100 | 4% | |
| No. 200 | 1.8% | |
| Total Wt. of Fine Fraction = 379.2g | | |
| 0.02 mm | | |

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ALASKA TESTLAB
A Division of DOWL LLC

Client: MWH

Project: Mat-Su River

Location: By Client,

Sample #1A

Engineering Classification: Poorly Graded GRAVEL with Sand, GP

Frost Classification: NFS MOA

# PARTICLE-SIZE DIST. ASTM D422

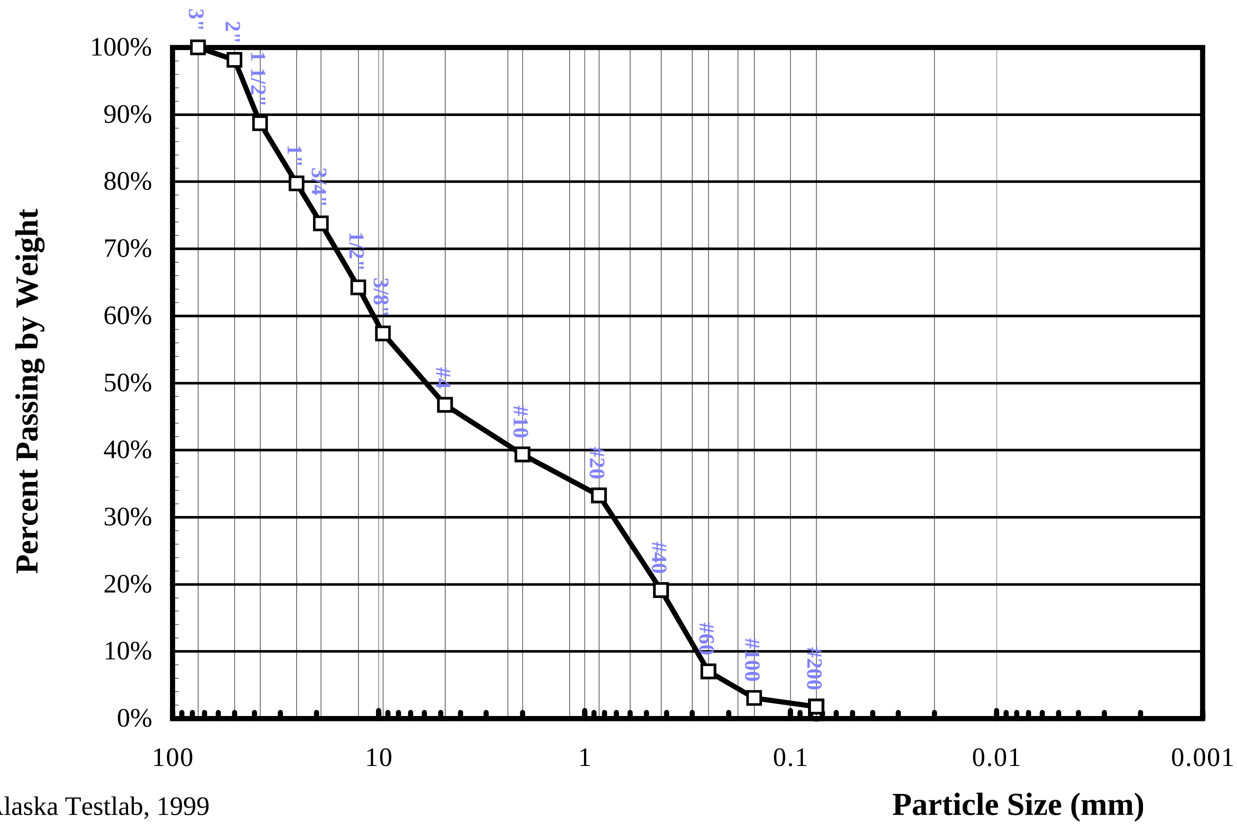
W.O. A30572

Lab No. 2922

Received: 12/10/03

Reported: 12/18/03

| SIZE | PASSING | SPECIFICATION |
|---|---|---|
| +3 in Not Included in Test = ~0% | | |
| 3" | 100% | |
| 2" | 98% | |
| 1 1/2" | 89% | |
| 1" | 80% | |
| 3/4" | 74% | |
| 1/2" | 64% | |
| 3/8" | 57% | |
| No. 4 | 47% | |
| Total Wt. = 16704g | | |
| No. 8 | | |
| No. 10 | 39% | |
| No. 16 | | |
| No. 20 | 33% | |
| No. 30 | | |
| No. 40 | 19% | |
| No. 50 | | |
| No. 60 | 7% | |
| No. 80 | | |
| No. 100 | 3% | |
| No. 200 | 1.7% | |
| Total Wt. of Fine Fraction = 360.8g | | |
| 0.02 mm | | |



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ALASKA TESTLAB
A Division of DOWL LLC

Client: MWH

Project: Mat-Su River

Location: By Client,

Sample #2

**PARTICLE-SIZE DIST. ASTM D422**

W.O. A30572

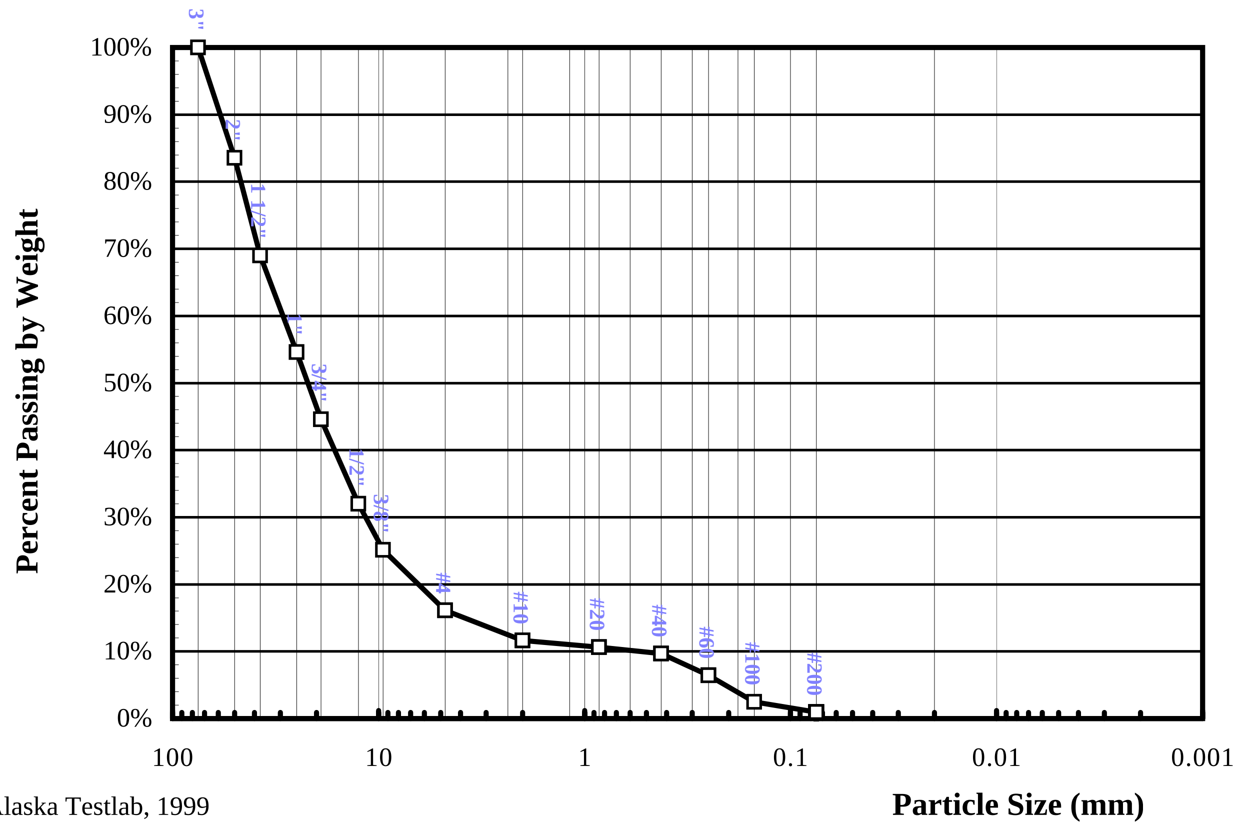
Lab No. 2923

Received: 12/10/03

Reported: 12/17/03

Engineering Classification: Poorly Graded GRAVEL with Sand, GP

Frost Classification: NFS MOA




| SIZE | PASSING | SPECIFICATION |
|---|---|---|
| +3 in Not Included in Test = ~0% | | |
| 3" | 100% | |
| 2" | 84% | |
| 1 1/2" | 69% | |
| 1" | 55% | |
| 3/4" | 45% | |
| 1/2" | 32% | |
| 3/8" | 25% | |
| No. 4 | 16% | |
| Total Wt. = 19516g | | |
| No. 8 | | |
| No. 10 | 12% | |
| No. 16 | | |
| No. 20 | 11% | |
| No. 30 | | |
| No. 40 | 10% | |
| No. 50 | | |
| No. 60 | 6% | |
| No. 80 | | |
| No. 100 | 2% | |
| No. 200 | 1% | |
| Total Wt. of Fine Fraction = 309.7g | | |
| 0.02 mm | | |



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ALASKA TESTLAB
A Division of DOWL LLC

Client: MWH

Project: Mat-Su River

Location: By Client,

Sample #3

**PARTICLE-SIZE DIST. ASTM D422**

W.O. A30572

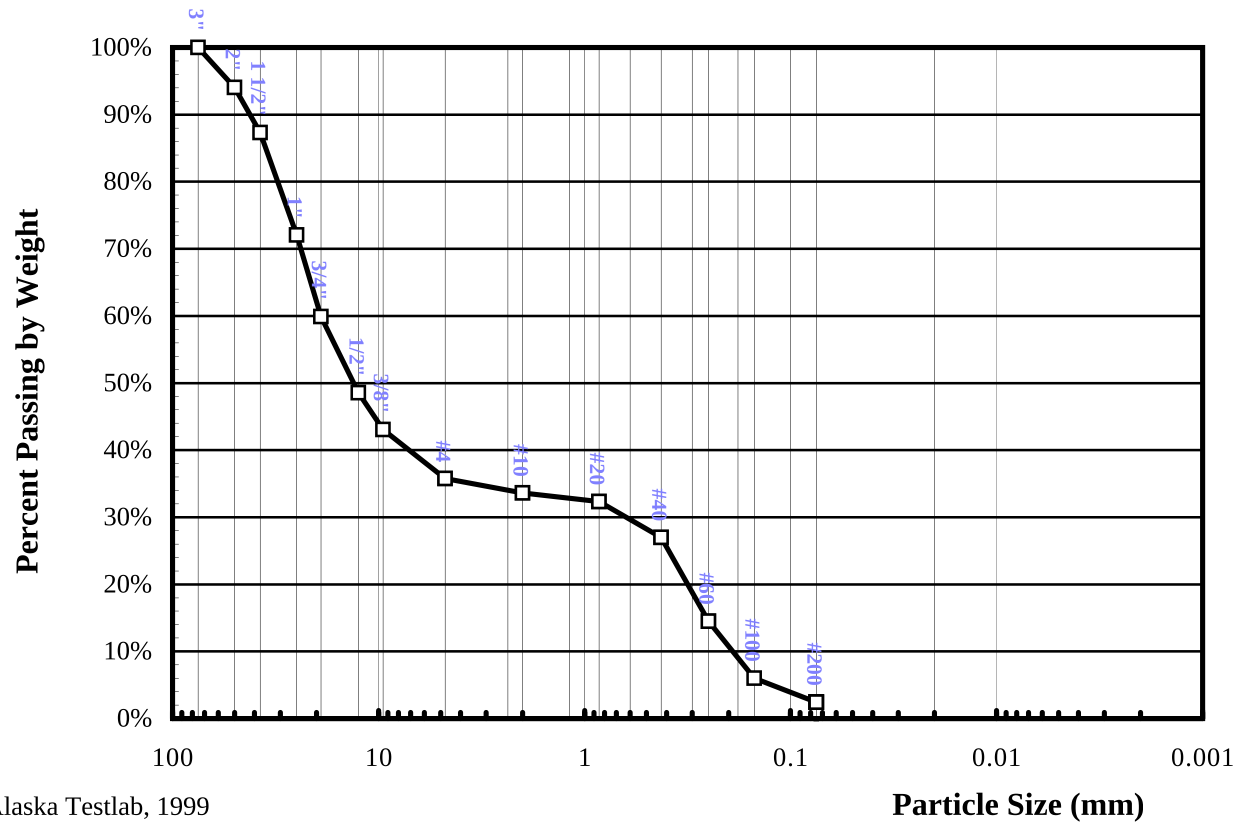
Lab No. 2924

Received: 12/10/03

Reported: 12/17/03

Engineering Classification: Poorly Graded GRAVEL with Sand, GP

Frost Classification: NFS MOA




| SIZE | PASSING | SPECIFICATION |
|---|---|---|
| +3 in Not Included in Test = ~0% | | |
| 3" | 100% | |
| 2" | 94% | |
| 1 1/2" | 87% | |
| 1" | 72% | |
| 3/4" | 60% | |
| 1/2" | 49% | |
| 3/8" | 43% | |
| No. 4 | 36% | |
| Total Wt. = 12957g | | |
| No. 8 | | |
| No. 10 | 34% | |
| No. 16 | | |
| No. 20 | 32% | |
| No. 30 | | |
| No. 40 | 27% | |
| No. 50 | | |
| No. 60 | 14% | |
| No. 80 | | |
| No. 100 | 6% | |
| No. 200 | 2.4% | |
| Total Wt. of Fine Fraction = 359.2g | | |
| 0.02 mm | | |



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ALASKA TESTLAB
A Division of DOWL LLC

Client: MWH

Project: Mat-Su River

Location: By Client,

Sample #4

# PARTICLE-SIZE DIST. ASTM D422

W.O. A30572

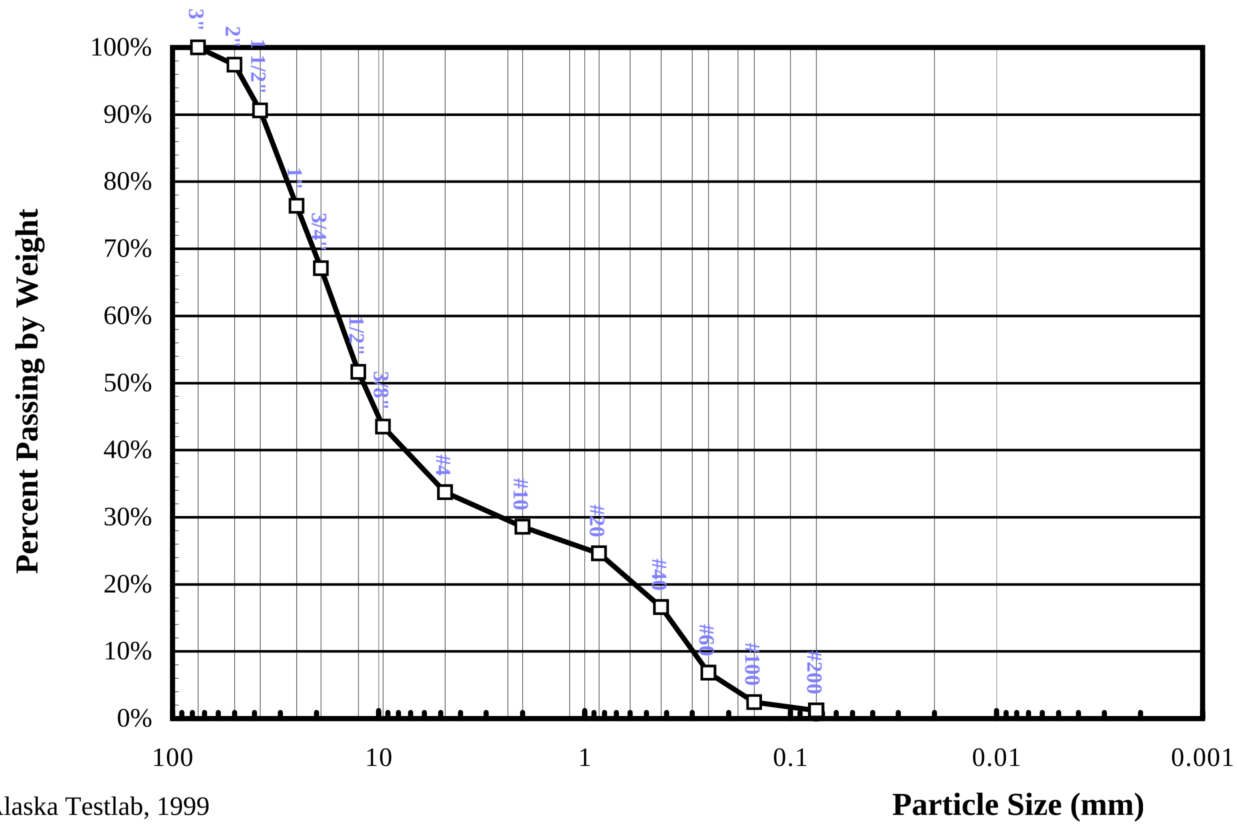
Lab No. 2925

Received: 12/10/03

Reported: 12/17/03

Engineering Classification: Well Graded GRAVEL with Sand, GW

Frost Classification: NFS MOA




| SIZE | PASSING | SPECIFICATION |
|---|---|---|
| +3 in Not Included in Test = ~0% | | |
| 3" | 100% | |
| 2" | 97% | |
| 1 1/2" | 91% | |
| 1" | 76% | |
| 3/4" | 67% | |
| 1/2" | 52% | |
| 3/8" | 44% | |
| No. 4 | 34% | |
| Total Wt. = 12578g | | |
| No. 8 | | |
| No. 10 | 29% | |
| No. 16 | | |
| No. 20 | 25% | |
| No. 30 | | |
| No. 40 | 17% | |
| No. 50 | | |
| No. 60 | 7% | |
| No. 80 | | |
| No. 100 | 2% | |
| No. 200 | 1.2% | |
| Total Wt. of Fine Fraction = 368.4g | | |
| 0.02 mm | | |



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ALASKA TESTLAB
A Division of DOWL LLC

Client: MWH

Project: Mat-Su River

Location: By Client,

Sample #5

## PARTICLE-SIZE DIST. ASTM D422

W.O. A30572

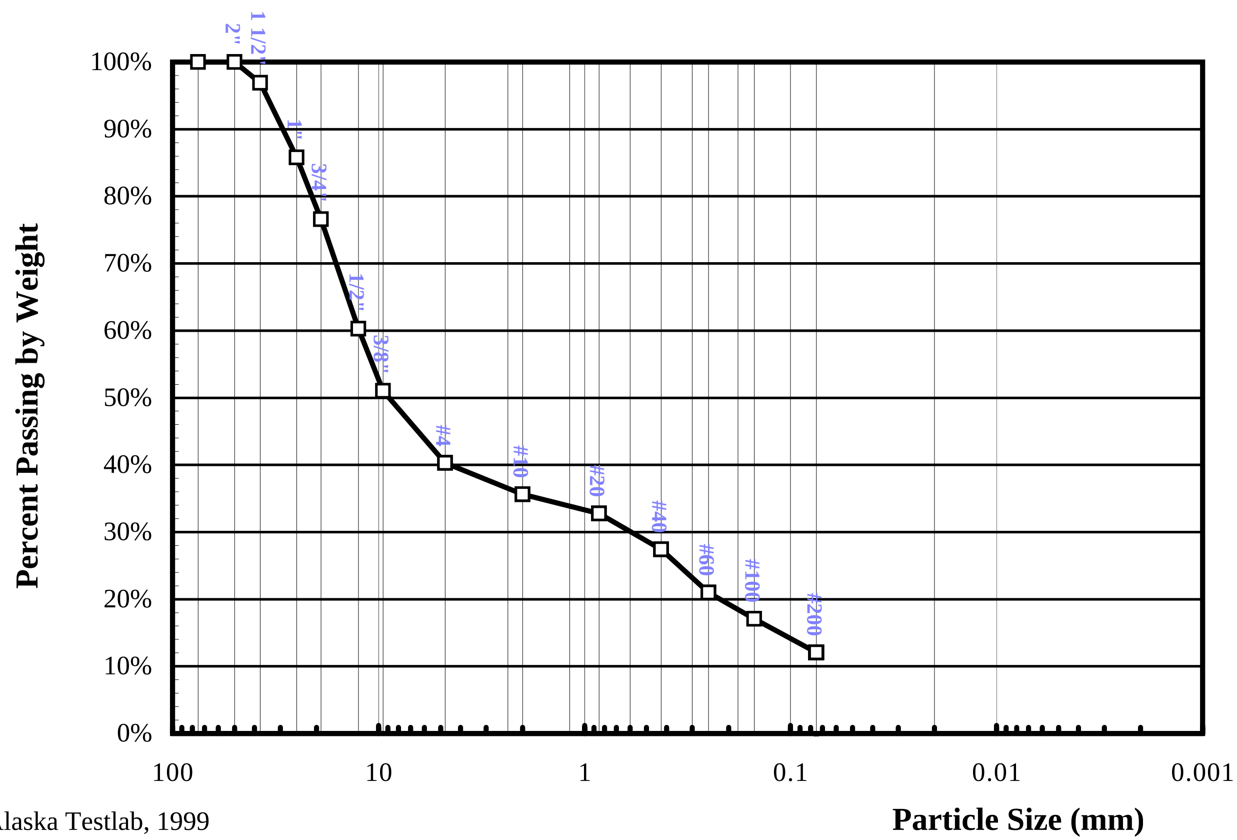
Lab No. 2926

Received: 12/10/03

Reported: 12/17/03

Engineering Classification: Poorly Graded GRAVEL with Silt and Sand, GP-GM

Frost Classification: Not Measured




| SIZE | PASSING | SPECIFICATION |
|---|---|---|
| +3 in Not Included in Test = ~0% | | |
| 3" | | |
| 2" | 100% | |
| 1 1/2" | 97% | |
| 1" | 86% | |
| 3/4" | 77% | |
| 1/2" | 60% | |
| 3/8" | 51% | |
| No. 4 | 40% | |
| Total Wt. = 13816g | | |
| No. 8 | | |
| No. 10 | 36% | |
| No. 16 | | |
| No. 20 | 33% | |
| No. 30 | | |
| No. 40 | 27% | |
| No. 50 | | |
| No. 60 | 21% | |
| No. 80 | | |
| No. 100 | 17% | |
| No. 200 | 12% | |
| Total Wt. of Fine Fraction = 396.8g | | |
| 0.02 mm | | |



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ALASKA TESTLAB
A Division of DOWL LLC

Client: MWH

Project: Mat-Su River

Location: By Client,

Sample #6

# PARTICLE-SIZE DIST. ASTM D422

W.O. A30572

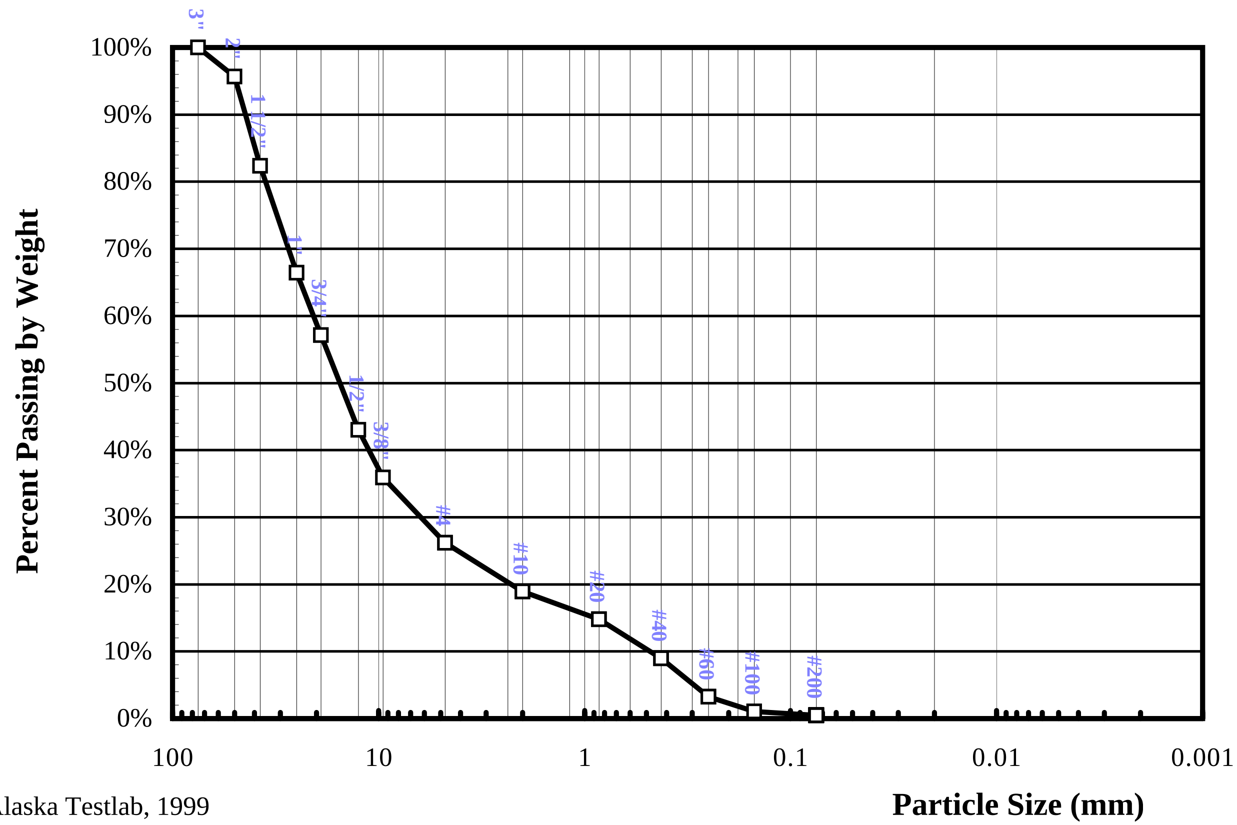
Lab No. 2927

Received: 12/10/03

Reported: 12/17/03

Engineering Classification: Poorly Graded GRAVEL with Sand, GP

Frost Classification: NFS MOA




| SIZE | PASSING | SPECIFICATION |
|---|---|---|
| +3 in Not Included in Test = ~0% | | |
| 3" | 100% | |
| 2" | 96% | |
| 1 1/2" | 82% | |
| 1" | 66% | |
| 3/4" | 57% | |
| 1/2" | 43% | |
| 3/8" | 36% | |
| No. 4 | 26% | |
| Total Wt. = 16582g | | |
| No. 8 | | |
| No. 10 | 19% | |
| No. 16 | | |
| No. 20 | 15% | |
| No. 30 | | |
| No. 40 | 9% | |
| No. 50 | | |
| No. 60 | 3% | |
| No. 80 | | |
| No. 100 | 1% | |
| No. 200 | 0.5% | |
| Total Wt. of Fine Fraction = 369.8g | | |
| 0.02 mm | | |



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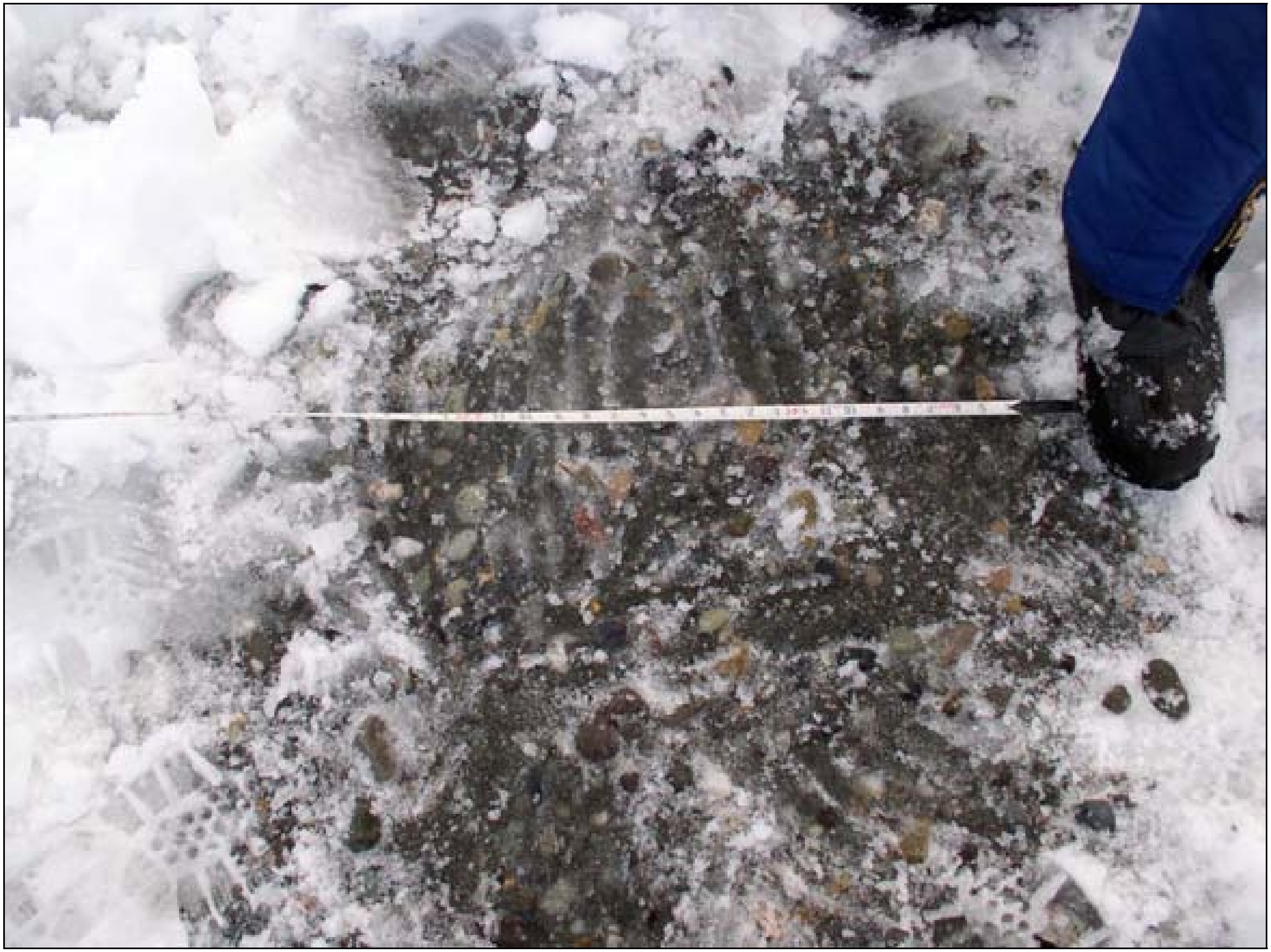
# APPENDIX C

*Pebble Count Locations - Photos*



Cross-section transect for Particle Counts

Cross-section transect for Particle Counts

Cross-section transect for Particle Counts

Cross-section transect for Particle Counts

Cross-section transect for Particle Counts

Cross-section transect for Particle Counts

River bar transect for Particle Counts

River bar transect for Particle Counts (Close up)

River bar transect for Particle Counts

River bar transect for Particle Counts

River bar transect, general area of sampling.

River bar transect, general area of sampling.

# APPENDIX D

*References*

Bevenger, G.S. and R.M. King, 1995. A pebble count procedure for accessing watershed cumulative effects. USDA, Forest Service, Rocky Mountain Forest and Range Experiment Station, Research Paper RM-RP-319, 17 pp.

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Leopold, L.B., 1970. An improved method for size distribution of stream bed gravel. *Water Resources Research* 6(5): 1357-1366.

Wohl, E.E., D.J. Anthony, S.W. Madsen, D.M. Thompson, 1996. A comparison of surface sampling methods for coarse fluvial sediments. *Water Resources Research*, 32 (10): 3219-3226.

Wolman, M.G., 1954. A method of sampling coarse bed material. *American Geophysical Union, Transactions*. 35: 951-956.

# Geomorphological Investigation of the Matanuska River - Palmer, Alaska

## Technical Memorandum

30 September 2004

*Prepared for:*

**MWH Americas, Inc.**
Anchorage, Alaska

**United States Natural Resources Conservation Service**
Anchorage, Alaska

*Prepared by:*


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West Sacramento, CA  95691
916-371-7400


nhc

## Introduction

The purpose of this technical memorandum is to provide a geomorphologic evaluation and review of the effectiveness of the proposed erosion control and dredging concepts on the Matanuska River. A consideration of the stability, hence longevity, of these works requires a review of sedimentation processes in the braided channel system, an understanding of the general mechanisms of channel deformation on braided channels, and an examination of channel characteristics within the study reach.

## Watershed geomorphology

The Matanuska River drains a watershed area of 2,070 sq. miles upstream of Old Glenn Highway Bridge near Palmer, Alaska, with roughly 10% of the basin occupied by the Matanuska Glacier, and an additional 2 - 3% by tributary glaciers. The main river channel extends more than 70 miles from the glacier to its confluence with the Knik River, where the two channels are building a compound delta at the head of Knik Arm of Cook Inlet. (Fahenstock and Bradley, 1973). The river valley is located in a glacial trough bounded by the Chugach Mountains to the south and the Talkeetna Mountains to the north.

The contemporary channel morphology of Matanuska River largely reflects upstream controls established by repeated glaciation, especially during the Quaternary period. Much of the river is bounded by thick glacial outwash deposits over tertiary bedrock that is exposed in several sections along the lower two-thirds of the channel. Near Palmer, a stagnant lobe of the Matanuska- -Knik glacier formed a variety of ice-contact features (Clardy et al., 1984) such as kames and eskers. Following deglaciation, the channel has eroded through the valley fill, leaving a sequence of stepped terraces formed from erosion through alluvial fan deposits.

The river is typically much wider and shallower along unconfined sections, where large deposits of sand and gravel have formed a series of alluvial braided reaches separated by narrower confined reaches. Confined sections are bounded by bedrock, glacial deposits or artificial constrictions such as roads and revetments. The constricted reaches further act as vertical control on the river by causing upstream accumulations of sand and gravel. This material is derived from a number of different sources, including landslides along valley slopes, erosion of river terraces, and tributary streams that form alluvial fans where they intersect the Matanuska River. Coarse sediment is also commonly supplied from exposed deposits at the base of receding glaciers in most proglacial watersheds, but Pearce et al. (2003) found that bedload constituted <1% of the total clastic yield, or roughly 260 metric tons per annum from Matanuska glacier. Alternatively, the authors noted that steep non-glacial tributaries near the glacier were much more significant bedload sources near the headwaters, and suggested that such areas potentially account for a substantial volume of coarse sediment throughout the entire watershed. Indeed, the presence of alluvial fans at the mouths of large tributaries including Gravel Creek, Chickaloon River, and Granite Creek confirms that these systems deliver large quantities of sediment directly into the main channel network (Figure 1).

The study reach adjacent to the town of Palmer provides a typical example of a braided alluvial fan deposit. The first comprehensive study of the deposition zone was provided by Fahnestock and Bradley (1973) who described the following:

*"The Matanuska at normal summer high flows is actively changing the details of its complex*

*pattern, vigorously attacking and undercutting a tree laden bank or island, depositing bars and levees across channel mouths, blocking flow from active channels or raising the local bed elevation to cause the reactivation of abandoned channels. Even at the gaging station at the bedrock narrows, the rattle and hiss of gravel bed load movement can be heard and discharge measurements on successive days show the changes in channel cross-section."*

The study reach is bounded by a narrow bedrock gorge at its upstream extent (where the USGS gaging station is located) that produces a high velocity flow jet during large discharge events. Coarse sediments from upstream sources pass through this constriction, and are deposited as a series of complex bar forms where the channel widens, flow diverges and bed shear stresses decline. Over the past few decades, this deposition has produced a large, elevated bar/island complex in the middle of this upper reach (reach 1) that bifurcates the flow and has resulted in direct shear erosion along outer channel banks and undercutting/ slumping at the base of high terraces. An additional medial bar/island complex has formed in the downstream reach (reach 2) and has caused similar concerns in the vicinity of the wastewater treatment ponds and the Circle View Estates subdivision.

At low flows, the two main channel branches are comprised of a highly complex sequence of transient bars separated by a network of narrow, shallow sub-channels with no clearly dominant thalweg. The network channels converge as discharge increases, but some bar elements remain exposed even at high (i.e. 2-year) flow, though individual units are typically small and randomly distributed. However, if woody debris becomes trapped on these surfaces, finer sand and silts are deposited in the lee, and vegetation can become established and stabilize the bar, allowing the deposit to grow. Much larger elevated bar deposits are also constructed as a remnant feature of channel abandonment. An example is found in reach 2 near the sewage treatment plant, where the channel flowed along the north bank in the 1970's, but has since avulsed to the south side and formerly eroding banks are not currently threatened (Figure 2). These areas form where the channel alignment directs flows against banks or channel constrictions, and sediment can accumulate vertically, especially during high magnitude events. Since abandoned areas are not re-worked by more modest floods, vegetation becomes established and island and floodplain deposits form over periods of years to decades. Reinfelds and Nanson (1993) found that abandonment of bar deposits by lateral migration of the braidtrain to be the dominant mechanism of floodplain formation on the Waimakariri River, New Zealand.

## Differences between channel types

In order to review the expected effectiveness and longevity of the proposed trench excavations, it is necessary to understand the dynamics of braided river channels,and how these channels are distinguished from other channel typologies. The term 'braided' is usually reserved for multi-channel rivers of steep slope, low sinuosity and high width/depth ratios (Miall, 1977). A variety of conditions have been identified as condusive to the development of braided channels (Knighton, 1998). Channel morphology is principally a product of the local flow and sediment regimes (cf. Mollard, 1973; Richards, 1982; Kellerhals et al., 1986; Church, 1992) and valley gradient (Carson, 1984; van den Berg, 1995). In addition, adjacent land use patterns, riparian vegetation, bank strength and anthropogenic modifications (e.g. bank hardening, gravel removal) have also been recognized as contributing factors that influence the entrainment, transport and deposition of sediments, hence the stability and morphology of alluvial channels.

Lane (1957) noted that although there is nearly an infinite variety of possible stream forms, similar combinations of some controlling variables were found to produce similar principal patterns, which he separated into meandering or braided types. Leopold and Wolman (1957) also noted that channel pattern formed a continuum, and introduced straight, meandering and braided channels as quasi-stable forms. Both studies introduced discriminating functions to explain the difference between meandering from braided channels. The widely cited function as given in Leopold and Wolman is:

slope = 0.0012 $Q_b^{-0.44}$, where $Q_b$ is bankfull discharge in cfs.

This equation (and similar relations) provide a means to predict channel pattern and assess channel stability based on a number of independently measured variables. This above relation implies that braided rivers have a steeper gradient than meandering rivers which convey the same bankflow flow (note that the braided Matanuska River falls well above this meandering threshold - see Figure 3). Since discharge and slope are components of stream power, braided rivers should also have a greater capacity to transport sediments at a given flow than do meandering channels. This was demonstrated by Desloges and Church (1989) who found that a discriminant function of the form $SQ^{0.5}$ could separate braided channels from more stable wandering channels. This function was combined with the generally accepted scale relation of channel width [b] ~ $Q^{0.5}$ to yield a relation of the form w = SQ/ ω, where ω is specific stream power. Most braided channels (including the Matanuska River) plot above this line. Since braided channels transport relatively higher volumes of coarse sediment than other channel types, they are inherently more unstable. However, Carson (1984) cautions that a neccessary prerequisite for braiding remains a sufficient supply of bed material, regardless of available transport capacity. This (high supply of bed material) is likely the dominant cause of braiding on Matanuska River.

The size of available sediment is also an important consideration, since particle mobility is a function of available shear stress. This point was argued by Carson (1984) who found that active gravel-bed channels plot above the meandering threshold slope simply because the critical threshold slope for coarse sediment mobility is greater. Alternatively stated, this means that the discharge-slope threshold for braiding increases with sediment size (Henderson, 1966; Carson, 1984; Dade, 2000). Since the bed material on Matanuska River is fairly small ($D_{50}$ = 12 mm) relative to available stream power, sediments are actively mobile during high flows events and the channel plots well within the 'braided' side of different discriminating function relating channel characteristics with bankfull discharge ane channel slope (Figure 3).

Discriminating functions have been increasingly used to gauge the sensitivity of river channels to change, to predict the direction of change, and even as a template to restore degraded channels. Over shorter periods of time, anthropogenic interference such as gravel removals, flow diversions, channel straightening and bank hardening are probably the dominant perturbing force on rivers, since natural trends (i.e. climate) tend to occur much more gradually. From an engineering perspective, such activities may cause a change in channel pattern, hence an associated change in bed and bank stability and the quality of aquatic habitat. Correspondingly, a channel that plots near a threshold line is expected to respond more dramatically (with respect to changing channel pattern) to activities such as gravel mining or bank hardening than a river that plots well above or below a threshold.

In general, the large size of the channel, abundant bedload and high available energy relative to the size of the bedload on Matanuska River indicate that the braided channel planform should not be highly sensitive to engineering changes provided that removal volumes do not exceed average annual rates of sediment deposition for extended periods. In contrast, our MIKE21 modeling studies (nhc, September 2004) have demonstrated that significant alterations in flow depth, velocity and sediment transport (but not channel bed configuration and pattern, since the fixed-bed model cannot predict changes in channel evolution due to changed hydraulic conditions) are expected within the immediate vicinity of the gravel excavation sites. In the absense of continued monitoring of channel response and maintenance of the excavation trenches, however, the channel is likely to naturally rehabilitate to its pre-disturbance morphology within two to five years.

## Braided channels

Braided rivers have a complex, transient morphology characterized by flows that diverge and converge around major assemblages of emergent bars and vegetated islands. The splitting and re-joining of flow paths around channel deposits results in a very dynamic rate of channel activity relative to other types of channels. As a consequence, bar migration, avulsions, and abandonment can all occur within a single flood event and on small braided channels, significant channel change has been observed daily (Goff and Ashmore, 1994; Lane et al., 1995). Observed changes are also episodic, even at constant discharge, as sediment is delivered downstream in pulses (Nicholas et al., 1995). Larger braided channels tend to exhibit less variability, in general, because the volume of material stored within the channels is greater than the sediment flux rate, so the time required to complete major modifications exceeds the duration of a single flood or freshet. Nevertheless, Fahnestock and Bradley (1973) suggested that the Matanuska can rework bars over many days and that radical modifications are apparent annually. A qualitative examination of channel morphology from two dates (representing pre- and post-freshet conditions) of aerial photography taken in 1981 confirms this observation (see Figure 4). As well, many avulsions are known to have occurred along the river over the past half-century and the entire braidplain within the reach is estimated to turn over every 75 years (nhc, June 2004).

Nicholas et al. (1995) note that the creation, migration and removal of bar units in braided rivers has been related to zones of preferential entrainment, transport and deposition resulting from spatial variations in channel morphology and hydraulics. The irregular bed topography of braided rivers produces spatially and temporally distributed shear stresses (Ferguson and Ashworth, 1992) that results in erratic bed movement depending on local combinations of sediment size and availability. Consequently, bar erosion and deposition can occur simultaneously within the same reach and braided rivers can evolve almost continuously during competent flows as sediment is exchanged. Hydrodynamic modeling simulations (nhc, Sept 2004) demonstrate these complex patterns of flow depth, velocity and relative transport rates on Matanuska River. Quantitative measurements of distributed rates of sediment transport have also been measured in the field on braided channel systems (Goff and Ashmore, 1994; Lane et al., 1995).

Despite their dynamic nature, braided channels can remain in equilibrium at the reach scale (Carson and Griffiths, 1989; Nicholas et al., 1995). In contrast to the instability of individual channels and bar assemblages, the braided planform itself can be considered a quasi-equilibrium channel form that can last for decades. Despite significant fluctuations in short-term storage and transfer, over many years, there may be no net accumulations or losses of sediment within a reach (Nicholas et al., 1995; van den Berg, 1995). Historical photo records of Matanuska River appear to confirm this assertion. Although individual bars and bar units show considerable variability as flow channels migrate, the general character of the river (2 main channels that diverge and converge around large central bar deposits) has remained fairly stable for nearly two decades.

## Characteristics of the study reach

From a geomorphologic perspective, the behaviour of the excavated channels is of concern on Matanuska River, since natural river instability may impact the effectiveness of the trenches to re-direct flows and reduce water levels.

The first major concern relates to the expected longevity of the excavated sites. To protect against flooding and erosion, a pit trap was designed to capture gravels, while several elongated trenches were designed to route flows. The pit trap should contain up to two years volume of annual gravel influx. nhc (June, 2004) estimated the average annual influx of gravel to the reach past the narrows at Old Glenn Highway Bridge to be roughly one-half million tons per year on average. The material would be naturally deposited throughout the reach as barforms, while a similar volume (though potentially reduced because of armouring) would naturally be removed into the downstream reach from erosional processes. A trench and pit trap immediately downstream of the Bridge is expected to 'capture' much of the discharge and annual influx of gravel. The increased velocities in the upstream trench are likely to transport much of the load conveyed from upstream into the pit trap, where velocities decline. There is a risk associated with the existing design that the trench will actually fill before the pit trap, however, high velocities are computed at the upstream limit of the trench as water "spills" into the trench cut, potentially lowering the risk of such an occurance. Filling of the downstream portion of the trench andpit trap may also occur if the trench begins to headcut, although this headcutting will also locally reduce water levels.

An adaptive strategy for implementing the excavation is recommended to test the behaviour of the existing design, and whether the pit trap acts as a receptor for incoming sediments. Should this design prove ineffective after one or two freshets, an alternative approach whereby the pit trap is placed at the upstream extent of the trench cut could be investigated. While this alteration almost certainly would capture most of the incoming gravel load, the consequent effectiveness of the downstream trench for altering flows has not been examined. In contrast, the downstream trenches are likely to be more stable. The combined impact of reduced downstream sediment flux below the pit trap, and reduced flow velocities adjacent to the trenches (see nhc, Sept 2004a) should decrease bar migration, hence lateral channel instability. The sediment flux is expected to recover to near existing conditions prior to the flow entering the downstream trenches due to the considerable distance between the upstream pit trap and downstream trenches. However, by reducing the local supply of bed material, some local incision is probable as available stream energy increases, although armouring should limit the effect (nhc, Sept 2004a).

A second major concern relates to the possibility that the excavations may become inactive due to channel shifting. As shown in Figure 4, flow channels can migrate considerable distances over the course of a single freshet. The main loci of channel bifurcations and shifts are associated with the upstream limit of major bar assemblages. Aggradation at the entrance to either channel can result in avulsions as the other channel captures more flow. An attempt has been made to align the upstream end of the proposed excavations with the larger flow channels to reduce this possibility. Since braided channels characteristically exhibit irregular and unpredicable morphologic development, there can be no guarantee that the proposed excavations will remain stable for a significant time period (i.e. multiple freshet seasons) to reduce flood levels and redirect flows as intended. Annual monitoring is reccommended and annual excavations are likely required to maintain the pit trap and trenches. Given the potential for these activities to modify the characteristics of aquatic habitat within the study reach, additional long-term monitoring of these sites for changes to fish density and diversity may be required.

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Figure 1. Confluence of alluvial fan with the Matanuska River upstream of the study reach.

Figure 2. Abandoned, vegetated channel adjacent to sewage treatment ponds.

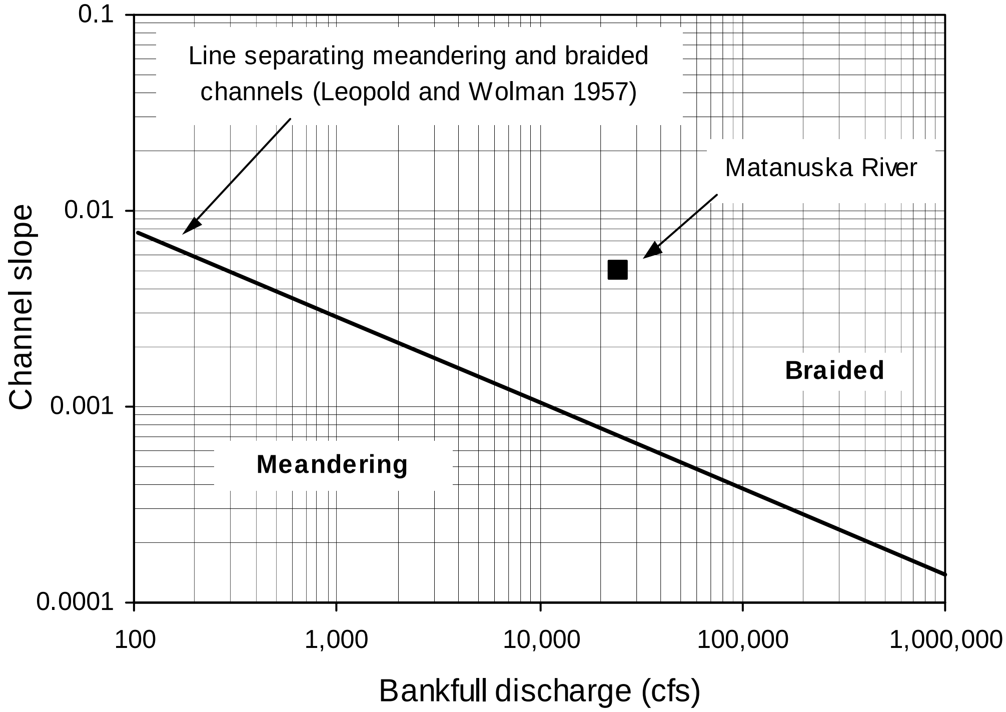



Figure 3. The Leopold-Wolman disriminating funciton for separating meandering and braided channels.

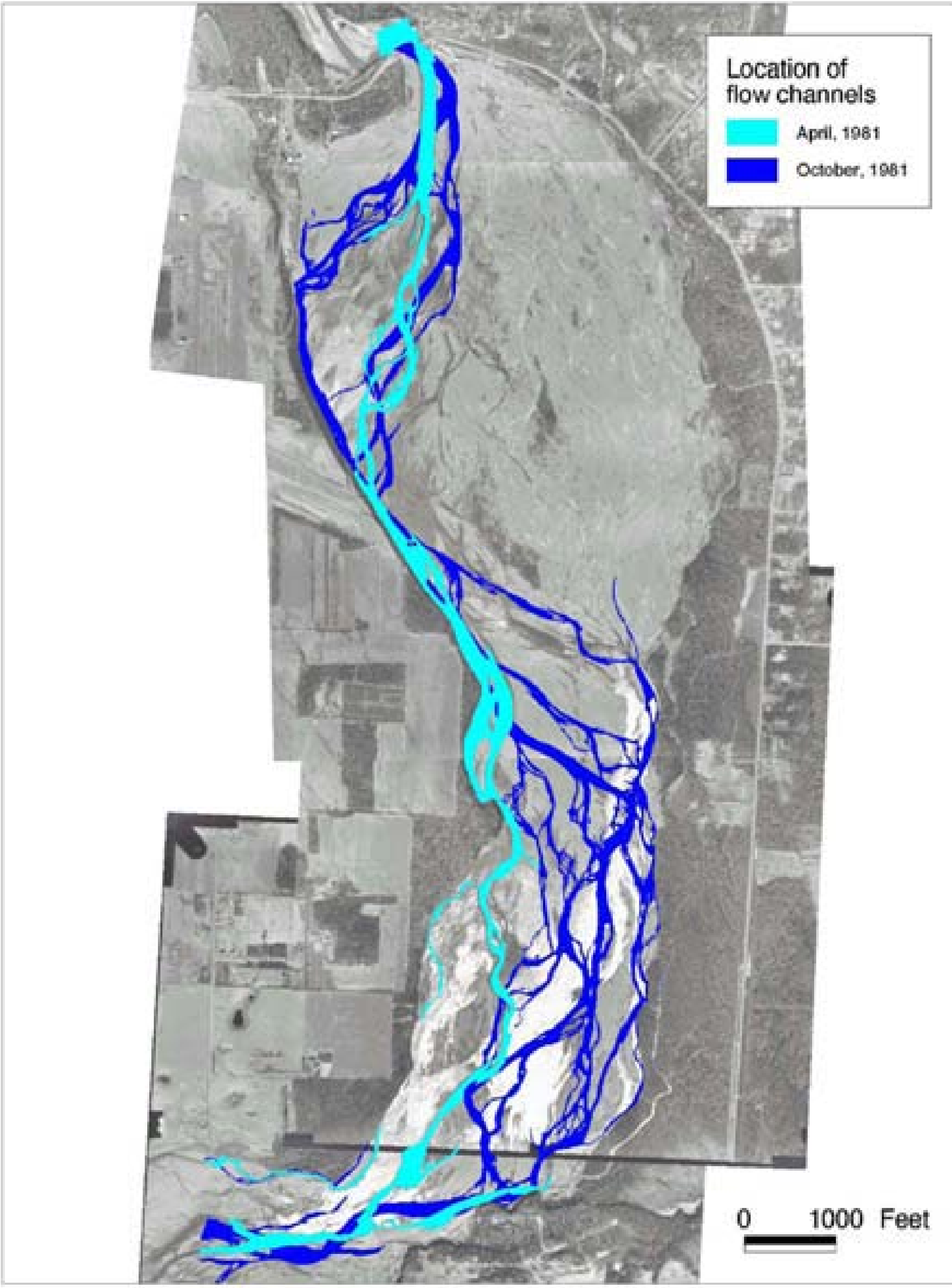



Figure 4. Pre- and post-freshet Matanuska River braid channel pattern.

# APPENDIX D

*Hydrologic Analysis*

MWH

**To:** File **Date:** March 16, 2004

**From:** Mel Langdon **Reference:** 1851040.010103

**Subject:** Matanuska River Hydrology

## 1.0 INTRODUCTION

The NRCS has commissioned a study to determine whether gravel mining in the Matanuska River can reduce erosion. The area considered for gravel mining, a subset of the study reach, extends from the Old Glenn Bridge downstream to tidewater, a distance of about 2 miles. This technical memorandum characterizes the hydrologic regime of the Matanuska River watershed in general as a basis for that study.

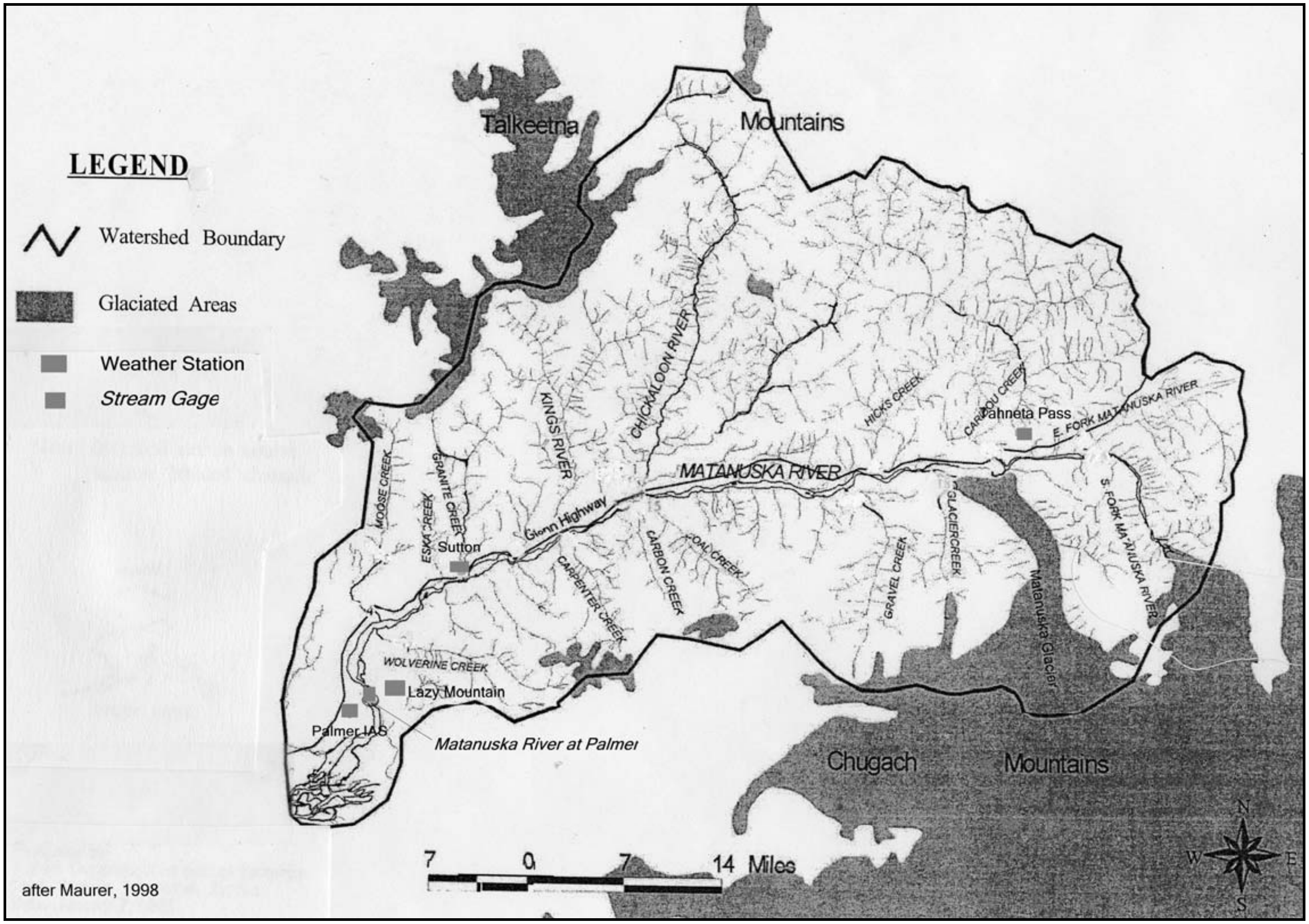
## 2.0 WATERSHED CHARACTERISTICS

The drainage area tributary to the Matanuska River at the Palmer gauge, at the downstream end of the study reach, is 2,070 square miles. The river flows southwest from its headwaters northeast of the Matanuska Glacier (Figure 1), approximately 75 miles to its mouth at Knik Arm (Maurer, 1998). Peaks in the Chugach Mountains, which form the boundary on the south side of the watershed, rise to elevations above 10,000 feet. In the Talkeetna Mountain Range to the north, peaks rise to 6,500 feet. The average elevation of the drainage area is 4,000 feet. With treeline at approximately 3,000 feet, the majority of the watershed is not forested. The largest tributaries flow south from the Talkeetna Mountains. Portions of the upper reaches of both the Talkeetna and Chugach mountain tributaries to the Matanuska River are covered with glaciers, so stream tributary to the Matanuska River may be glacial or non-glacial in origin.

The lower Matanuska Valley lies in a structural trough that trends northeast-southwest. The northwest border of the trough is defined by the Castle Mountain Fault, along which older rocks of the Talkeetna Mountains (mostly Cretaceous and tertiary-age granitic intrusives and sedimentary rocks) (LaSage, 1992), have been thrown up against younger rocks on the valley floor (Barnes, 1962). The Chugach Mountains are composed of cretaceous-jurassic metasedimentary and metaigneous rocks. The Talkeetna Mountains are composed of granitic and gneissic rocks. Folding and faulting has deformed the rocks of the valley floor. The March 27, 1964 earthquake caused regional subsidence of about 2 feet in the lower third of the valley (Plafker, 1969).

Younger deposits in the basin are the result of the last major ice expansion. Glacier drift, including till, was deposited over scoured bedrock and as the ice receded ice-contact deposits, such as kames, eskers, and crevasse fills, produced uneven terrain. Winds in the lower valley resulted in aeolian deposits northwest of the mouth of the river (Trainer, 1961).

**Figure 1 Matanuska River Watershed (after Maurer, 1998)**



The river itself has a broad, braided floodplain, with some bedrock constructions, for the lower two-thirds of its length. In some places, the floodplain is up to a mile wide.

Coal was mined in the Matanuska Valley from 1916 to 1967 in the vicinity of Chickaloon and Eska on the north side of the river (WCC, 1984). In the 1930s, lands northwest of the mouth of the Matanuska River were opened to agricultural development. The farming area is located in a roughly rectangular area 10 to 12 miles wide and extending from the Chugach Mountains west some 15 to 20 miles. Only a portion of this farmed area is within the Matanuska River watershed. The City of Palmer is the largest urban area in the drainage area and is located to the west of the river within the study area. Agriculture and mining are not expanding in the basin; some agriculture land is being converted to urban use and old mines are being reclaimed. Rapid urban growth continues, as evidenced by the 4.5 percent annual population growth in the City of Palmer over the last 10 years. However, much of the watershed remains undeveloped. An estimate of the current land use areas is shown in Table 1.

**Table 1**
**Estimated Areal Extent of Land Uses in the Matanuska Valley**

| Type of Land Use | Area (square miles) | Percent of Total Area |
|---|---|---|
| Agriculture | 40 | 2 |
| Mining | <20 | <1 |
| Roads and Urban | 150 | 8 |
| Undeveloped – vegetated | 1,670 | 80 |
| Undeveloped – glacier | 250 | 12 |
| **Total** | 2,070 | 100 |

Key:
< – less than

The Matanuska glacier is one source of sediment. Sediment discharge from glacier (discharge from meltwater pools) is not coincident with peak discharge, and it appears that the release of coarse sediment from the glacier is more dependent on drainage networks within the glacier ice than on peak discharges (Pearce, et al., 2003). Steep, non-glacial tributaries downstream of the Matanuska Glacier, particularly those heading toward the Talkeetna Mountains on the north side of the valley, are thought to contribute significantly more bedload than the Matanuska Glacier (Pearce, et al., 2003).

## 3.0 STREAMFLOW PATTERNS

Daily mean average flows are available for the Matanuska River gauge at Palmer, Alaska for water years 1950 through 1972, 1986, 1992, and 2001 with partial records for 1973 and 2000. Streamflow shows a strong seasonal variation, as shown on Figures 2 and 3. Over 70 percent of the annual flow occurs from June through August.

**Figure 2 Percent of Matanuska River Discharge by Month**

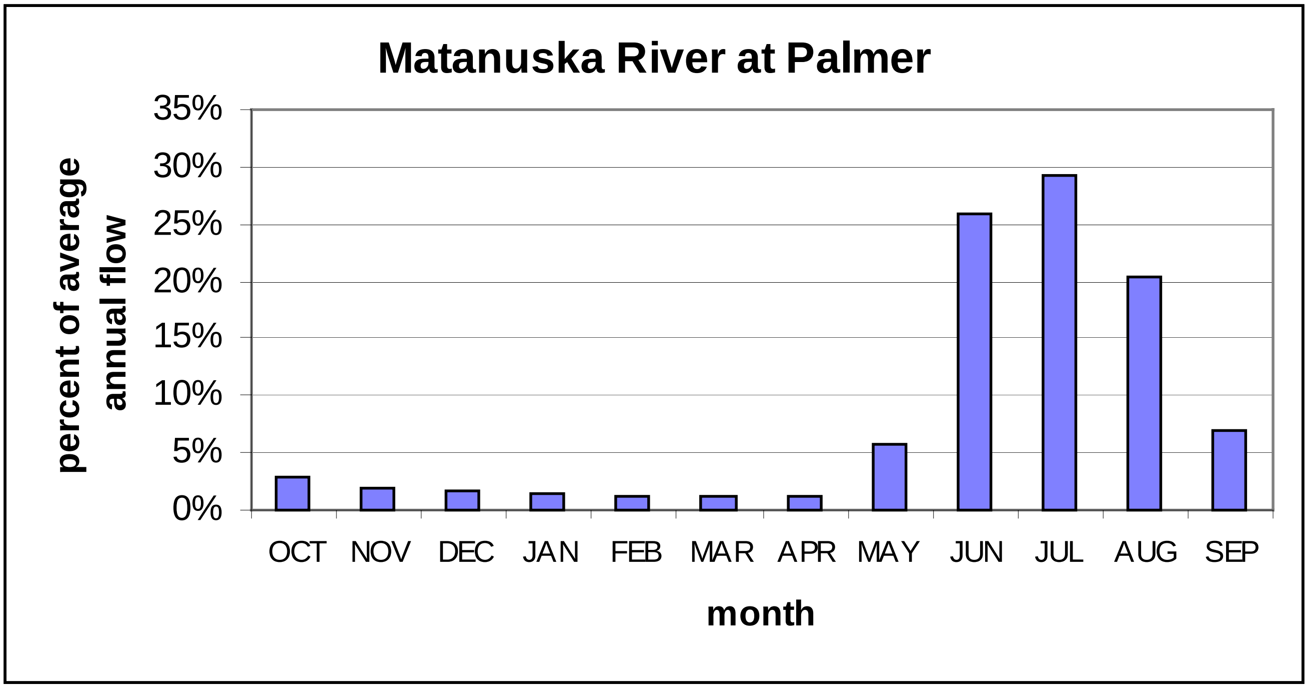
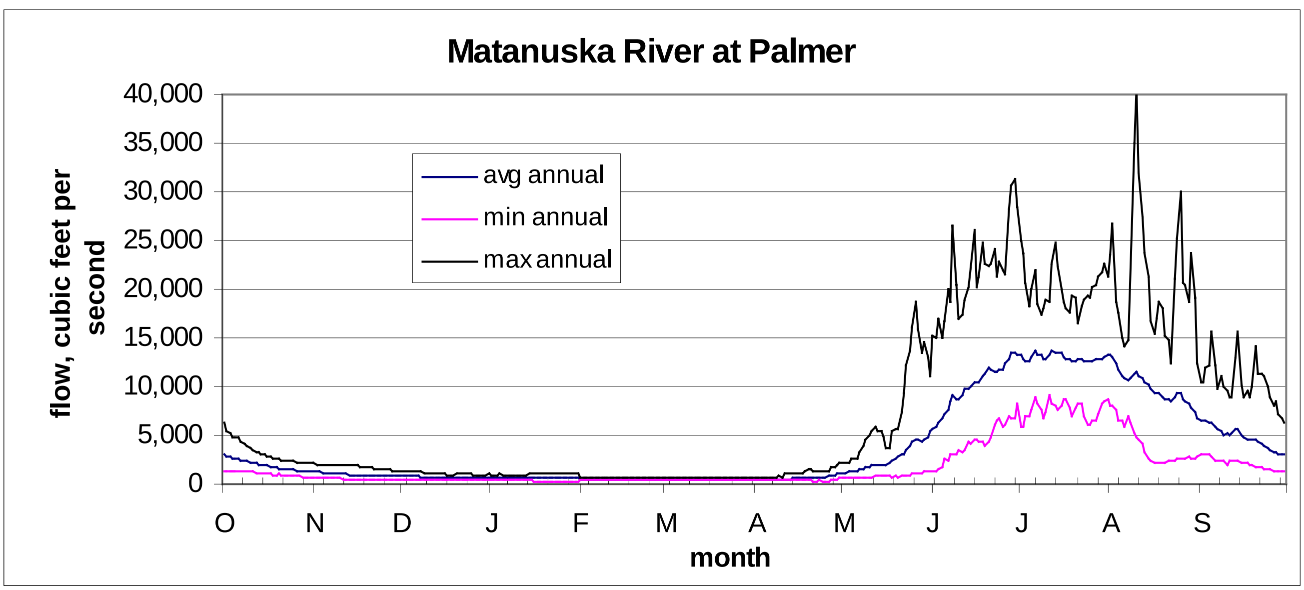
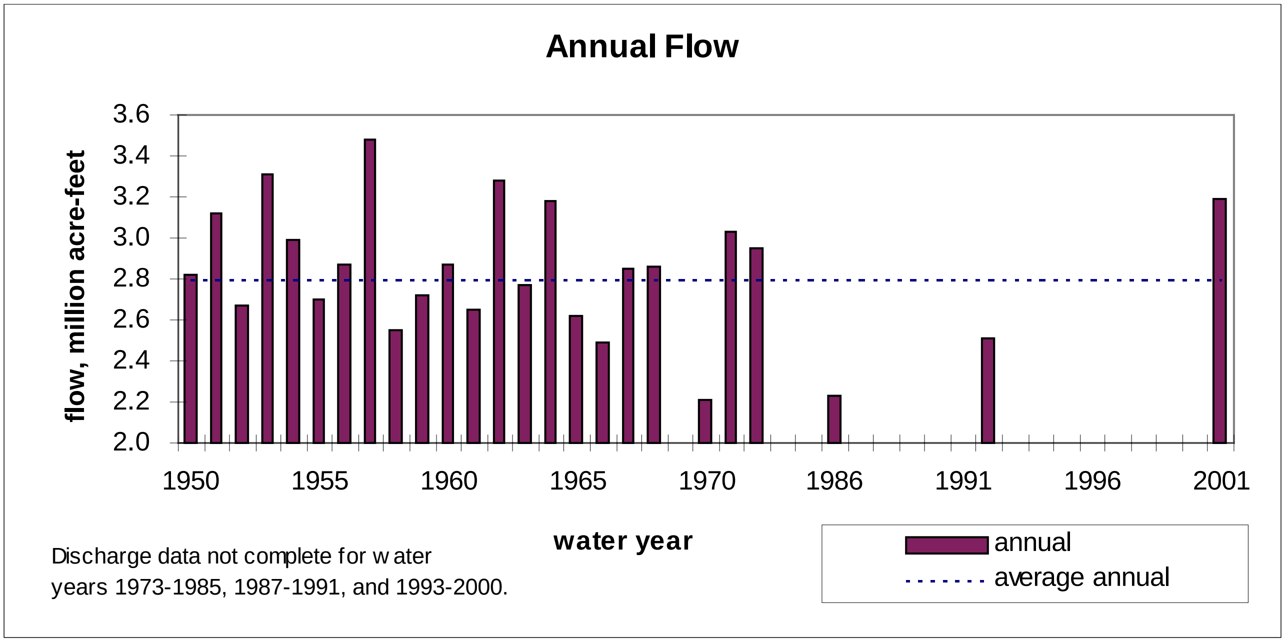



**Figure 3 Matanuska River Discharge by Month**



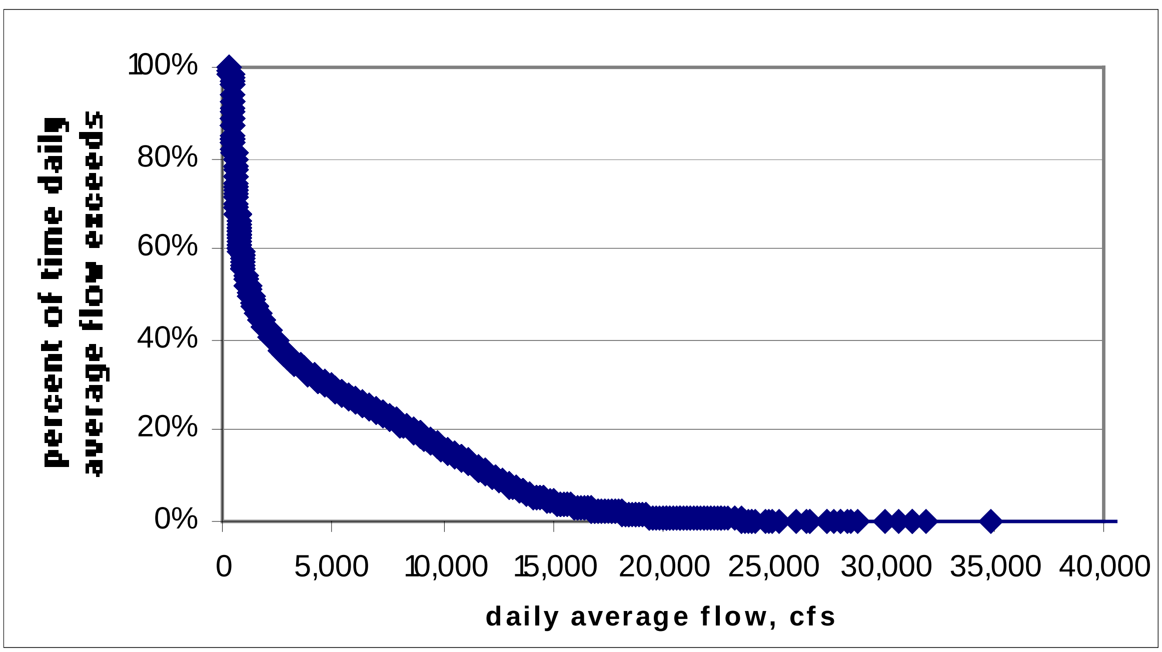

Annual flows are shown on Figure 4. The average annual flow is 2,800,000 acre-feet, or 3,900 cubic feet per second (cfs). This is equivalent to 2.2 feet of runoff over the entire watershed.

**Figure 4 Matanuska River Annual Flows**



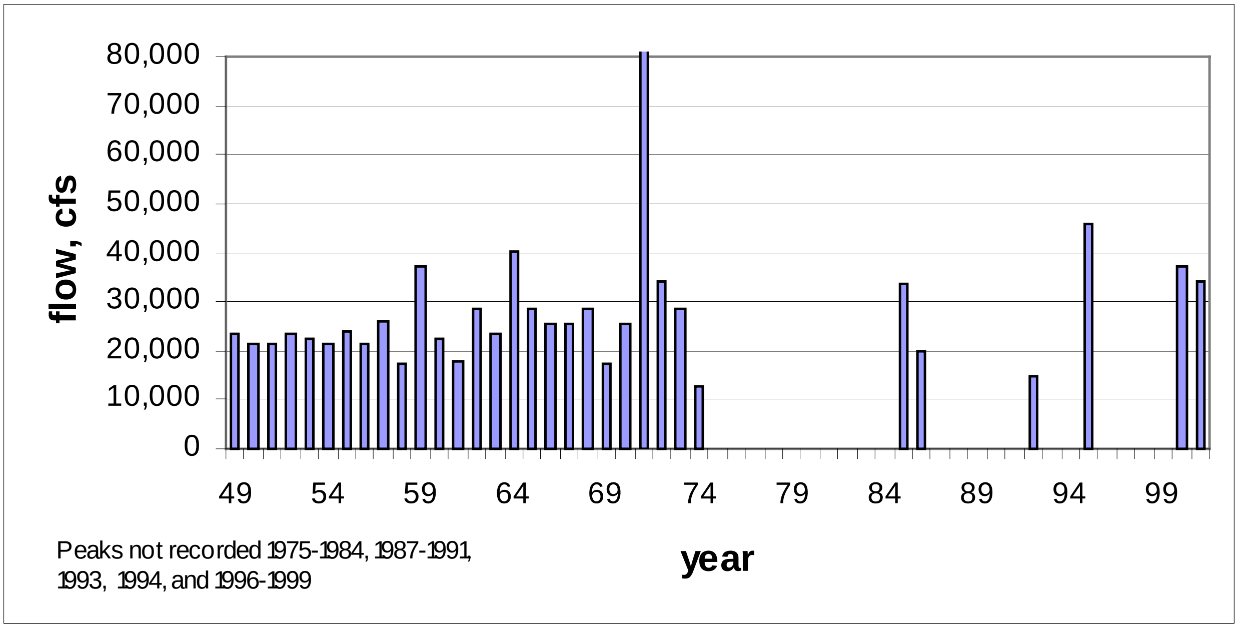

The flow duration, that is the cumulative frequency of occurrence of average daily flows as a percent of all flows, is shown on Figure 5. Although the long-term average flow is 3,900 cfs, the median, or 50 percent exceedence flow, is only 1,300 cfs. The 1 percent exceedence flow is 20,000 cfs.

**Figure 5 Flow Duration for Matanuska River (1949 to 2001)**



Historic annual peak flows are shown on Figure 6. The peak instantaneous discharge of record, 82,100 cfs on August 10, 1971, was due to heavy precipitation and the break-out of a morainal dam near the confluence of Granite Creek and the Matanuska River (DGS, 1974).

**Figure 6 Instantaneous Peak Flows**




Peak flows for given recurrence intervals were determined based on data through 1989 and censoring the 1971 flow, are presented in Table 2 (Lipscomb, 1989). Peak flows based on the addition of data through 2001 and the use of weighted skew are also shown in Table 2.

**Table 2 Peak Flow Frequency Analysis for the Matanuska River**

| Recurrence Interval (years) | Through 1989 (Lipscomb, 1989) | | Updated through 2001 | |
|---|---|---|---|---|
| | Annual Exceedance Probability | Discharge (cfs) | Adjusted Annual Exceedance Probability | Discharge (cfs) |
| 2 | 0.5 | 24,500 | 0.5 | 24,800 |
| 10 | 0.1 | 35,800 | 0.1 | 36,200 |
| 25 | 0.04 | 41,700 | 0.046 | 41,800 |
| 50 | 0.02 | 46,200 | 0.025 | 45,900 |
| 100 | 0.01 | 50,800 | 0.015 | 49,900 |

The years with daily average flows exceeding the 1 percent discharge (20,000 cfs) are presented in Table 3.

**Table 3**
**Years with Daily Average Discharges Exceeding 20,000 cfs**

| Year | Number of Events |
|---|---|
| 1952 | 4 |
| 1953 | 4 |
| 1954 | 1 |
| 1955 | 1 |
| 1957 | 1 |
| 1959 | 3 |
| 1962 | 8 |
| 1963 | 1 |
| 1964 | 9 |
| 1965 | 4 |
| 1968 | 2 |
| 1970 | 1 |
| 1971 | 12 |
| 1972 | 2 |
| 1985 | 8 |
| 2000 | 21 |
| 2001 | 10 |

The peak annual flows generally occur from June through September, with the majority in June. The distribution of these flows over the summer months is shown in Table 4, along with the distribution of the top 1 percent of flows (those exceeding 20,000 cfs).

**Table 4 Monthly Distribution of Peak Flows**

| | Peak Annual Flows | | Top 1 Percent Flows | |
|---|---|---|---|---|
| Month | Number | Percent | Number | Percent |
| June | 11 | 44% | 42 | 46% |
| July | 8 | 32% | 35 | 38% |
| August | 5 | 20% | 15 | 16% |
| September | 1 | 4% | 0 | 0% |

Total annual flow and peak daily average flows do not show a trend over the period of record. However, a trend is evident at the 95 percent confidence level ($z = 1.94$) for instantaneous peak flows.

## 4.0 PRECIPITATION AND MELT PATTERNS

Daily precipitation and temperature data are available for 17 stations in the Matanuska River drainage. Only five stations have periods of records for 20 years or longer. Four of these were used to characterize precipitation and melt patterns in the drainage area; these are shown on

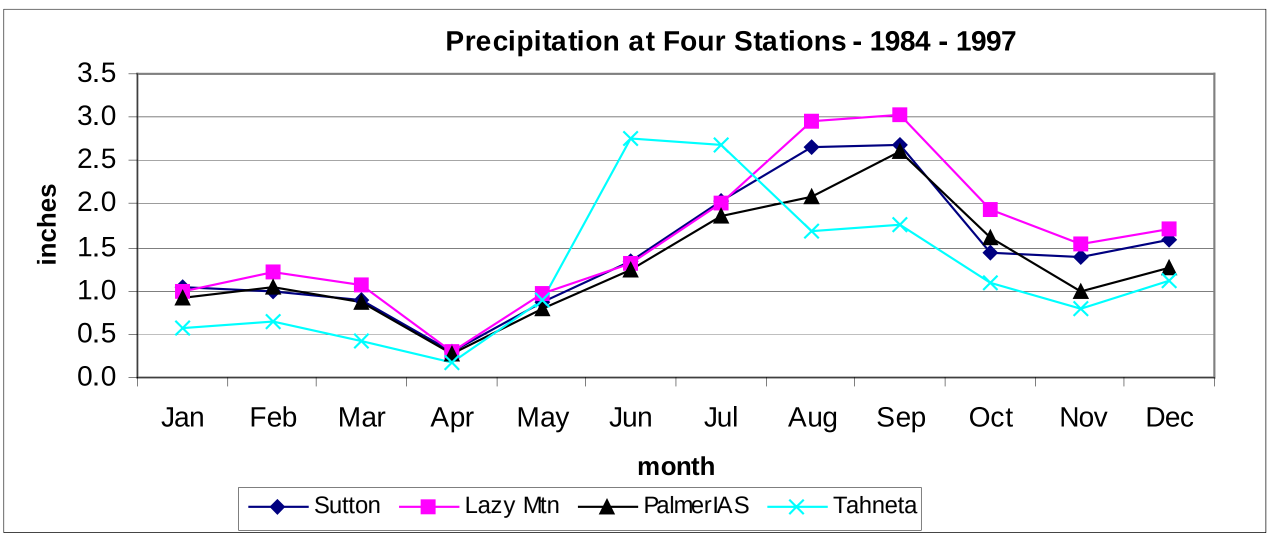
Figure 1. (The fifth is located downgradient of the study area.) Periods of record for these four stations do not all coincide, and some data are missing for various years for all gauges. A summary of the available precipitation data is presented in Table 5. All four stations have concurrent data for 1984 through 1997.

**Table 5 Long Period Weather Stations in the Matanuska Valley**

| Station Name | Lazy Mountain | Palmer IAS | Sutton 2 E | Tahneta Pass |
|---|---|---|---|---|
| Station No | 505464 | 506870 | 508915 | 508945 |
| Latitude | 6138N | 6136N | 6143N | 6149N |
| Longitude | 14902W | 14908W | 14853W | 14733W |
| Elevation (ft) | 790 | 200 - 320 | 550 | 2621 |
| Beginning Date | 7/21/84 | 9/1/49 | 12/1/77 | 3/1/78 |
| Ending Date | 12/31/03 | 4/30/98 | 10/31/03 | 9/30/00 |
| Number of Years with Data | 20 | 49 | 27 | 23 |
| Number of Calendar Years with Complete Precipitation Data | 13 | 35 | 13 | 16 |

The annual precipitation for the four stations for the concurrent period is shown on Figure 7. Annual precipitation varies from 15 inches at Tahneta Pass to 19 inches at Lazy Mountain. Significantly, there are no weather stations above 2,500 feet or in areas away from the valley. Orogenic effects are expected to produce higher rainfall at higher elevations, as suggested by the data from the Lazy Mountain gauge. This also seems likely, since the annual runoff of 2.2 feet exceeds the average precipitation at any of the four stations, although the extent to which glacier melt augments the precipitation is not easy to quantify because of the lack of precipitation data over the entire watershed.

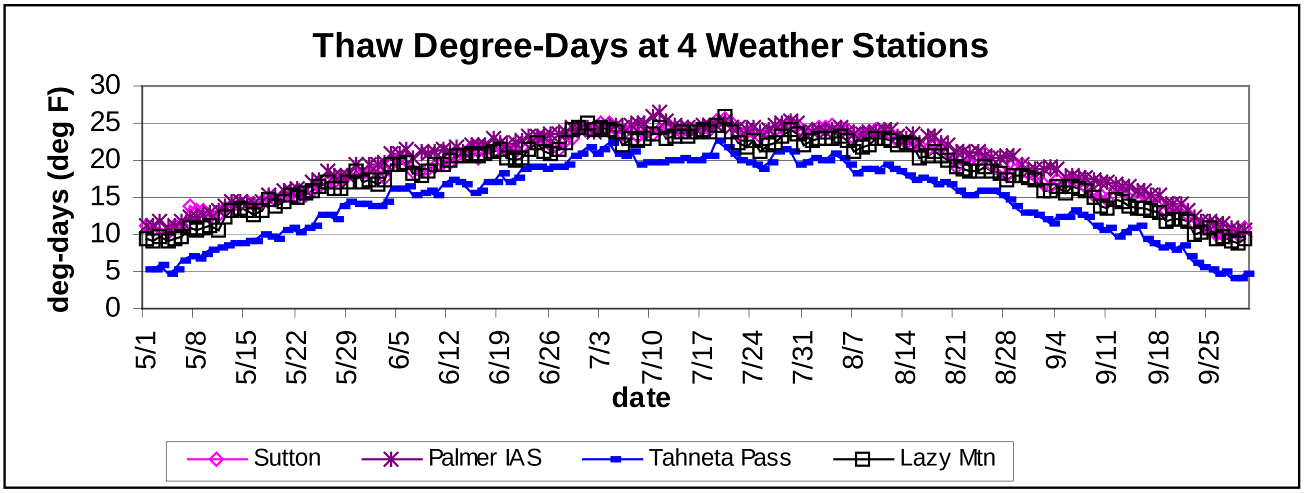
**Figure 7 Monthly Precipitation at Four Stations in the Matanuska Valley**



The timing of the peak annual rainfall at higher elevations may be shifted to earlier in the years, as suggested by the Tahneta Pass gauge. No trends in precipitation were detected for any of the four stations over their discrete periods of record.

Since streamflow in the Matanuska River is affected by glacier melt, temperature and thaw-degree days at the four weather stations were evaluated. Degree-days above 32 were computed for May through September of each year at each station for which data temperature data were available. In order to achieve data sets of adequate length, temperature data was estimated if only one or two consecutive days' data were missing. Seasonal thaw-degree days for the four stations are shown in Figure 8.

**Figure 8 Seasonal Thaw-degree days**




Annual average, maximum, and minimum thaw-degree days are presented in Table 6.

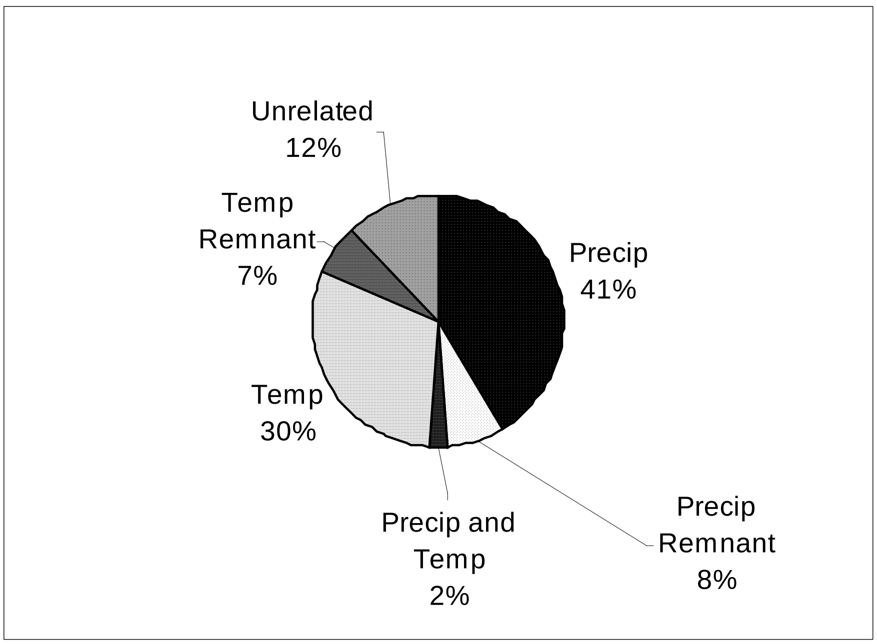
**Table 6 Summer Thaw-degree days at Four Stations in the Matanuska Valley**

| Station Name | Lazy Mountain | Palmer IAS | Sutton 2 E | Tahneta Pass |
|---|---|---|---|---|
| Station Number | 505464 | 506870 | 508915 | 508945 |
| Minimum Thaw Degree-Day Summer | 2,460 | 2,620 | 2,620 | 1,982 |
| Average Thaw Degree-Day Summer | 2,780 | 2,970 | 2,970 | 2,250 |
| Maximum Thaw Degree-Day Summer | 3,080 | 3,190 | 3,190 | 2,590 |
| Number of Years with Complete Summer Temperature Data | 19 | 34 | 13 | 18 |

A trend test run was conducted on the annual average temperature, the annual average June through September temperature, the May through September thaw-degree days and the July thaw-degree days. A trend was detected for each of these parameters in the Palmer IAS data set, but not for any other.

The relationship between peak flows and rainfall or snow/glacial melt was examined. For the period of record concurrent with the streamflow gauge and weather station data, 92 days had average daily flows over 20,000 cfs, the 1 percent exceedence flow. All of these flows occurred in the months June through August. The precipitation and thaw-degree days for the day of and the day preceding the high flow were added. If the combined precipitation exceeded 0.2 inches or the combined thaw-degree days exceeded 20 percent of the long-term average for that day, the flow was associated with one of those events. High flow days that followed days that qualified under either the precipitation or temperature criteria, but did not meet the criteria themselves, were also correlated with those temperature or precipitation events. Nearly 51 percent of the high flow events appeared to be related to precipitation, 37 percent to warm temperatures, and 12 percent could not be correlated. Figure 9 presents the percentage of flows corresponding to weather events.

**Figure 9 Weather Events Corresponding to High Flows**




This evaluation did not produce a predictive model. Weather events that did meet these criteria did not always produce high flows, which is most likely due to the lack of data over the entire watershed and non-uniform rainfall distribution over the watershed.

# 5.0 WATERSHED STORAGE AND GROUNDWATER

The alluvium of the broad, braided Matanuska River floodplain, particularly in places where it forms deltas, forms a large unconfined aquifer along the river system. Downstream the Old Glenn Highway Bridge, this unconfined aquifer is thought to extend up to __ miles northwest of the river. However, this area also contains continuous confining units as well (Jokel et al., 1991). There are many drinking water wells tapping the deeper, confined aquifers in the area. The combination of groundwater wells and natural seepage deplete the aquifer, this is balanced by recharge from the Matanuska River through this reach.

Small mountain streams in the eastern part of the basin disappear as they descend towards the Matanuska River (Jokela et al., 1991). These streams provide recharge tot he groundwater system in the foothills. In some instances, the Castle Mountain fault redirects streamflow.

The many small lakes in the lower third of the Matanuska Valley are glacial in origin and are associated with groundwater discharges. Lakes that were generally formed in depressions left by melting glacial ice are probably spring-fed. The spring water is generally related to local unconfined aquifers.

## 6.0 WATERSHED RUNOFF PROCESSES

The Matanuska Valley spans transitional and continental climate zones. The lower reaches of the river experience high winds due to pressure gradients (Dale, 1956). Precipitation from November through March generally occurs as snow, with the period lengthening at higher altitudes. This leads to low runoff throughout the winter and peak runoff during the snow melt season (June and July). June and July are also the peak precipitation months at higher elevations (Tahneta Pass). At lower elevations, the peak rainfall occurs in August, but this does not coincide with peak runoff.

# APPENDIX A

*Streamflow Data and Analysis*

## ANNUAL DATA

**Matanuska River flow**

**CALCULATE TREND STATISTICS**

| | | | | | |
|---|---|---|---|---|---|
| **Number of time series in the calculation:** | 3 | | | | |
| **Number of annual values in the calculation:** | 26 | 25 | 31 | 0 | 0 |
| **Select the FIRST YEAR of the calculation:** | 1950 | 1950 | 1949 | | |
| **Select the LAST YEAR of the calculation:** | 2001 | 2001 | 2001 | | |

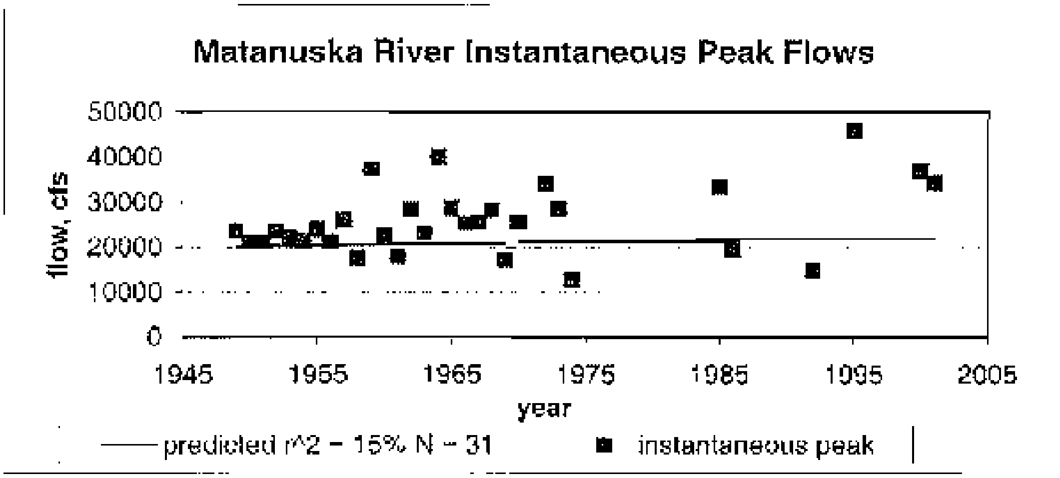
| Year | avgannflow | peak | instpeak | | |
|---|---|---|---|---|---|
| 1949 | | | 23600 | | |
| 1950 | 3908 | 18500 | 21200 | | |
| 1951 | 4323 | 18100 | 21400 | | |
| 1952 | 3684 | 22600 | 23400 | | |
| 1953 | 4582 | 20800 | 22200 | | |
| 1954 | 4134 | 20200 | 21500 | | |
| 1955 | 3732 | 20400 | 24000 | | |
| 1956 | 3966 | 19600 | 21400 | | |
| 1957 | 4815 | 22500 | 25900 | | |
| 1958 | 3531 | 15600 | 17500 | | |
| 1959 | 3757 | 30000 | 37300 | | |
| 1960 | 3959 | 18700 | 22600 | | |
| 1961 | 3664 | 15200 | 18000 | | |
| 1962 | 4542 | 24200 | 28400 | | |
| 1963 | 3837 | 21100 | 23200 | | |
| 1964 | 4384 | 26700 | 40100 | | |
| 1965 | 3628 | 24800 | 28600 | | |
| 1966 | 3439 | 19800 | 25300 | | |
| 1967 | 3941 | 19000 | 25500 | | |
| 1968 | 3947 | 22900 | 28300 | | |
| 1969 | 2562 | 15000 | 17200 | | |
| 1970 | 3065 | 20700 | 25600 | | |
| 1971 | 4196 | | | | |
| 1972 | 4072 | 22600 | 34000 | | |
| 1973 | | | 28600 | | |
| 1974 | | | 12900 | | |
| 1985 | | | 33500 | | |
| 1986 | 3081 | 16100 | 19700 | | |
| 1992 | 3476 | 14200 | 14900 | | |
| 1995 | | | 46000 | | |
| 2000 | | | 37000 | | |
| 2001 | 4421 | 31300 | 34300 | | |

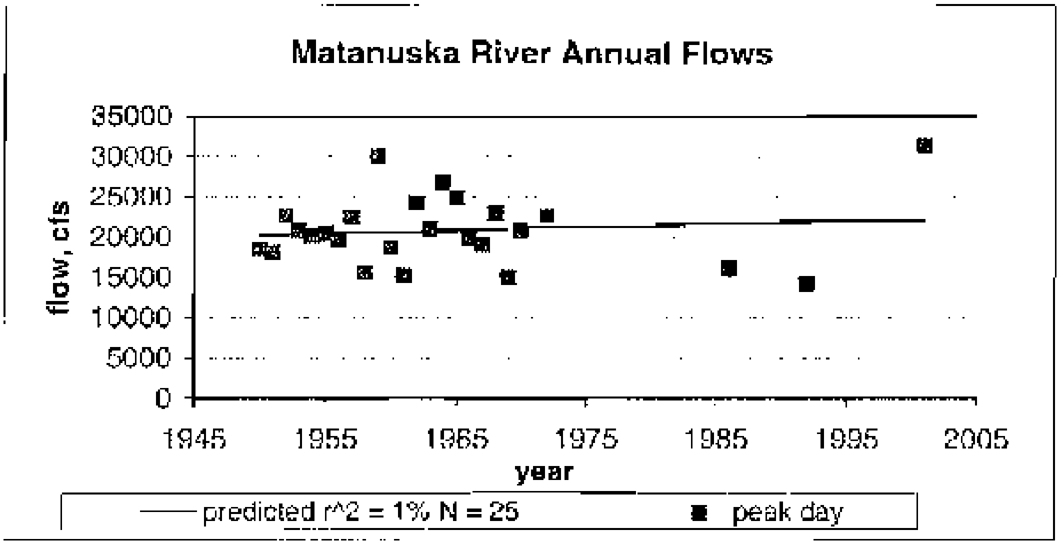
# TREND STATISTICS

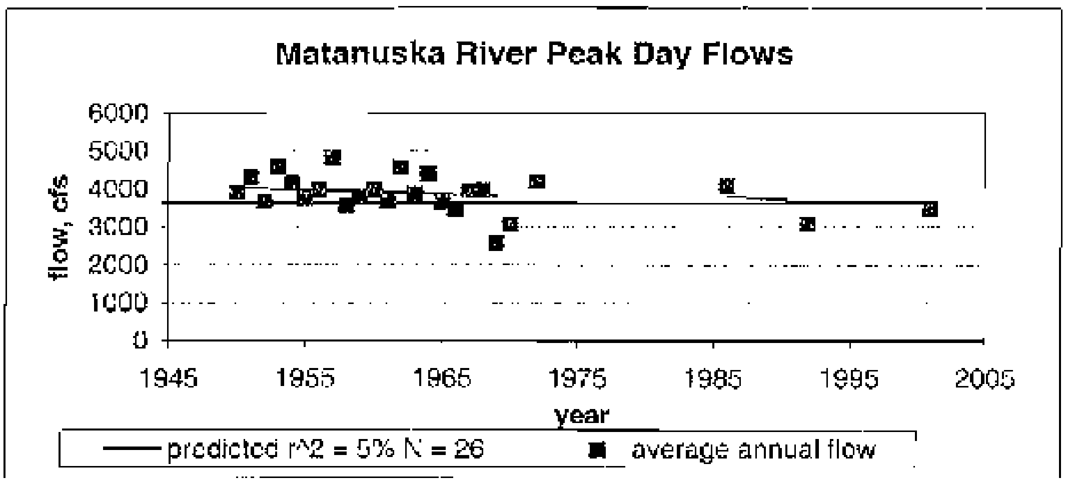
**Matanuska River flow**

| | | | | Mann-Kendall trend | | | Sen's slope estimate | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Time series** | **First year** | **Last Year** | **n** | **Test S** | **Test Z** | **Signific.** | **Q** | **Qmin99** | **Qmax99** | **Qmin95** | **Qmax95** |
| *avgannflow* | *1950* | *2001* | *26* | | -1.32 | | -18.042 | -57.712 | 16.836 | -46.105 | 9.703 |
| *peak* | *1950* | *2001* | *25* | | 0.14 | | 20.000 | -324.066 | 360.349 | -249.496 | 273.741 |
| *instpeak* | *1949* | *2001* | *31* | | 1.94 | + | 306.250 | -100.000 | 576.764 | -2.138 | 506.988 |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |

## Matanuska River Flows - trends over time - linear regression



**Log Pearson III analysis** — Matanuska River at Palmer, AK — gaged instantaneous peak flows

drainage area 2070 sq mi — min 12900 cfs max 46000 cfs

| Date | WaterYr | annual peak Q | y log(Q) | y-mean(y) | (y-mean(y))^3 | outlier? ** |
|---|---|---|---|---|---|---|
| 7/11/1949 | 1949 | 26800 | 4.4 | 0.0 | 0.000 | no |
| 7/25/1950 | 1950 | 21200 | 4.33 | -0.1 | 0.000 | no |
| 6/6/1951 | 1951 | 21400 | 4.33 | -0.1 | 0.000 | no |
| 7/30/1952 | 1952 | 23400 | 4.37 | 0.0 | 0.000 | no |
| 5/28/1953 | 1953 | 22400 | 4.35 | 0.0 | 0.000 | no |
| 7/31/1954 | 1954 | 21500 | 4.33 | -0.1 | 0.000 | no |
| 9/27/1955 | 1955 | 24000 | 4.30 | 0.0 | 0.000 | no |
| 7/31/1956 | 1956 | 21400 | 4.33 | -0.1 | 0.000 | no |
| 6/29/1957 | 1957 | 25900 | 4.41 | 0.0 | 0.000 | no |
| 7/5/1958 | 1958 | 17500 | 4.24 | 0.2 | 0.004 | no |
| 5/24/1959 | 1959 | 37300 | 4.57 | 0.2 | 0.005 | no |
| 5/25/1960 | 1960 | 22600 | 4.35 | 0.0 | 0.000 | no |
| 6/21/1961 | 1961 | 18000 | 4.26 | -0.1 | -0.003 | no |
| 6/18/1962 | 1962 | 28400 | 4.45 | 0.1 | 0.000 | no |
| 5/23/1963 | 1963 | 23200 | 4.37 | 0.0 | 0.000 | no |
| 6/9/1964 | 1964 | 40100 | 4.60 | 0.2 | 0.009 | no |
| 7/13/1965 | 1965 | 28800 | 4.46 | 0.1 | 0.000 | no |
| 7/29/1966 | 1966 | 25300 | 4.40 | 0.0 | 0.000 | no |
| 6/12/1967 | 1967 | 25500 | 4.41 | 0.0 | 0.000 | no |
| 5/15/1968 | 1968 | 28300 | 4.45 | 0.1 | 0.000 | no |
| 8/5/1969 | 1969 | 17200 | 4.24 | -0.2 | -0.004 | no |
| 8/27/1970 | 1970 | 25800 | 4.41 | 0.0 | 0.000 | no |
| 8/14/1972 | 1972 | 34000 | 4.53 | 0.1 | 0.003 | no |
| 3/15/1973 | 1973 | 28800 | 4.46 | 0.1 | 0.000 | no |
| 1974-09 | 1974 | 12900 | 4.11 | 0.3 | 0.023 | no |
| 7/1/1985 | 1985 | 33500 | 4.53 | 0.1 | 0.002 | no |
| 7/21/1986 | 1986 | 19700 | 4.29 | 0.1 | 0.001 | no |
| 7/1/1992 | 1992 | 14900 | 4.17 | -0.2 | -0.011 | no |
| 9/22/1995 | 1995 | 46000 | 4.66 | 0.3 | 0.019 | no |
| 7/9/2000 | 2000 | 37000 | 4.57 | 0.2 | 0.005 | no |
| 6/23/2001 | 2001 | 34300 | 4.54 | 0.1 | 0.003 | no |

High outlier (62,100 cfs 8/10/1971 - water yr 1971) censored

| | | | | |
|---|---|---|---|---|
| count | 31 | | sum | 0.000 |
| mean (y) | 25806.5 | 4.4 | | |
| st dev (y) | 7628.033 | 0.128 | weighted skew used, | |
| station skew | | -0.005 | | 0.096 |

*station skew = n*sum((y-mean y)^3)/((n-1)(n-2)stdev(y)^3)*

interpolating from Appendix 3, WRC, 1981 — Kt for given recurrence interval

| 1-Px | Px | T, yrs | lookup offset | Kt is | log(Q) |
|---|---|---|---|---|---|
| 0.01 | 0.99 | 1.01 | 12 | -2.256 | 4.111 |
| 0.30 | 0.70 | 1.43 | 11 | -0.536 | 4.328 |
| 0.40 | 0.60 | 1.67 | 10 | -0.287 | 4.358 |
| 0.43 | 0.57 | 1.75 | 9 | -0.193 | 4.371 |
| 0.50 | 0.50 | 2 | 0 | -0.010 | 4.394 |
| 0.90 | 0.10 | 10 | 8 | 1.291 | 4.560 |
| 0.96 | 0.04 | 25 | 5 | 1.703 | 4.621 |
| 0.98 | 0.02 | 50 | 4 | 2.103 | 4.661 |
| 0.99 | 0.01 | 100 | 3 | 2.390 | 4.698 |
| 1.00 | 0.001 | 1000 | 2 | 3.227 | 4.803 |

** Test for outliers — $xH$ = mean(x) + Kn (stdev)

high 4.73

low 4.07

Outlier test, Reference 1: App 4; Bulletin 17B, WRC

**Confidence Limit Calculations**

Reference 1: Appendix 9; Bulletin 17B, WRC

assume 0.05, 0.95 limits

Zc 1.65

U = x + sKu

L = x + sKl

Ku = Kg + (Kg^2 - ab)^0.5 / a

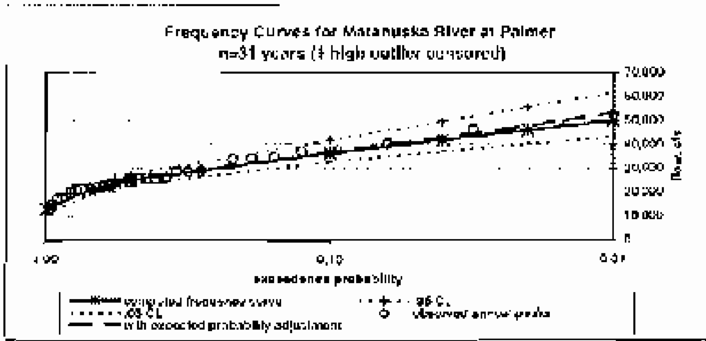
Kl = Kg - (Kg^2 - ab)^0.5 / a

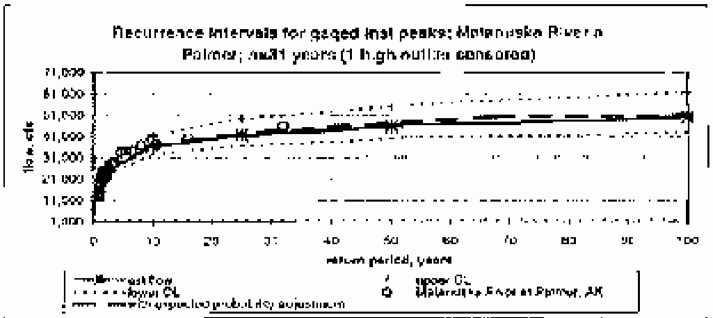
a = 1-( zc^2 / 2*(N-1))

b = Kg^2 - Zc^2/N

| a |
|---|
| 0.95 |

| Px | b | P | Ku | Kl | U | L | Qu | Ql |
|---|---|---|---|---|---|---|---|---|
| 0.99 | 5.00 | 0.99 | -1.78 | -2.95 | 4.17 | 4.02 | 14842 | 10559 |
| 0.70 | 0.20 | 0.70 | -0.24 | -0.89 | 4.37 | 4.28 | 23222 | 19226 |
| 0.60 | 0.00 | 0.60 | 0.00 | -0.62 | 4.40 | 4.32 | 24861 | 20789 |
| 0.57 | -0.05 | 0.57 | 0.10 | -0.51 | 4.41 | 4.33 | 25631 | 21463 |
| 0.50 | -0.08 | 0.50 | 0.28 | -0.32 | 4.43 | 4.36 | 27024 | 22609 |
| 0.10 | 1.58 | 0.10 | 1.77 | 0.94 | 4.62 | 4.51 | 41550 | 32839 |
| 0.04 | 3.09 | 0.04 | 2.37 | 1.37 | 4.69 | 4.57 | 49465 | 37019 |
| 0.02 | 4.34 | 0.02 | 2.76 | 1.65 | 4.74 | 4.60 | 55465 | 40136 |
| 0.01 | 5.66 | 0.01 | 3.12 | 1.90 | 4.79 | 4.64 | 61623 | 43160 |
| 0.001 | 10.33 | 0.00 | 4.16 | 2.60 | 4.92 | 4.72 | 83266 | 52955 |




streamflow analysis region 4

generalized skew: 0.0

for streamflow analysis region 4 - SC Alaska (reference 2)

W — use station (S), weighted station (W), or generalized (G) skew?

| Values in cfs | | | | |
|---|---|---|---|---|
| est flow | +/- | lower CL | upper CL | cfs/mi2 |
| 12,012 | 2141 | 10559 | 14842 | 6.2 |
| 21,286 | 1998 | 19226 | 23222 | 10.3 |
| 22,816 | 2046 | 20789 | 24861 | 11.0 |
| 23,517 | 2084 | 21463 | 25631 | 11.4 |
| 24,756 | 2170 | 22609 | 27024 | 12.0 |
| 36,197 | 4478 | 32839 | 41500 | 17.5 |
| 41,758 | 6223 | 37019 | 49465 | 20.2 |
| 45,647 | 7673 | 40136 | 55465 | 22.1 |
| 49,904 | 9232 | 43160 | 61623 | 24.1 |
| 63,526 | 9232 | 43160 | 61623 | 30.7 |

with expected probability adjustment

| Pn * | Years |
|---|---|
| 0.108 | 9 |
| 0.046 | 22 |
| 0.025 | 40 |
| 0.015 | 67 |
| 0.002 | 423 |

Reference 1, App 11, Bulletin 17B, WRC

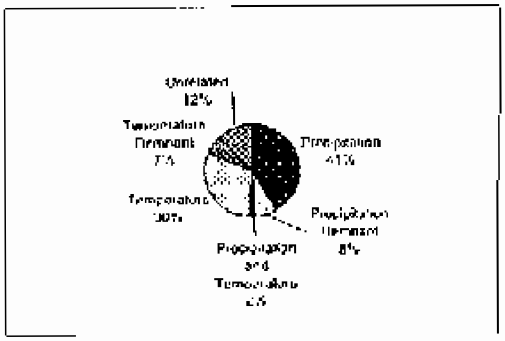
Interpolate from adjustment for 20, 50 and 100 year flow

| | |
|---|---|
| 20 | 45,000 |
| 50 | 47,400 |
| 100 | 51,200 |


References:
1 U.S. Water Resources Council, 1981, Guidelines for Determining Flood Flow Frequency
2 Curran, J.H., D.F. Meyer, G.D. Tasker, 2003, Estimating the Magnitude and Frequency of Peak Streamflows for Ungaged Sites on Streams in Alaska and Conterminous Basins in Canada: Water Resources Investigations Report 03-4188

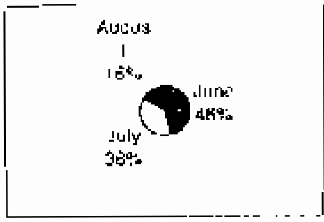

censored fix Mat R LP III.xls

| Number of events | % of Total | Linked Weather Event |
|---|---|---|
| 39 | 41% | Precipitation |
| 7 | 8% | Precipitation Remnant |
| 2 | 2% | Precipitation and Temperature |
| 28 | 30% | Temperature |
| 5 | 7% | Temperature Remnant |
| 11 | 12% | Unrelated |
| 92 | | Total |




| Year | Number of events | % of Total |
|---|---|---|
| 1952 | 4 | 4% |
| 1953 | 4 | 4% |
| 1954 | 1 | 1% |
| 1955 | 1 | 1% |
| 1957 | 1 | 1% |
| 1959 | 3 | 3% |
| 1962 | 8 | 9% |
| 1963 | 1 | 1% |
| 1964 | 9 | 10% |
| 1965 | 4 | 4% |
| 1966 | 2 | 2% |
| 1970 | 1 | 1% |
| 1971 | 12 | 13% |
| 1972 | 2 | 2% |
| 1995 | 8 | 9% |
| 2000 | 21 | 23% |
| 2001 | 10 | 11% |

| Month | Number of events | % of Total |
|---|---|---|
| June | 42 | 46% |
| July | 35 | 38% |
| August | 15 | 16% |
| Total | 92 | |



## Correlate High Matanuska River Discharge to Weather Events

| Chronological Order | | | | Precipitation, inches, this day + preceding day | | | | Thaw degree-days - % dep from avg deg day of this + preceding day | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 505870 | 508915 | 505464 | 508945 | 505870 | 508915 | 505464 | 508945 |
| Date | Linked Weather Event | Rank of Discharge | Average Day Discharge, cfs | Palmer | Sutton | Lazy Mtn | Tahneta | Palmer | Sutton | Lazy Mtn | Tahneta |
| 7/28/1952 | P | 59 | 21,400 | 0.48 | -- | -- | -- | 16% | -- | -- | -- |
| 7/29/1952 | P | 55 | 21,700 | 0.43 | -- | -- | -- | -6% | -- | -- | -- |
| 7/30/1952 | P | 28 | 22,600 | 0.55 | -- | -- | -- | 17% | -- | -- | -- |
| 7/31/1952 | P | 60 | 21,400 | 0.57 | -- | -- | -- | -12% | -- | -- | -- |
| 6/27/1953 | T | 79 | 20,500 | 0.00 | -- | -- | -- | 56% | -- | -- | -- |
| 6/28/1953 | T | 72 | 20,600 | 0.00 | -- | -- | -- | 41% | -- | -- | -- |
| 7/26/1953 | T | 87 | 20,200 | 0.00 | -- | -- | -- | 28% | -- | -- | -- |
| 7/27/1953 | T | 81 | 20,400 | 0.00 | -- | -- | -- | 24% | -- | -- | -- |
| 7/31/1954 | P | 88 | 20,200 | 1.11 | -- | -- | -- | -1% | -- | -- | -- |
| 8/27/1955 | P | 82 | 20,400 | 0.30 | -- | -- | -- | -18% | -- | -- | -- |
| 8/20/1957 | P | 42 | 22,500 | 0.49 | -- | -- | -- | 3% | -- | -- | -- |
| 8/24/1959 | P | 21 | 25,200 | 2.47 | -- | -- | -- | 6% | -- | -- | -- |
| 8/25/1959 | P | 8 | 30,000 | 3.52 | -- | -- | -- | 4% | -- | -- | -- |
| 8/26/1959 | P | 77 | 20,600 | 0.95 | -- | -- | -- | 7% | -- | -- | -- |
| 6/16/1962 | ?T | 83 | 20,300 | 0.04 | -- | -- | -- | -6% | -- | -- | -- |
| 6/17/1962 | T | 62 | 21,300 | 0.01 | -- | -- | -- | 21% | -- | -- | -- |
| 6/18/1962 | T | 33 | 23,300 | 0.00 | -- | -- | -- | 22% | -- | -- | -- |
| 6/19/1962 | T | 48 | 22,100 | 0.00 | -- | -- | -- | 20% | -- | -- | -- |
| 6/20/1962 | ?T | 51 | 21,900 | 0.00 | -- | -- | -- | 16% | -- | -- | -- |
| 6/21/1962 | ?T | 37 | 22,700 | 0.00 | -- | -- | -- | 16% | -- | -- | -- |
| 6/22/1962 | P | 25 | 24,200 | 0.24 | -- | -- | -- | 13% | -- | -- | -- |
| 6/25/1962 | T | 39 | 23,600 | 0.00 | -- | -- | -- | 24% | -- | -- | -- |
| 5/25/1963 | P | 66 | 21,100 | 0.93 | -- | -- | -- | 10% | -- | -- | -- |
| 6/8/1964 | U | 18 | 26,600 | 0.00 | -- | -- | -- | 1% | -- | -- | -- |
| 6/9/1964 | U | 90 | 20,500 | 0.14 | -- | -- | -- | 6% | -- | -- | -- |
| 6/14/1964 | T | 46 | 22,200 | 0.00 | -- | -- | -- | 28% | -- | -- | -- |
| 6/15/1964 | T | 20 | 26,000 | 0.00 | -- | -- | -- | 28% | -- | -- | -- |
| 6/15/1964 | P | 74 | 20,700 | 0.77 | -- | -- | -- | 0% | -- | -- | -- |
| 6/25/1964 | P | 49 | 22,000 | 0.31 | -- | -- | -- | 10% | -- | -- | -- |
| 7/31/1964 | ?P | 64 | 21,200 | 0.10 | -- | -- | -- | 0% | -- | -- | -- |
| 8/1/1964 | P | 32 | 23,500 | 0.31 | -- | -- | -- | -11% | -- | -- | -- |
| 8/2/1964 | P | 17 | 26,700 | 0.31 | -- | -- | -- | -18% | -- | -- | -- |
| 7/12/1965 | U | 71 | 20,900 | 0.05 | -- | -- | -- | 4% | -- | -- | -- |
| 7/13/1965 | U | 23 | 24,800 | 0.14 | -- | -- | -- | 2% | -- | -- | -- |
| 7/14/1965 | U | 43 | 22,500 | 0.09 | -- | -- | -- | 3% | -- | -- | -- |
| 7/16/1965 | U | 91 | 20,100 | 0.05 | -- | -- | -- | 1% | -- | -- | -- |
| 6/13/1968 | U | 84 | 20,300 | 0.00 | -- | -- | -- | 3% | -- | -- | -- |
| 6/14/1968 | P | 35 | 22,900 | 0.53 | -- | -- | -- | 5% | -- | -- | -- |
| 6/28/1970 | P | 75 | 20,700 | 0.41 | -- | -- | -- | 7% | -- | -- | -- |
| 6/20/1971 | P | 65 | 21,000 | 0.29 | -- | -- | -- | -10% | -- | -- | -- |
| 6/23/1971 | P | 61 | 21,400 | 0.22 | -- | -- | -- | -10% | -- | -- | -- |
| 6/24/1971 | ?P | 36 | 22,900 | 0.02 | -- | -- | -- | 12% | -- | -- | -- |
| 6/25/1971 | ?P | 89 | 20,200 | 0.02 | -- | -- | -- | 17% | -- | -- | -- |
| 7/6/1971 | U | 55 | 21,700 | 0.00 | -- | -- | -- | 1% | -- | -- | -- |
| 8/8/1971 | P | 53 | 21,800 | 1.07 | -- | -- | -- | -9% | -- | -- | -- |
| 8/9/1971 | P | 2 | 34,900 | 1.84 | -- | -- | -- | -4% | -- | -- | -- |
| 8/10/1971 | P | 1 | 40,700 | 1.62 | -- | -- | -- | -4% | -- | -- | -- |
| 8/11/1971 | P | 3 | 32,000 | 1.01 | -- | -- | -- | 1% | -- | -- | -- |
| 8/12/1971 | P | 15 | 27,400 | 0.41 | -- | -- | -- | 0% | -- | -- | -- |
| 8/13/1971 | ?P | 28 | 23,900 | 0.00 | -- | -- | -- | 4% | -- | -- | -- |
| 8/14/1971 | ?P | 63 | 21,300 | 0.00 | -- | -- | -- | 1% | -- | -- | -- |
| 6/14/1972 | U | 50 | 20,200 | 0.00 | -- | -- | -- | 7% | -- | -- | -- |
| 7/12/1972 | P | 39 | 22,000 | 0.50 | -- | -- | -- | 10% | -- | -- | -- |
| 6/30/1985 | T | 34 | 23,200 | 0.00 | 0.00 | 0.00 | 0.00 | 20% | 13% | 11% | 21% |
| 7/1/1985 | T | 13 | 28,000 | 0.00 | 0.00 | 0.00 | 0.01 | 34% | 29% | 18% | 22% |
| 7/2/1985 | T | 22 | 24,900 | 0.00 | 0.00 | 0.00 | 0.01 | 24% | 18% | 9% | 9% |
| 7/3/1985 | ?T | 29 | 23,700 | 0.10 | 0.19 | 0.12 | 0.02 | 3% | 4% | -7% | -8% |
| 7/4/1985 | P | 78 | 20,600 | 0.11 | 0.24 | 0.23 | 0.03 | 0% | -7% | -19% | -15% |
| 7/7/1985 | T | 50 | 22,000 | 0.00 | 0.04 | 0.03 | 0.01 | 18% | 9% | 12% | 29% |
| 7/13/1985 | ?P | 85 | 20,500 | 0.22 | 0.25 | 0.13 | 0.03 | 0% | 10% | 10% | -7% |
| 7/14/1985 | P | 86 | 20,300 | 0.20 | 0.14 | 0.13 | 0.60 | -6% | -4% | -7% | -3% |
| 6/13/2000 | U | 67 | 21,100 | -- | 0.00 | 0.00 | 0.00 | -- | 8% | 3% | 15% |
| 6/24/2000 | T | 44 | 22,400 | -- | 0.00 | 0.00 | 0.00 | -- | 6% | 4% | 20% |
| 6/25/2000 | T | 19 | 26,500 | -- | 0.00 | 0.00 | 0.00 | -- | 15% | 20% | 25% |
| 6/26/2000 | T | 79 | 20,800 | -- | 0.00 | 0.00 | 0.00 | -- | 16% | 28% | 29% |
| 6/27/2000 | T | 52 | 21,900 | -- | 0.00 | 0.00 | 0.00 | -- | 18% | 21% | 31% |
| 6/28/2000 | T | 27 | 24,000 | -- | 0.06 | 0.00 | 0.00 | | 22% | 25% | 20% |
| 6/29/2000 | P | 60 | 21,100 | -- | 0.28 | 0.18 | 0.00 | -- | 14% | 16% | 10% |
| 6/30/2000 | P | 9 | 28,900 | -- | 0.25 | 0.29 | 0.00 | -- | 15% | -1% | 8% |
| 7/1/2000 | ?P | 4 | 31,300 | -- | 0.08 | 0.05 | 0.00 | -- | 16% | 4% | 10% |
| 7/2/2000 | ?P | 76 | 20,700 | -- | 0.03 | 0.00 | 0.00 | -- | 14% | 3% | 9% |
| 7/4/2000 | U | 70 | 21,000 | -- | 0.00 | 0.00 | 0.00 | -- | 12% | 9% | 10% |
| 7/5/2000 | P | 5 | 31,300 | -- | 0.40 | 0.26 | 0.20 | -- | 8% | 6% | 8% |
| 7/6/2000 | P | 12 | 28,100 | -- | 0.41 | 0.00 | 0.20 | -- | 2% | -2% | 12% |
| 7/7/2000 | P/T | 26 | 24,100 | -- | 0.01 | 0.27 | 0.00 | -- | 4% | -6% | 27% |
| 7/8/2000 | T | 47 | 22,200 | -- | 0.00 | 0.00 | 0.00 | -- | 10% | 4% | 30% |
| 7/12/2000 | P/T | 31 | 23,600 | -- | 0.00 | 0.08 | 0.30 | -- | 12% | 3% | 22% |
| 7/13/2000 | P | 16 | 27,400 | -- | 0.45 | 0.17 | 0.50 | | 23% | 18% | 17% |
| 7/14/2000 | P | 14 | 27,700 | -- | 1.15 | 0.45 | 0.50 | -- | 13% | 9% | 5% |
| 7/15/2000 | P | 54 | 21,800 | -- | 0.71 | 0.34 | 0.00 | -- | -2% | -2% | 3% |
| 7/16/2000 | P | 40 | 22,800 | -- | 0.21 | 0.02 | 0.00 | | -4% | 2% | -1% |
| 7/17/2000 | P | 57 | 21,600 | | 0.60 | 0.43 | 0.00 | | -8% | -2% | 6% |
| 5/17/2001 | T | 92 | 20,100 | -- | 0.00 | 0.00 | -- | -- | 10% | 28% | -- |
| 5/18/2001 | T | 24 | 24,700 | -- | 0.00 | 0.00 | -- | -- | 23% | 21% | -- |
| 5/19/2001 | T | 41 | 22,600 | -- | 0.00 | 0.00 | -- | -- | 20% | 16% | -- |
| 5/20/2001 | ?T | 66 | 21,200 | -- | 0.00 | 0.00 | -- | | 13% | 12% | -- |
| 6/26/2001 | T | 68 | 21,600 | -- | 0.00 | 0.00 | -- | -- | 29% | 28% | -- |
| 6/27/2001 | T | 11 | 28,300 | -- | 0.03 | 0.01 | -- | -- | 28% | 26% | -- |
| 6/28/2001 | T | 7 | 30,700 | -- | 0.00 | 0.06 | -- | -- | 25% | 22% | -- |
| 6/29/2001 | T | 6 | 31,300 | -- | 0.00 | 0.05 | -- | -- | 30% | 19% | -- |
| 6/30/2001 | T | 10 | 28,500 | -- | 0.00 | 0.00 | -- | -- | 23% | 14% | -- |
| 7/1/2001 | ?T | 45 | 22,400 | -- | 0.00 | 0.00 | -- | -- | 6% | -1% | -- |
| Total number of days > 0.2 | | | | 27 | 11 | 7 | 5 | 12 | 10 | 9 | 11 |
| Maximum 2-day precipitation, inches | | | | 3.63 | 1.16 | 0.65 | 0.83 | | | | |

# Correlate High Matanuska River Discharge to Weather Events

Ranked by discharge

| Date | Linked Weather Event | Rank of Discharge | Average Day Discharge, cfs | Month | Year |
|---|---|---|---|---|---|
| 8/10/71 | P | 1 | 40,700 | 8 | 1971 |
| 8/9/71 | P | 2 | 34,900 | 8 | 1971 |
| 8/11/71 | P | 3 | 32,900 | 8 | 1971 |
| 7/1/00 | ?P | 4 | 31,300 | 7 | 2000 |
| 7/5/00 | P | 5 | 31,300 | 7 | 2000 |
| 6/29/01 | T | 6 | 31,300 | 6 | 2001 |
| 6/28/01 | T | 7 | 30,700 | 6 | 2001 |
| 8/23/59 | P | 8 | 30,000 | 8 | 1959 |
| 6/30/00 | P | 9 | 28,900 | 6 | 2000 |
| 6/30/01 | T | 10 | 28,900 | 6 | 2001 |
| 6/27/01 | T | 11 | 28,550 | 6 | 2001 |
| 7/6/00 | P | 12 | 28,500 | 7 | 2000 |
| 7/1/85 | T | 13 | 28,000 | 7 | 1985 |
| 7/14/00 | P | 14 | 27,700 | 7 | 2000 |
| 8/12/71 | P | 15 | 27,400 | 8 | 1971 |
| 7/10/00 | P | 16 | 27,400 | 7 | 2000 |
| 8/2/64 | P | 17 | 26,700 | 8 | 1964 |
| 6/8/64 | U | 18 | 26,600 | 6 | 1964 |
| 6/23/00 | T | 19 | 26,500 | 6 | 2000 |
| 6/15/64 | T | 20 | 26,000 | 6 | 1964 |
| 8/24/59 | P | 21 | 25,200 | 8 | 1959 |
| 7/2/85 | T | 22 | 24,900 | 7 | 1985 |
| 7/15/85 | U | 23 | 24,800 | 7 | 1985 |
| 6/18/01 | T | 24 | 24,700 | 6 | 2001 |
| 6/22/62 | P | 25 | 24,200 | 6 | 1962 |
| 7/7/00 | P/T | 26 | 24,100 | 7 | 2000 |
| 6/28/00 | T | 27 | 24,000 | 6 | 2000 |
| 8/13/71 | ?P | 28 | 23,800 | 8 | 1971 |
| 7/3/85 | ?T | 29 | 23,700 | 7 | 1985 |
| 8/29/62 | T | 30 | 23,600 | 8 | 1962 |
| 7/12/00 | P/T | 31 | 23,600 | 7 | 2000 |
| 8/1/64 | P | 32 | 23,500 | 8 | 1964 |
| 6/18/62 | T | 33 | 23,300 | 6 | 1962 |
| 6/30/85 | T | 34 | 23,[illegible] | 6 | 1985 |
| 6/16/64 | P | 35 | 22,900 | 6 | 1964 |
| 6/24/71 | ?P | 36 | 22,800 | 6 | 1971 |
| 6/21/62 | ?T | 37 | 22,700 | 6 | 1962 |
| 7/30/52 | P | 38 | 22,600 | 7 | 1952 |
| 7/12/72 | P | 39 | 22,600 | 7 | 1972 |
| 7/16/00 | P | 40 | 22,600 | 7 | 2000 |
| 6/19/01 | T | 41 | 22,600 | 6 | 2001 |
| 8/20/57 | P | 42 | 22,500 | 8 | 1957 |
| 7/14/85 | U | 43 | 22,500 | 7 | 1985 |
| 6/24/00 | T | 44 | 22,400 | 6 | 2000 |
| 7/1/01 | ?T | 45 | 22,400 | 7 | 2001 |
| 6/14/64 | T | 46 | 22,200 | 6 | 1964 |
| 7/8/00 | T | 47 | 22,200 | 7 | 2000 |
| 6/19/62 | T | 48 | 22,100 | 6 | 1962 |
| 6/25/64 | P | 49 | 22,000 | 6 | 1964 |
| 7/7/85 | T | 50 | 22,000 | 7 | 1985 |
| 8/20/62 | ?T | 51 | 21,900 | 8 | 1962 |
| 6/27/00 | T | 52 | 21,900 | 6 | 2000 |
| 8/8/71 | P | 53 | 21,800 | 8 | 1971 |
| 7/15/00 | P | 54 | 21,800 | 7 | 2000 |
| 7/20/52 | P | 55 | 21,700 | 7 | 1952 |
| 7/6/71 | U | 56 | 21,700 | 7 | 1971 |
| 7/17/00 | P | 57 | 21,600 | 7 | 2000 |
| 6/26/01 | T | 58 | 21,600 | 6 | 2001 |
| 7/28/52 | P | 59 | 21,400 | 7 | 1952 |
| 7/31/52 | P | 60 | 21,400 | 7 | 1952 |
| 6/23/71 | P | 61 | 21,400 | 6 | 1971 |
| 6/17/62 | T | 62 | 21,300 | 6 | 1962 |
| 8/14/71 | ?P | 63 | 21,300 | 8 | 1971 |
| 7/31/64 | ?P | 64 | 21,200 | 7 | 1964 |
| 6/20/01 | ?T | 65 | 21,200 | 6 | 2001 |
| 8/23/63 | P | 66 | 21,100 | 8 | 1963 |
| 8/13/00 | U | 67 | 21,100 | 8 | 2000 |
| 6/29/00 | P | 68 | 21,100 | 6 | 2000 |
| 6/22/71 | P | 69 | 21,000 | 6 | 1971 |
| 7/4/00 | U | 70 | 21,000 | 7 | 2000 |
| 7/12/85 | U | 71 | 20,900 | 7 | 1985 |
| 6/29/53 | T | 72 | 20,800 | 6 | 1953 |
| 6/26/00 | T | 73 | 20,800 | 6 | 2000 |
| 6/19/64 | P | 74 | 20,700 | 6 | 1964 |
| 6/28/70 | P | 75 | 20,700 | 6 | 1970 |
| 7/2/00 | ?P | 76 | 20,700 | 7 | 2000 |
| 8/26/59 | P | 77 | 20,600 | 8 | 1959 |
| 7/4/85 | P | 78 | 20,600 | 7 | 1985 |
| 6/27/53 | T | 79 | 20,500 | 6 | 1953 |
| 6/9/64 | U | 80 | 20,500 | 6 | 1964 |
| 7/27/53 | T | 81 | 20,400 | 7 | 1953 |
| 8/27/55 | P | 82 | 20,400 | 8 | 1955 |
| 6/16/62 | ?T | 83 | 20,300 | 6 | 1962 |
| 6/13/68 | U | 84 | 20,300 | 6 | 1968 |
| 7/13/85 | P | 85 | 20,300 | 7 | 1985 |
| 7/14/55 | P | 86 | 20,300 | 7 | 1955 |
| 7/26/53 | T | 87 | 20,200 | 7 | 1953 |
| 7/31/54 | P | 88 | 20,200 | 7 | 1954 |
| 6/25/71 | ?P | 89 | 20,200 | 6 | 1971 |
| 6/14/72 | U | 90 | 20,200 | 6 | 1972 |
| 7/16/55 | U | 91 | 20,100 | 7 | 1955 |
| 6/17/01 | T | 92 | 20,100 | 6 | 2001 |

# APPENDIX B

*Climate Data and Analysis*

Weather Stations in the Matanuska Valley with Daily Data

| Station name | Station No | begin date | end date | latitude | longitude | elev (m) x10 | | | No of Years |
|---|---|---|---|---|---|---|---|---|---|
| PALMER CORRECTION CE | 500040 | 19660301 | 19730701 | 6142N | 14859W | 2530 | 3/1/1966 | 7/1/1973 | 8 |
| ALPINE INN | 500238 | 19631001 | 19711231 | 6143N | 14854W | 1400 | 10/1/1963 | 1/1/1972 | 10 |
| EUREKA | 502952 | 19530701 | 19681001 | 6157N | 14710W | 10160 | 7/1/1953 | 10/1/1968 | 16 |
| EUREKA | 502952 | 19681001 | 19681224 | 6157N | 14710W | 10190 | 10/1/1968 | 12/24/1968 | |
| GUNSIGHT | 503473 | 19660601 | 19741016 | 6154N | 14718W | 9020 | 6/1/1966 | 10/16/1974 | 9 |
| HOUSTON 2 SE | 503739 | 19830922 | 19910902 | 6137N | 14742W | 732 | 9/22/1983 | 9/2/1991 | 9 |
| LAZY MOUNTAIN | 505464 | 19840721 | 20031231 | 6138N | 14902W | 2409 | 7/21/1984 | 12/31/2003 | 20 |
| PALMER 4 SSE | 505721 | 19490901 | 19520301 | 6133N | 14905W | 240 | 9/1/1949 | 3/1/1952 | 6 |
| PALMER 4 SSE | 505721 | 19520401 | 19541101 | 6132N | 14905W | 550 | 4/1/1952 | 11/1/1954 | |
| PALMER IAS | 506870 | 19490901 | 19510501 | 6136N | 14908W | 920 | 9/1/1949 | 5/1/1951 | 50 |
| PALMER IAS | 506870 | 19510501 | 19580401 | 6136N | 14905W | 610 | 5/1/1951 | 4/1/1958 | |
| PALMER IAS | 506870 | 19580401 | 19581010 | 6136N | 14905W | 700 | 4/1/1958 | 10/1/1958 | |
| PALMER IAS | 506870 | 19581010 | 19610601 | 6136N | 14907W | 700 | 10/1/1958 | 6/1/1961 | |
| PALMER IAS | 506870 | 19611010 | 19660701 | 6134N | 14906W | 700 | 10/1/1961 | 7/1/1966 | |
| PALMER IAS | 506870 | 19660701 | 19820101 | 6136N | 14906W | 700 | 7/1/1966 | 1/1/1982 | |
| PALMER IAS | 506870 | 19820101 | 19980430 | 6136N | 14906W | 685 | 1/1/1982 | 12/31/1993 | |
| PALMER 2 ESE | 506872 | 19610601 | 19640601 | 6135N | 14903W | 400 | 6/1/1961 | 6/1/1964 | 4 |
| PALMER 4 SE | 506873 | 19560601 | 19601601 | 6132N | 14905W | 310 | 6/1/1956 | 6/1/1960 | 5 |
| PALMER 4 SSE | 506874 | 19541201 | 19550701 | 6132N | 14905W | 550 | 12/1/1954 | 7/1/1955 | 2 |
| MATANUSKA VALLEY 9 | 506875 | 19621101 | 19631010 | 6139N | 14912W | 1920 | 11/1/1962 | 10/1/1963 | 2 |
| PALMER CORRECTION CE | 506876 | 19730701 | 19781130 | 6142N | 14859W | 2530 | 7/1/1973 | 12/1/1978 | 6 |
| PLANT MATERIALS CNTR | 507352 | 19741201 | 19820101 | 6132N | 14905W | 210 | 12/1/1974 | 1/1/1982 | 21 |
| PLANT MATERIALS CNTR | 507352 | 19820101 | 19890525 | 6132N | 14905W | 204 | 1/1/1982 | 5/26/1989 | |
| PLANT MATERIALS CNTR | 507352 | 19890526 | 19940430 | 6132N | 14905W | 204 | 5/26/1989 | 4/30/1994 | |
| SHEEP MOUNTAIN | 508407 | 19490901 | 19521201 | 6148N | 14741W | 7060 | 9/1/1949 | 12/1/1952 | 18 |
| SHEEP MOUNTAIN | 508407 | 19530101 | 19660501 | 6148N | 14741W | 6950 | 1/1/1953 | 5/1/1966 | |
| SUTTON 2 E | 508915 | 19771201 | 19820101 | 6143N | 14853W | 1680 | 12/1/1977 | 1/1/1982 | 27 |
| SUTTON 2 E | 508915 | 19820101 | 19860501 | 6143N | 14853W | 1676 | 1/1/1982 | 5/2/1986 | |
| SUTTON 2 E | 508915 | 19860501 | 20031031 | 6143N | 14853W | 1676 | 5/2/1986 | 10/31/2003 | |
| TAHNETA PASS | 508945 | 19780301 | 19820101 | 6149N | 14733W | 7990 | 3/1/1978 | 1/1/1982 | 23 |
| TAHNETA PASS | 508945 | 19820101 | 20000930 | 6149N | 14733W | 7987 | 1/1/1982 | 9/30/2000 | |

## Weather Stations in the Matanuska Valley

| Station name | Lazy Mountain | Palmer IAS | Sutton 2 E | Tahneta Pass |
|---|---|---|---|---|
| Station No | 505484 | 506870 | 508915 | 508946 |
| Latitude | 6138N | 6136N | 6143N | 6149N |
| Longitude | 14902W | 14908W | 14853W | 14733W |
| Elevation (ft) | 790 | 200 - 320 | 550 | 2621 |
| Beginning Date | 30894 | 18142 | 28460 | 28550.00 |
| Ending date | 37986 | 35915 | 37025 | 36799.00 |
| Number of years with data | 20 | 49 | 27 | 23 |
| Number of complete calendar years | 13 | 35 | 13 | 16 |
| 49 | | D | | |
| 50 | | D | | |
| 51 | | P | | |
| 52 | | P | | |
| 53 | | P | | |
| 54 | | P | | |
| 55 | | D | | |
| 56 | | D | | |
| 57 | | P | | |
| 58 | | D | | |
| 59 | | P | | |
| 60 | | D | | |
| 61 | | D | | |
| 62 | | D | | |
| 63 | | P | | |
| 64 | | P | | |
| 65 | | P | | |
| 66 | | P | | |
| 67 | | P | | |
| 68 | | P | | |
| 69 | | D | | |
| 70 | | P | | |
| 71 | | P | | |
| 72 | | P | | |
| 73 | | P | | |
| 74 | | P | | |
| 75 | | P | | |
| 76 | | D | | |
| 77 | | P | D | |
| 78 | | P | D | D |
| 79 | | P | P | D |
| 80 | | P | P | P |
| 81 | | D | D | D |
| 82 | | P | D | P |
| 83 | | P | D | P |
| 84 | D | P | P | P |
| 85 | D | P | P | P |
| 86 | P | P | D | P |
| 87 | P | P | D | P |
| 88 | D | P | D | P |
| 89 | P | P | D | P |
| 90 | P | P | D | P |
| 91 | D | P | P | D |
| 92 | D | D | P | P |
| 93 | P | D | D | P |
| 94 | P | P | P | D |
| 95 | P | P | P | P |
| 96 | P | P | P | P |
| 97 | P | D | P | P |
| 98 | P | | P | P |
| 99 | D | | D | D |
| 00 | P | | D | D |
| 01 | P | | P | |
| 02 | P | | P | |
| 03 | D | | D | |

D indicates some data available for this year
P indicates precipitation data available for entire year

Palmer IAS station moved 5 times over period of record
Sutton 2 E station moved 2 times over period of record
Tahneta Pass station moved once over period of record

# TREND STATISTICS

**Thaw Deg Days in Mat River Drainage**

| Time series | First year | Last Year | n | Test S | Test Z | Signific. | Q | Qmin99 | Qmax99 | Qmin95 | Qmax95 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Mann-Kendall trend | | | Sen's slope estimate | | | | |
| *TahnJul* | *1979* | *2000* | *20* | | 1.14 | | 1.780 | -2.388 | 6.936 | -0.837 | 4.533 |
| *TanAll* | *1979* | *1998* | *17* | | 1.28 | | 11.460 | -16.418 | 44.055 | -9.908 | 34.168 |
| *Sutjul* | *1978* | *2003* | *25* | | 1.75 | + | 1.860 | -0.778 | 5.024 | -0.258 | 4.156 |
| *Sutall* | *1978* | *2003* | *14* | | 1.20 | | 20.858 | -21.451 | 45.081 | -10.757 | 42.283 |
| *LazMJul* | *1985* | *2003* | *19* | | 0.63 | | 0.989 | -3.228 | 7.072 | -2.392 | 5.014 |
| *LazMall* | *1985* | *2003* | *18* | | 1.52 | | 13.245 | -9.392 | 40.963 | -4.468 | 31.135 |
| *PalmJul* | *1950* | *1997* | *42* | | 1.37 | | 0.748 | -0.727 | 2.403 | -0.399 | 1.947 |
| *PalmAll* | *1950* | *1996* | *35* | | 3.47 | *** | 10.820 | 4.022 | 18.757 | 5.487 | 17.113 |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |

## ANNUAL DATA

Thaw Deg Days in Mat River Drainage

**CALCULATE TREND STATISTICS**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Number of time series in the calculation:** | 8 | | | | | | | |
| **Number of annual values in the calculation:** | 20 | 17 | 26 | 13 | 19 | 18 | 42 | 35 |
| **Select the FIRST YEAR of the calculation:** | 1979 | 1979 | 1978 | 1978 | 1985 | 1985 | 1950 | 1950 |
| **Select the LAST YEAR of the calculation:** | 2000 | 1998 | 2003 | 2003 | 2003 | 2003 | 1997 | 1996 |

| | TahnJul | TahnAll | SuinJul | SuinAll | LazMJul | LazMAll | PalmJul | PalmAll |
|---|---|---|---|---|---|---|---|---|
| 1950 | | | | | | | 736 | 3109 |
| 1951 | | | | | | | 845 | |
| 1952 | | | | | | | 780 | |
| 1953 | | | | | | | 826 | |
| 1954 | | | | | | | 756 | |
| 1955 | | | | | | | | |
| 1956 | | | | | | | | |
| 1957 | | | | | | | 770 | |
| 1958 | | | | | | | 757 | |
| 1959 | | | | | | | | |
| 1960 | | | | | | | | |
| 1961 | | | | | | | | |
| 1962 | | | | | | | 741 | 2709 |
| 1963 | | | | | | | 743 | 2943 |
| 1964 | | | | | | | 685 | 2722 |
| 1965 | | | | | | | 689 | 2670 |
| 1966 | | | | | | | 608 | 2729 |
| 1967 | | | | | | | 802 | 3165 |
| 1968 | | | | | | | 800 | 3031 |
| 1969 | | | | | | | 770 | 3089 |
| 1970 | | | | | | | 709 | 2799 |
| 1971 | | | | | | | 738 | 2759 |
| 1972 | | | | | | | 818 | 2916 |
| 1973 | | | | | | | 744 | 2811 |
| 1974 | | | | | | | 757 | 3250 |
| 1975 | | | | | | | 763 | 2984 |
| 1976 | | | | | | | 796 | 3049 |
| 1977 | | | | | | | 844 | 3233 |
| 1978 | | | 687 | | | | 711 | 3036 |
| 1979 | 657 | 2418 | 764 | | | | 793 | 3286 |
| 1980 | 607 | 2049 | 736 | | | | 742 | 2884 |
| 1981 | | | 702 | | | | 720 | 3041 |
| 1982 | 591 | 2108 | | | | | 692 | 2077 |
| 1983 | 620 | 2199 | 736 | | | | 766 | 3024 |
| 1984 | 605 | 2276 | 722 | | | | 742 | 3073 |
| 1985 | 648 | 1992 | 770 | | 734 | 2535 | 810 | 2897 |
| 1986 | 629 | 2150 | 736 | | 699 | 2685 | 778 | 3081 |
| 1987 | 589 | 2094 | 702 | | 678 | 2595 | 740 | 2959 |
| 1988 | 634 | 2124 | 745 | | 708 | 2673 | 758 | 3009 |
| 1989 | 700 | 2453 | 767 | | 747 | 2852 | 818 | 3215 |
| 1990 | 669 | 2585 | 727 | | 742 | 2959 | 818 | 3336 |
| 1991 | 586 | | 713 | 2909 | 674 | | 728 | 3124 |
| 1992 | 632 | 1977 | 758 | 2615 | 718 | 2456 | | |
| 1993 | 689 | 2610 | 814 | 3151 | 782 | 3004 | 844 | 3349 |
| 1994 | 599 | | 726 | 2972 | 703 | 2814 | 780 | 3195 |
| 1995 | 642 | 2451 | 758 | 3134 | 709 | 2943 | 771 | 3304 |
| 1996 | 646 | 2333 | 730 | 2845 | 739 | 2817 | 794 | 3134 |
| 1997 | 713 | 2520 | 836 | 3193 | 821 | 3075 | 847 | |
| 1998 | 602 | 2135 | 754 | 2886 | 709 | 2614 | | |
| 1999 | | | 740 | 2971 | 696 | 2759 | | |
| 2000 | 649 | | 746 | 2816 | 701 | 2641 | | |
| 2001 | | | 729 | 3020 | 681 | 2828 | | |
| 2002 | | | 806 | 3063 | 751 | 2890 | | |
| 2003 | | | 822 | 3037 | 801 | 2905 | | |

# TREND STATISTICS

Jun-Sep Avg T - Mat R Drainage

| | | | | Mann-Kendall trend | | | Sen's slope estimate | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Time series | First year | Last Year | n | Test S | Test Z | Signific. | Q | Qmin99 | Qmax99 | Qmin95 | Qmax95 |
| *TahnSumrT* | *1979* | *2000* | *18* | | 0.91 | | 0.063 | -0.151 | 0.299 | -0.092 | 0.237 |
| *SuttSumrT* | *1991* | *2003* | *13* | | 0.92 | | 0.054 | -0.245 | 0.392 | -0.139 | 0.321 |
| *LazyMSumrT* | *1985* | *2003* | *19* | | 1.61 | | 0.102 | -0.060 | 0.268 | -0.008 | 0.225 |
| *PalmSumrT* | *1950* | *1996* | *35* | | 2.06 | * | 0.049 | -0.016 | 0.113 | 0.006 | 0.094 |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |

## ANNUAL DATA

Jun-Sep Avg T - Mat R Drainage

**CALCULATE TREND STATISTICS**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Number of time series in the calculation:** | 4 | | | | | | | |
| **Number of annual values in the calculation:** | 18 | 13 | -19 | 35 | 0 | 0 | 0 | 0 |
| **Select the FIRST YEAR of the calculation:** | 1979 | 1991 | 1985 | 1950 | | | | |
| **Select the LAST YEAR of the calculation:** | 2000 | 2003 | 2003 | 1996 | | | | |

| | TahnSumrT | SultSumrT | LazyMSum | PalmSumrT |
|---|---|---|---|---|
| 1950 | | | | 36 |
| 1951 | | | | 36 |
| 1952 | | | | 37 |
| 1953 | | | | |
| 1954 | | | | |
| 1955 | | | | |
| 1956 | | | | |
| 1957 | | | | |
| 1958 | | | | |
| 1959 | | | | 36 |
| 1960 | | | | |
| 1961 | | | | |
| 1962 | | | | 35 |
| 1963 | | | | 36 |
| 1964 | | | | 34 |
| 1965 | | | | 34 |
| 1966 | | | | 33 |
| 1967 | | | | 37 |
| 1968 | | | | 36 |
| 1969 | | | | |
| 1970 | | | | 36 |
| 1971 | | | | 34 |
| 1972 | | | | 34 |
| 1973 | | | | 35 |
| 1974 | | | | 37 |
| 1975 | | | | 35 |
| 1976 | | | | |
| 1977 | | | | 38 |
| 1978 | | | | 38 |
| 1979 | 50 | | | 38 |
| 1980 | 47 | | | 37 |
| 1981 | | | | |
| 1982 | 48 | | | 35 |
| 1983 | 47 | | | 36 |
| 1984 | 49 | | | 37 |
| 1985 | 47 | | 51 | 36 |
| 1986 | 48 | | 51 | 38 |
| 1987 | 47 | | 51 | 38 |
| 1988 | 48 | | 51 | 38 |
| 1989 | 50 | | 53 | 37 |
| 1990 | 50 | | 53 | 37 |
| 1991 | 48 | 53 | 52 | 37 |
| 1992 | 46 | 51 | 49 | |
| 1993 | 49 | 54 | 53 | 40 |
| 1994 | | 53 | 53 | 36 |
| 1995 | 50 | 55 | 53 | 36 |
| 1996 | 48 | 52 | 52 | 33 |
| 1997 | 51 | 55 | 54 | |
| 1998 | 49 | 53 | 51 | |
| 1999 | | 54 | 52 | |
| 2000 | | 52 | 51 | |
| 2001 | | 54 | 53 | |
| 2002 | | 54 | 53 | |
| 2003 | | 54 | 53 | |

# TREND STATISTICS

Temp/Precip in Mat River Drainage

| | | | | Mann-Kendall trend | | | Sen's slope estimate | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Time series | First year | Last Year | n | Test S | Test Z | Signific. | Q | Qmin99 | Qmax99 | Qmin95 | Qmax95 |
| *TahnT* | *1980* | *1998* | *16* | | -0.95 | | -0.064 | -0.275 | 0.217 | -0.205 | 0.101 |
| *SuttonT* | *1979* | *2002* | *18* | | 0.04 | | 0.003 | -0.157 | 0.131 | -0.107 | 0.094 |
| *LazyMT* | *1986* | *2002* | *15* | | -0.10 | | -0.033 | -0.328 | 0.306 | -0.297 | 0.191 |
| *PalmerT* | *1950* | *1996* | *35* | | 2.06 | | 0.049 | -0.016 | 0.113 | 0.006 | 0.094 |
| *TahnP* | *1980* | *1998* | *16* | | -1.31 | | -0.131 | -0.464 | 0.185 | -0.420 | 0.093 |
| *SuttonP* | *1979* | *2002* | *13* | | -0.43 | | -0.088 | -0.420 | 0.630 | -0.325 | 0.286 |
| *LazyMP* | *1986* | *2002* | *13* | | -0.43 | | -0.251 | -0.988 | 0.710 | -0.685 | 0.294 |
| *PalmerP* | *1951* | *1996* | *36* | | -0.48 | | -0.026 | -0.114 | 0.079 | -0.099 | 0.051 |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |
| *0* | *0* | *0* | *0* | | | | | | | | |

ANNUAL DATA

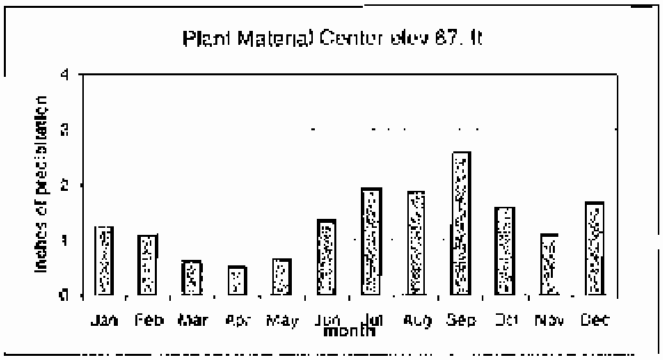
**Temp/Precip in Mat River Drainage**

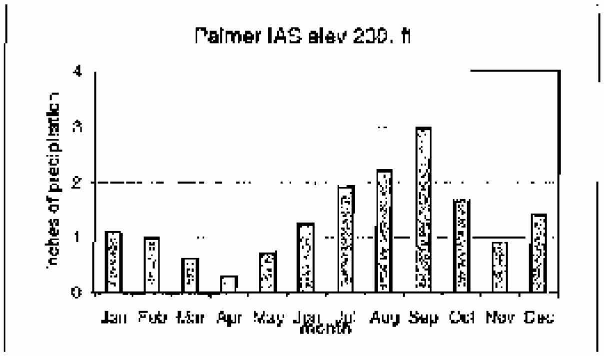
**CALCULATE TREND STATISTICS**

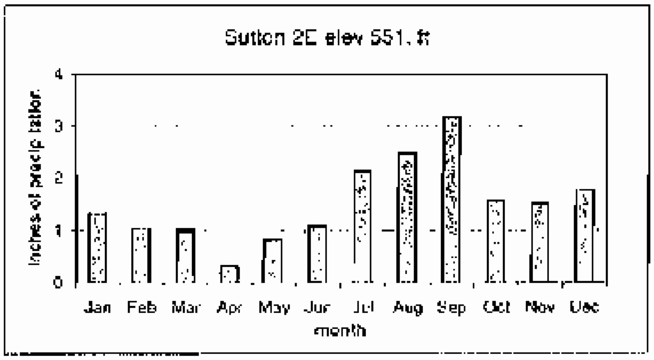
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Number of time series in the calculation:** | 8 | | | | | | | |
| **Number of annual values in the calculation:** | 16 | 18 | 15 | 35 | 16 | 13 | 13 | 36 |
| **Select the FIRST YEAR of the calculation:** | 1980 | 1979 | 1986 | 1950 | 1980 | 1979 | 1986 | 1951 |
| **Select the LAST YEAR of the calculation:** | 1998 | 2002 | 2002 | 1996 | 1998 | 2002 | 2002 | 1996 |

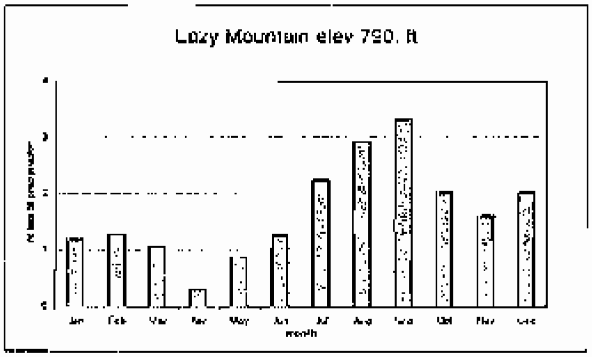
| | TahoT | SuttonT | LazyMT | PalmerT | TahoP | SuttonP | LazyMP | PalmerP |
|---|---|---|---|---|---|---|---|---|
| 1950 | | | | 36 | | | | |
| 1951 | | | | 36 | | | | 17 |
| 1952 | | | | 37 | | | | 19 |
| 1953 | | | | | | | | 14 |
| 1954 | | | | | | | | 14 |
| 1955 | | | | | | | | |
| 1956 | | | | | | | | |
| 1957 | | | | | | | | 17 |
| 1958 | | | | | | | | |
| 1959 | | | | 36 | | | | 21 |
| 1960 | | | | | | | | |
| 1961 | | | | | | | | |
| 1962 | | | | 35 | | | | |
| 1963 | | | | 38 | | | | 16 |
| 1964 | | | | 34 | | | | 15 |
| 1965 | | | | 34 | | | | 16 |
| 1966 | | | | 33 | | | | 12 |
| 1967 | | | | 37 | | | | 20 |
| 1968 | | | | 36 | | | | 11 |
| 1969 | | | | | | | | |
| 1970 | | | | 36 | | | | 12 |
| 1971 | | | | 34 | | | | 16 |
| 1972 | | | | 34 | | | | 15 |
| 1973 | | | | 35 | | | | 12 |
| 1974 | | | | 37 | | | | 13 |
| 1975 | | | | 35 | | | | 13 |
| 1976 | | | | | | | | 15 |
| 1977 | | | | 39 | | | | 14 |
| 1978 | | | | 38 | | | | 16 |
| 1979 | | 37 | | 38 | | 19 | | 21 |
| 1980 | 30 | 37 | | 37 | 14 | 22 | | 14 |
| 1981 | | | | | | | | |
| 1982 | 28 | | | 35 | 15 | | | 17 |
| 1983 | 29 | 37 | | 39 | 17 | | | 14 |
| 1984 | 30 | 37 | | 37 | 18 | 16 | | 14 |
| 1985 | 28 | 35 | | 36 | 17 | 18 | | 13 |
| 1986 | 29 | | 37 | 38 | 11 | | 19 | 18 |
| 1987 | 29 | | 36 | 38 | 15 | | 20 | 17 |
| 1988 | 29 | | | 38 | 18 | | | 15 |
| 1989 | 31 | 36 | 36 | 37 | 14 | | 24 | 16 |
| 1990 | 31 | | 35 | 37 | 14 | | 24 | 18 |
| 1991 | | 36 | | 37 | | 14 | | 14 |
| 1992 | 29 | 35 | 33 | | 15 | 16 | | |
| 1993 | 32 | 38 | 38 | 40 | 13 | | 24 | |
| 1994 | | 35 | 34 | 38 | | 16 | 17 | 15 |
| 1995 | 28 | 36 | 35 | 36 | 16 | 13 | 15 | 14 |
| 1996 | 27 | 33 | 33 | 33 | 11 | 14 | 13 | 12 |
| 1997 | 29 | 37 | 36 | | 16 | 18 | 21 | |
| 1998 | 28 | 37 | 36 | | 12 | 14 | 13 | |
| 1999 | | 34 | 33 | | | | | |
| 2000 | | 37 | 37 | | | | 20 | |
| 2001 | | 37 | 35 | | | 18 | 17 | |
| 2002 | | 38 | 37 | | | 23 | 21 | |

1984 to 1993 only



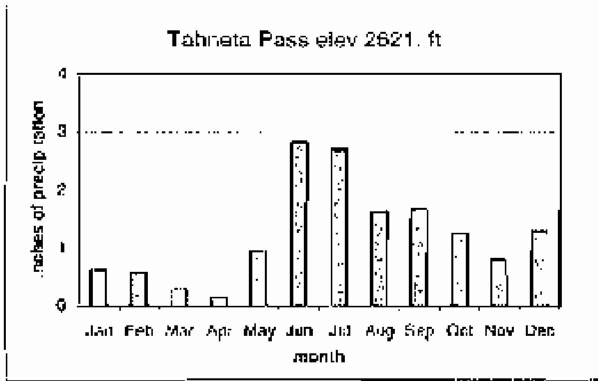



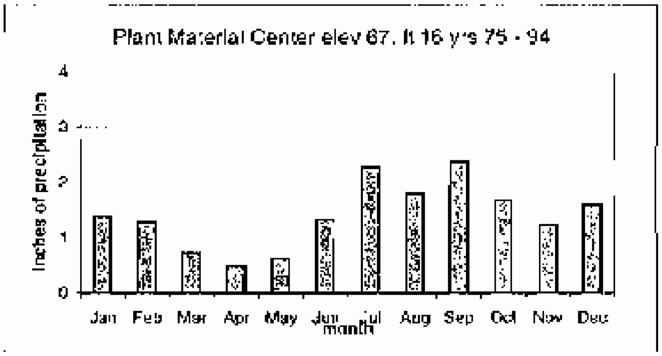



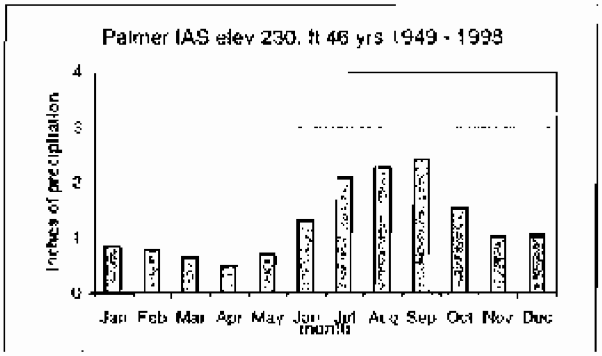

1984 through 1993

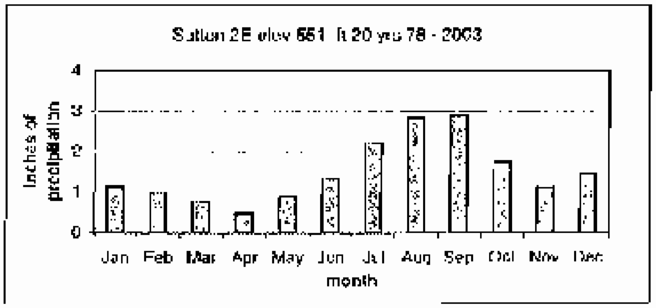
| Station | Elevation, ft | Annual Precip. inches |
|---|---|---|
| Plant Material Center | 67 | 16.3 |
| Palmer IAS | 230 | 16.2 |
| Sutton 2E | 551 | 18.3 |
| Lazy Mountain | 790 | 20.2 |
| Tahneta Pass | 2621 | 14.8 |

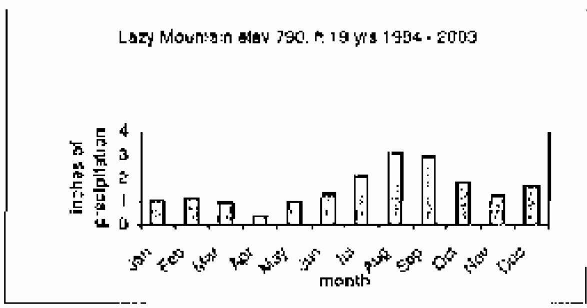


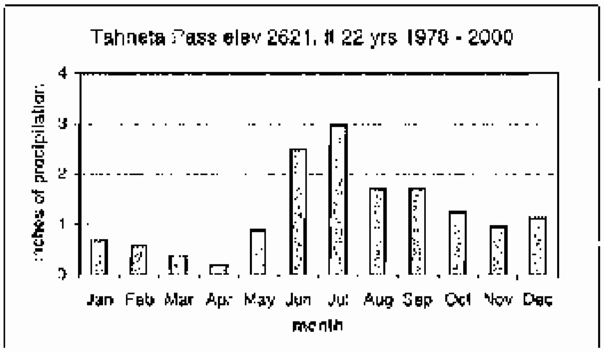
Period of record for each station




| Station | Elevation, ft | | | Annual Precip. inches |
|---|---|---|---|---|
| Plant Material Center | 67 | 16 yrs | 1975 - 1994 | 17.0 |
| Palmer IAS | 230 | 46 yrs | 1949 - 1998 | 15.3 |
| Sutton 2E | 551 | 20 yrs | 1978 - 2003 | 18.0 |
| Lazy Mountain | 790 | 19 yrs | 1984 - 2003 | 18.7 |
| Tahneta Pass | 2021 | 22 yrs | 1978 - 2000 | 15.0 |

# peak flows > 20,000

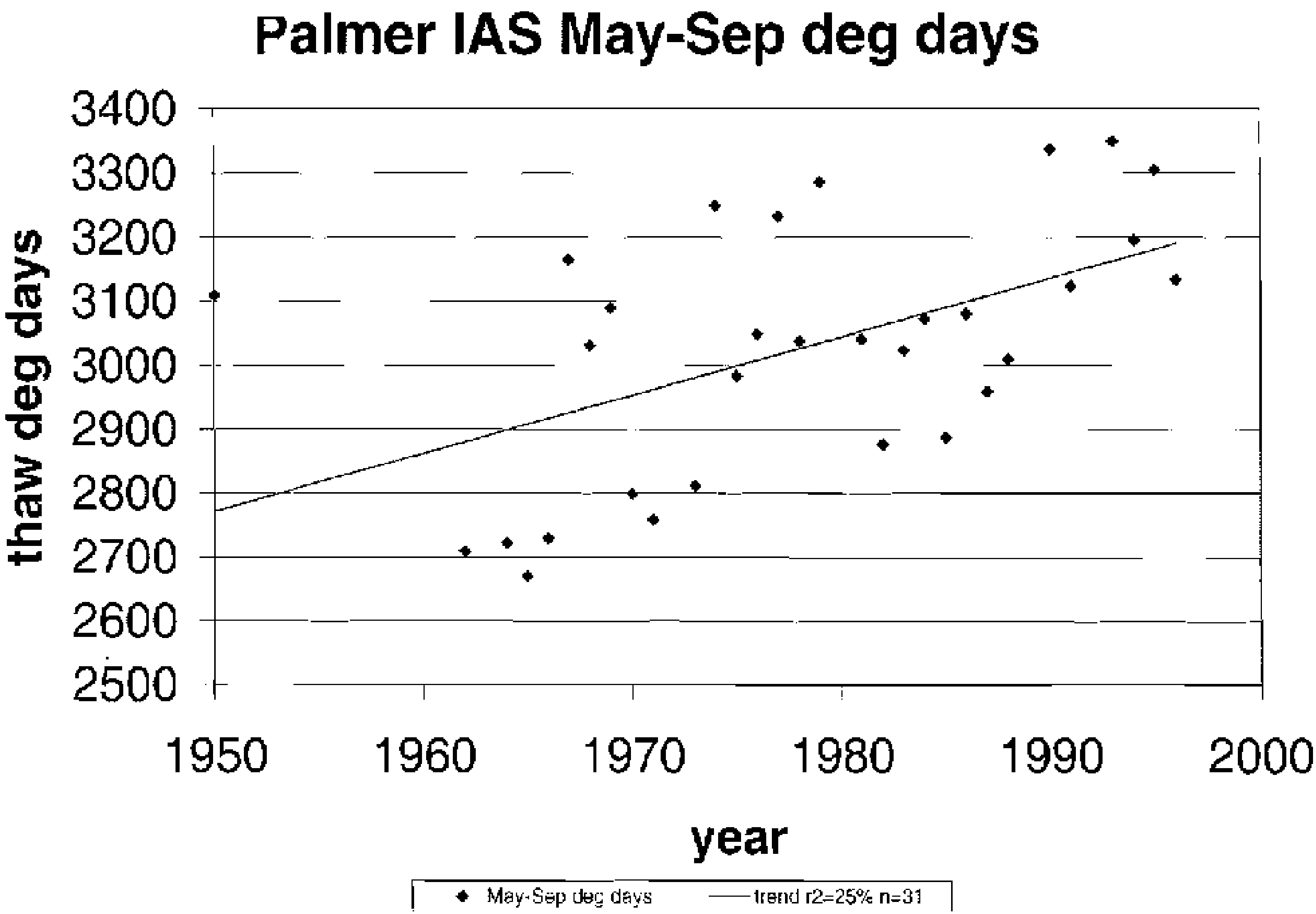
water yrs 1950 2001

1983-2000

87-91

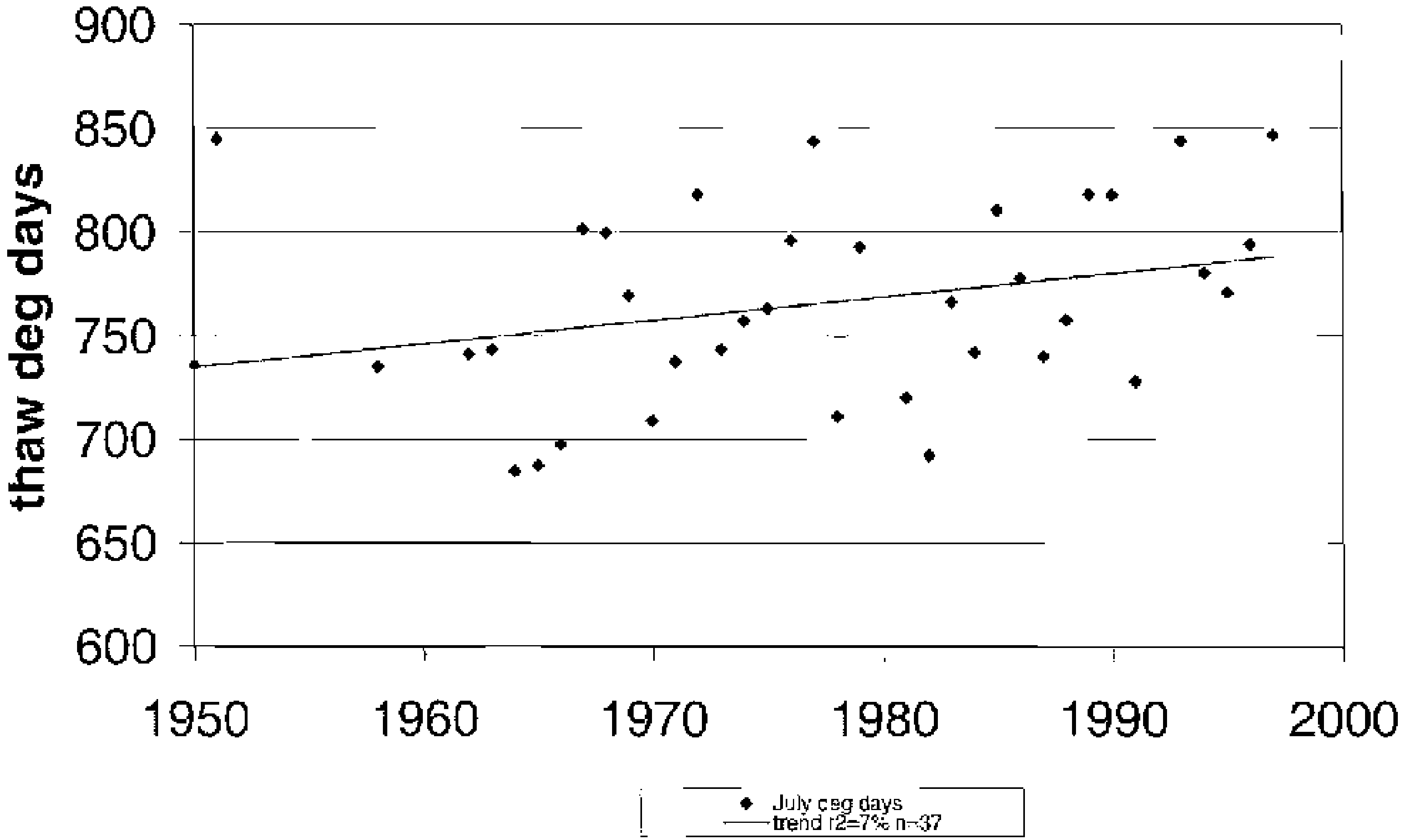
50-72
P73
74-85
86
87-91
92
93-98
P 2000
2001

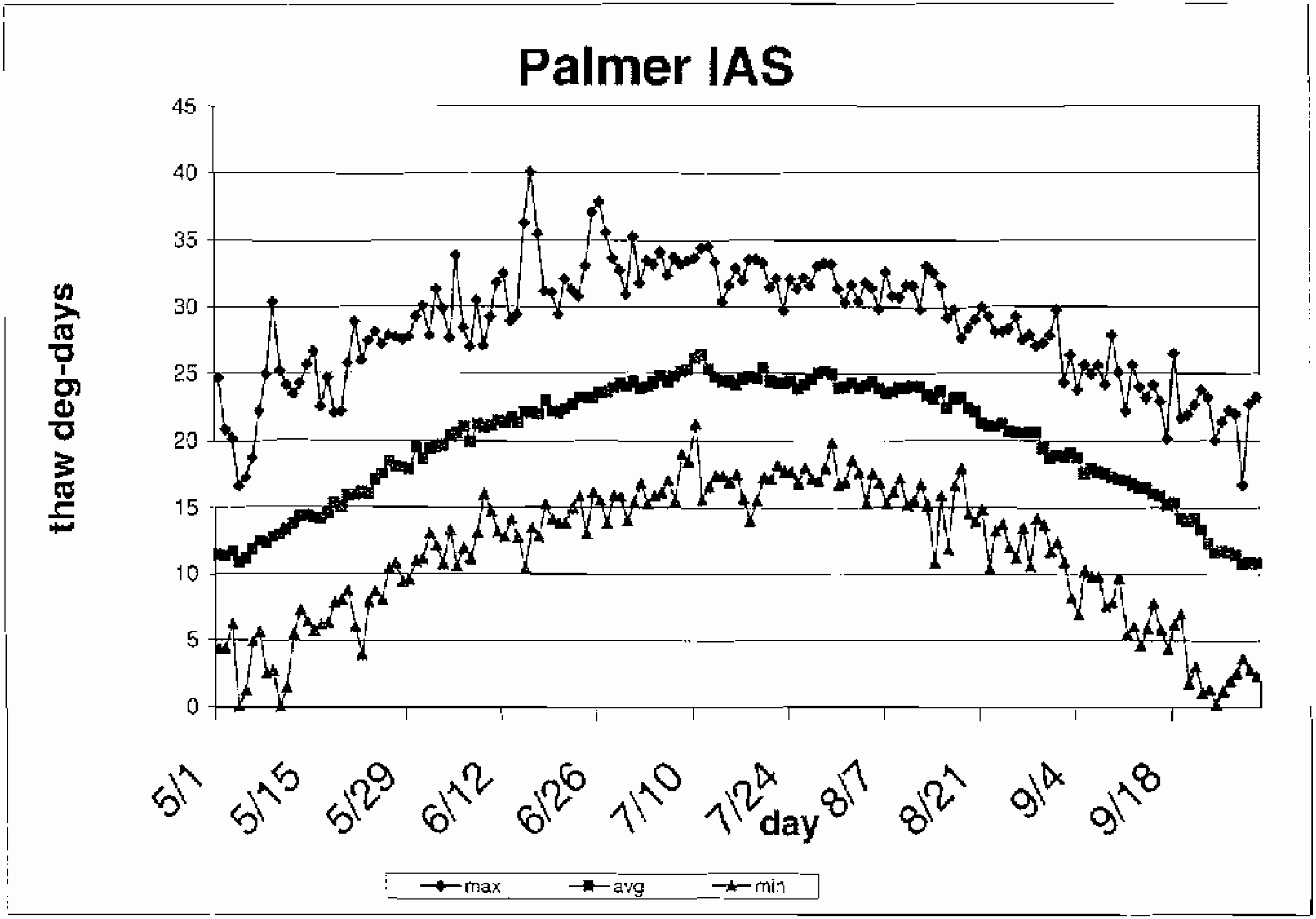
EL 230'


Palmer IAS May-Sep deg days
thaw deg days
3400
3300
3200
3100
3000
2900
2800
2700
2600
2500
1950
1960
1970
1980
1990
2000
year
May-Sep deg days
trend r2=25% n=31

EL 230

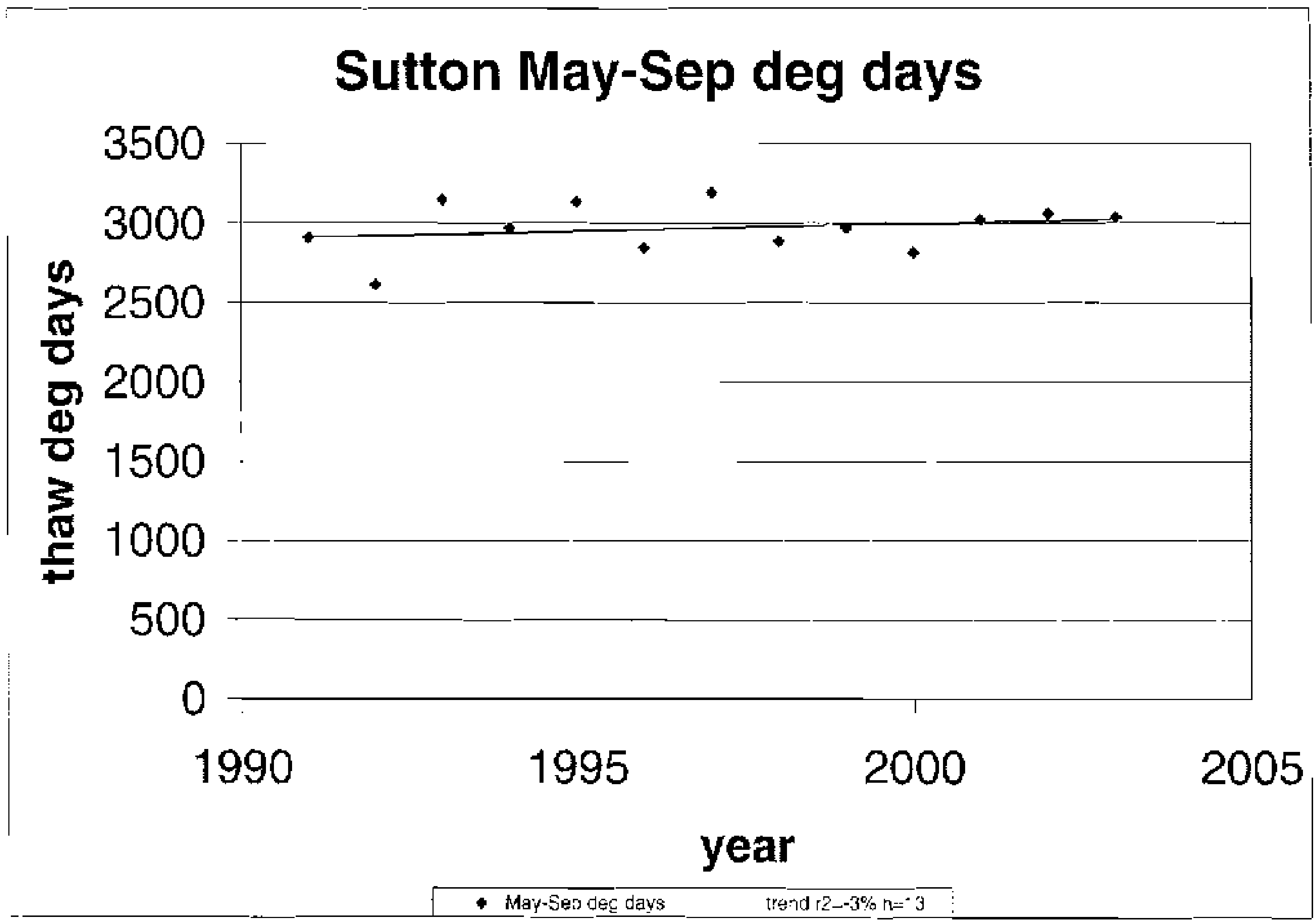
## Palmer IAS July deg days



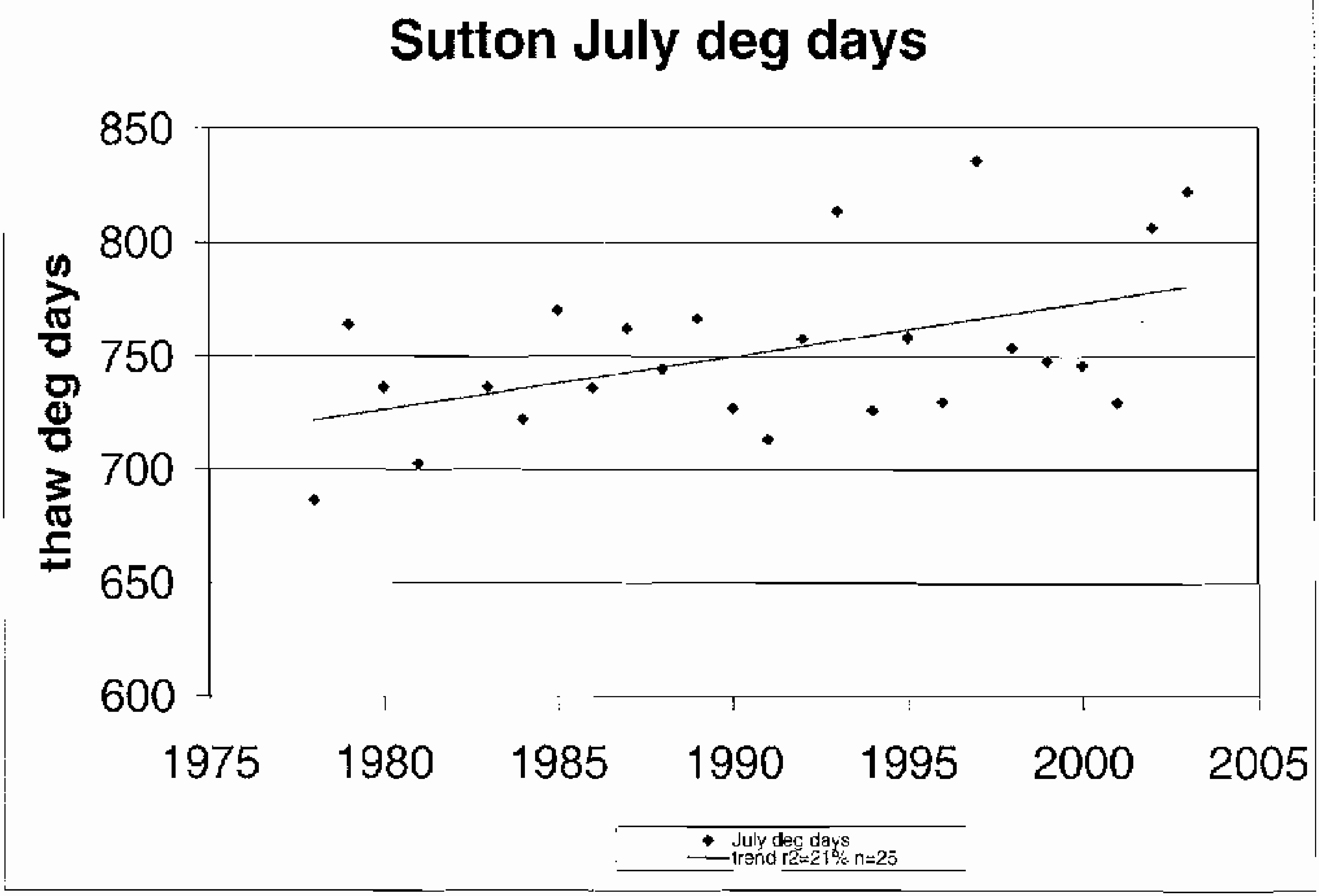


Palmer IAS
thaw deg-days
45
40
35
30
25
20
15
10
5
0
5/1
5/15
5/29
6/12
6/26
7/10
7/24
day
8/7
8/21
9/4
9/18
max
avg
min

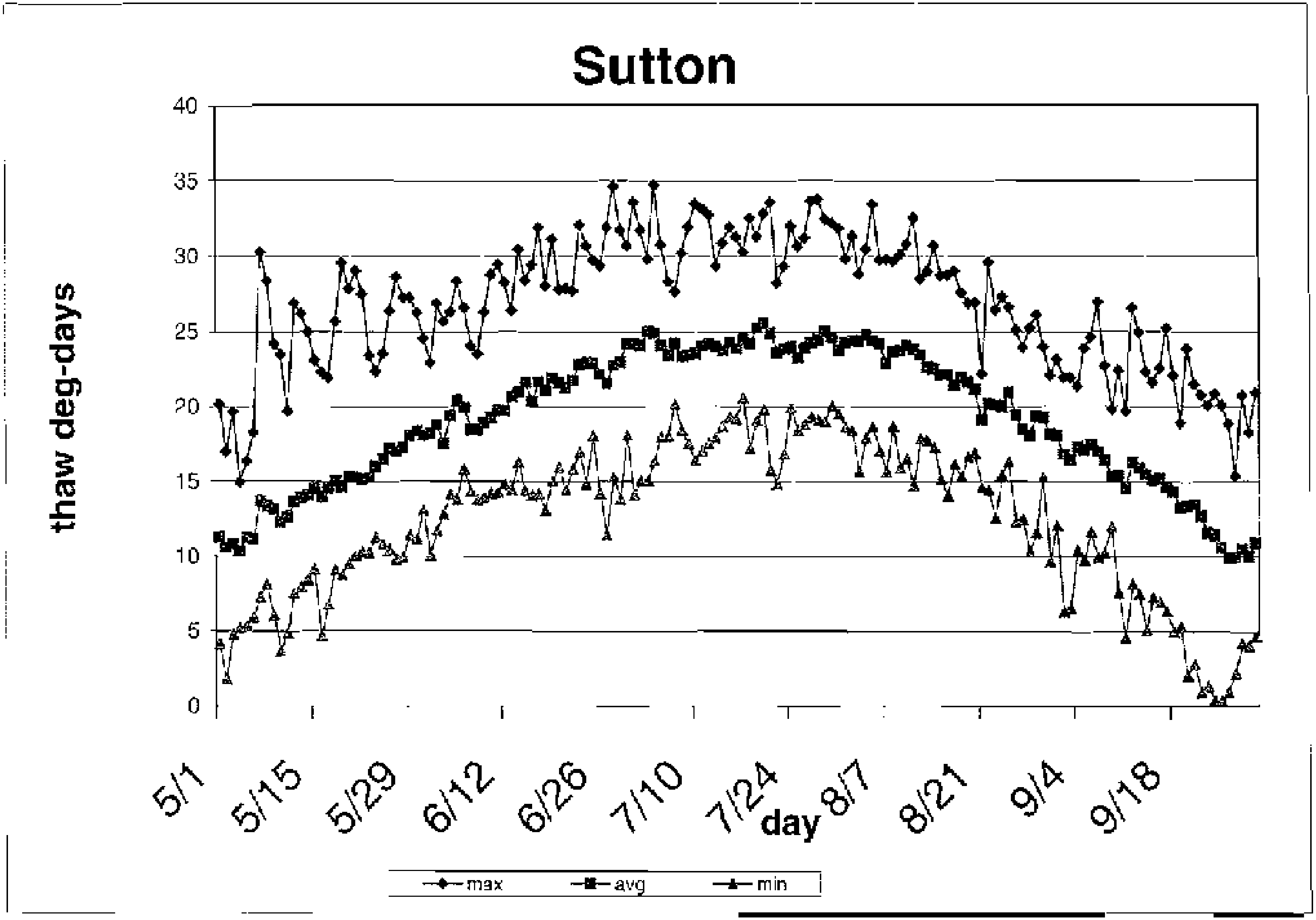
EL 5571


Sutton May-Sep deg days
thaw deg days
3500
3000
2500
2000
1500
1000
500
0
1990
1995
2000
2005
year
May-Sep deg days
trend r2=-3% n=13

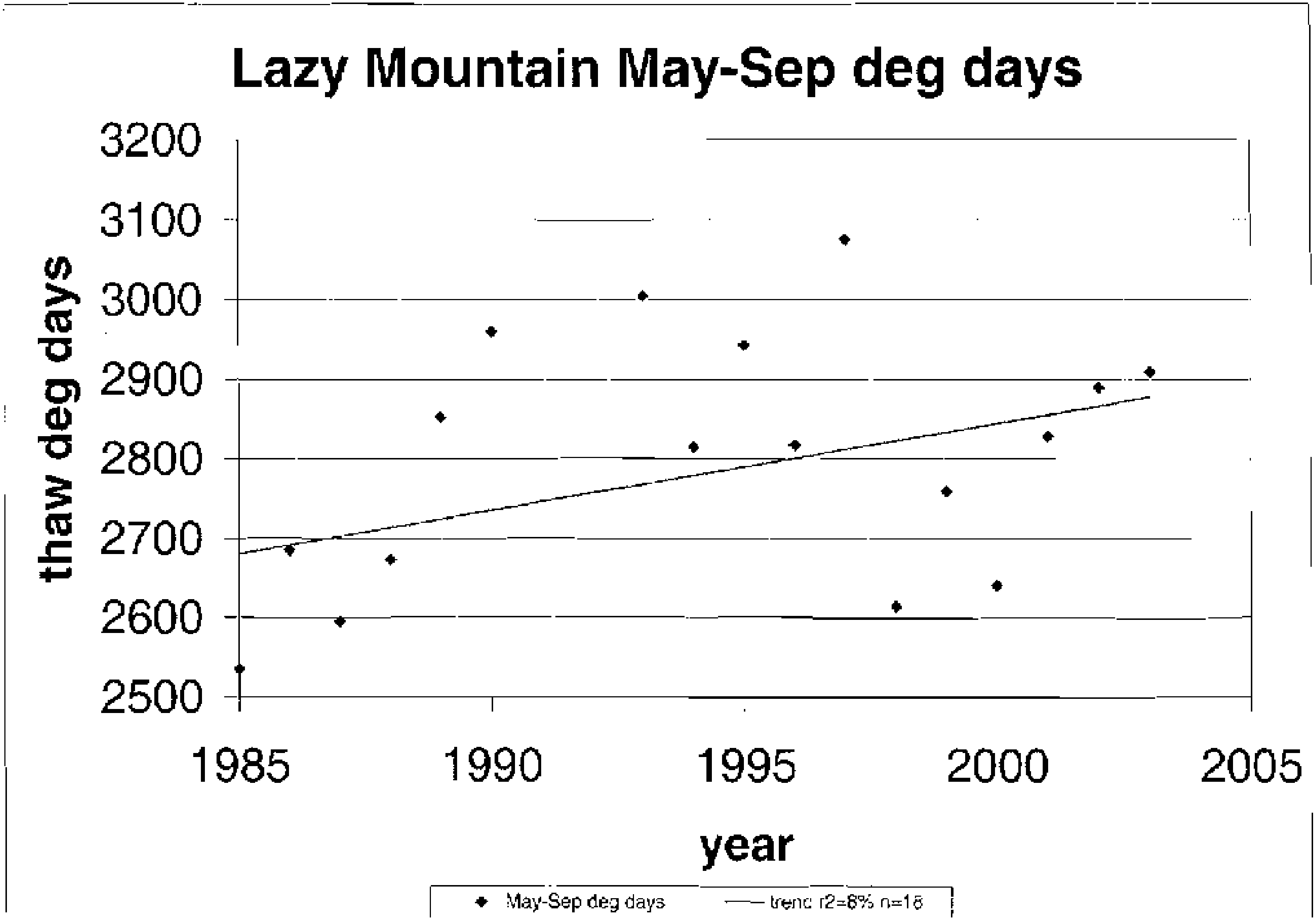
EL 550



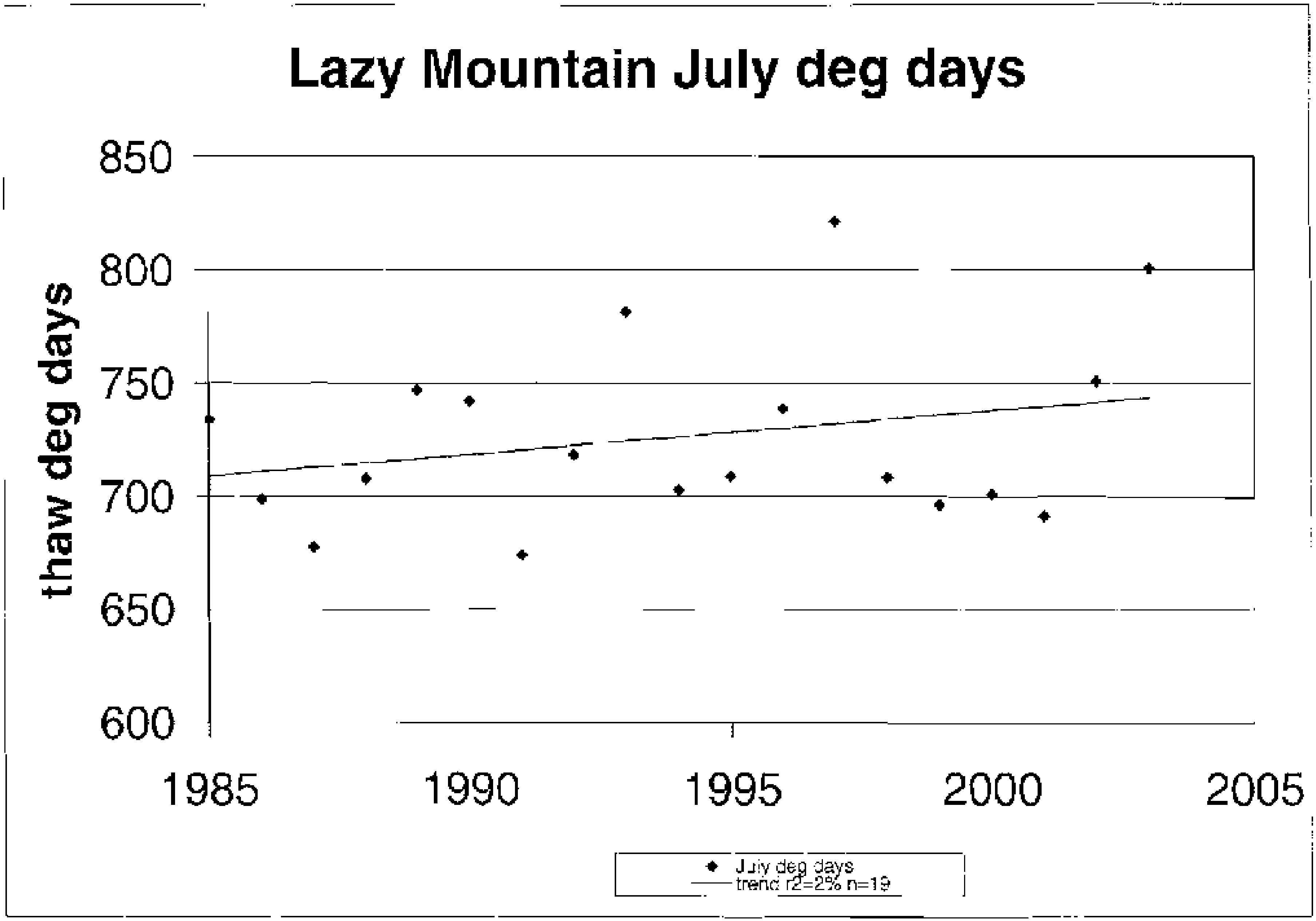
Sutton July deg days
thaw deg days
850
800
750
700
650
600
1975
1980
1985
1990
1995
2000
2005
July deg days
trend r2=21% n=25


Sutton
thaw deg-days
40
35
30
25
20
15
10
5
0
5/1
5/15
5/29
6/12
6/26
7/10
7/24
day
8/7
8/21
9/4
9/18
max
avg
min

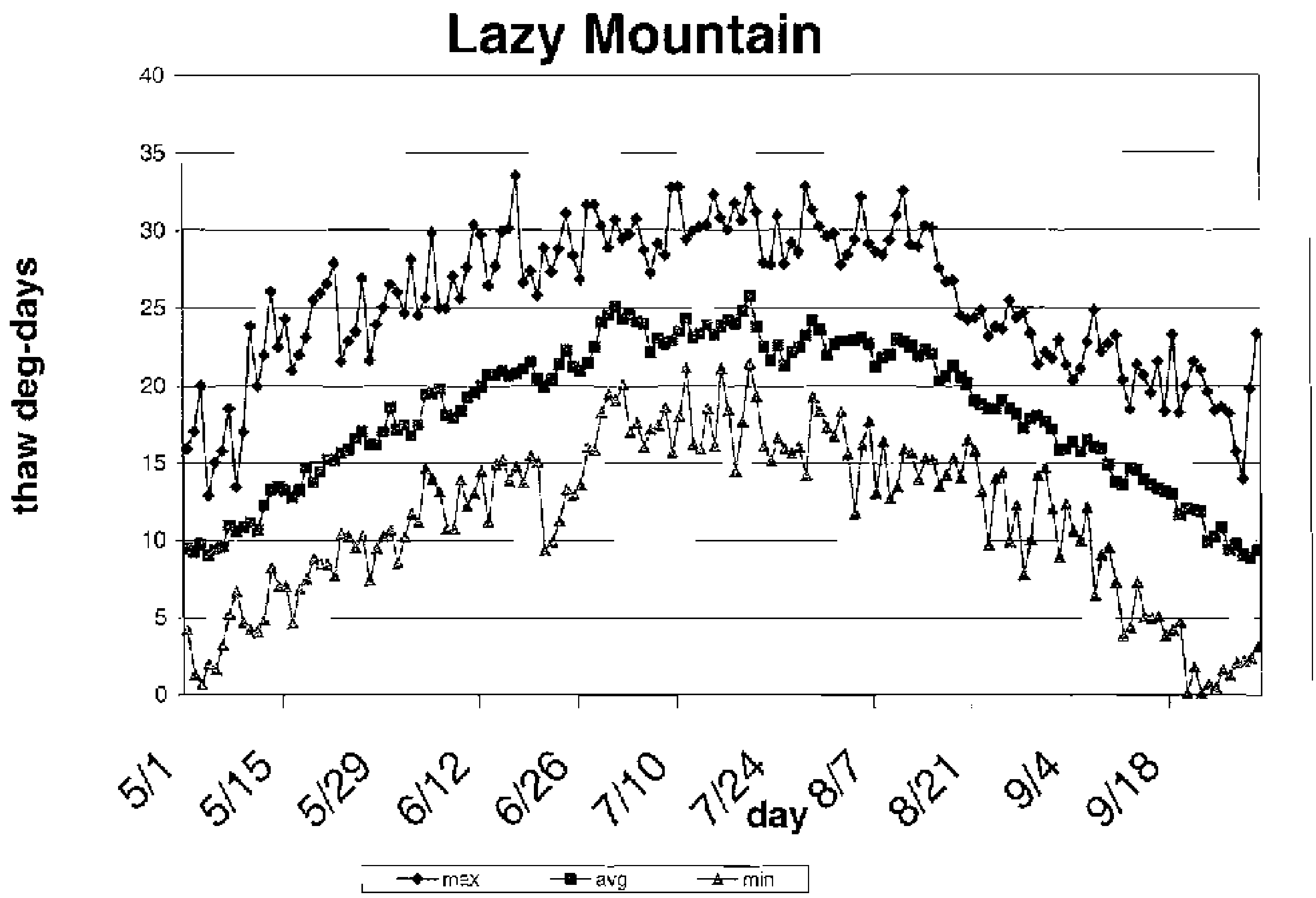
FL 790


Lazy Mountain May-Sep deg days
thaw deg days
3200
3100
3000
2900
2800
2700
2600
2500
1985
1990
1995
2000
2005
year
May-Sep deg days
trend r2=8% n=18

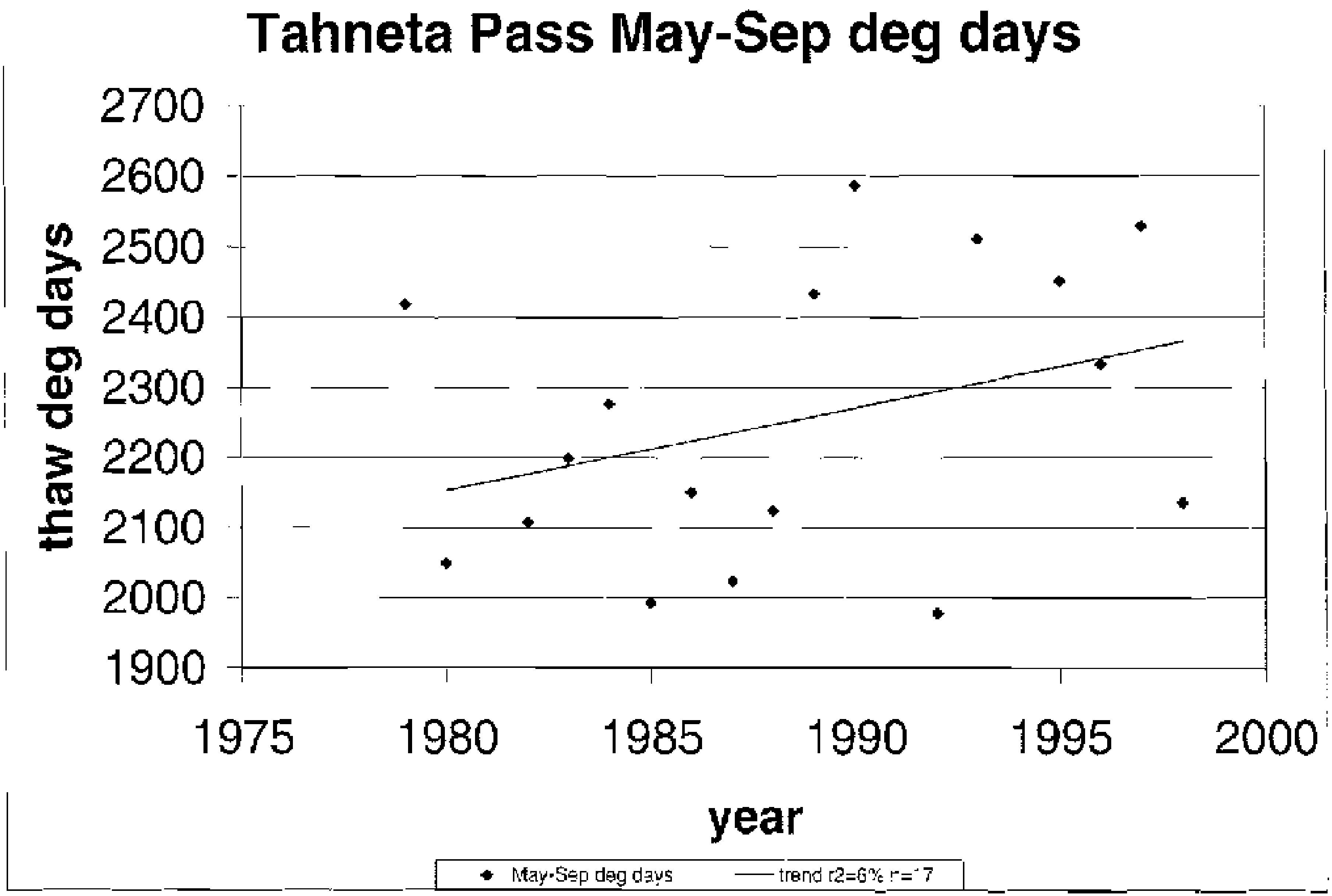
EC 790



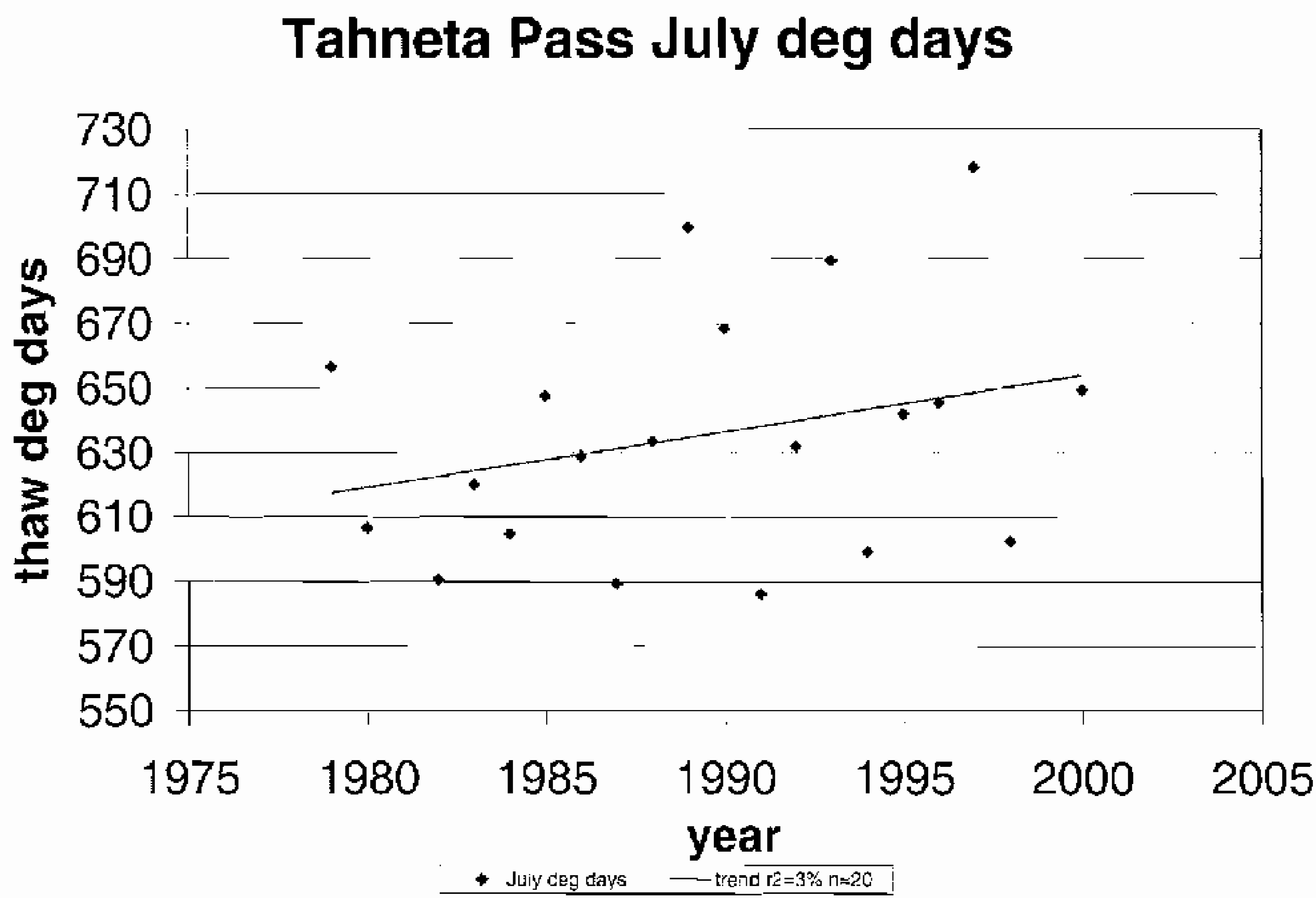
Lazy Mountain July deg days
thaw deg days
850
800
750
700
650
600
1985
1990
1995
2000
2005
July deg days
trend r2=2% n=19

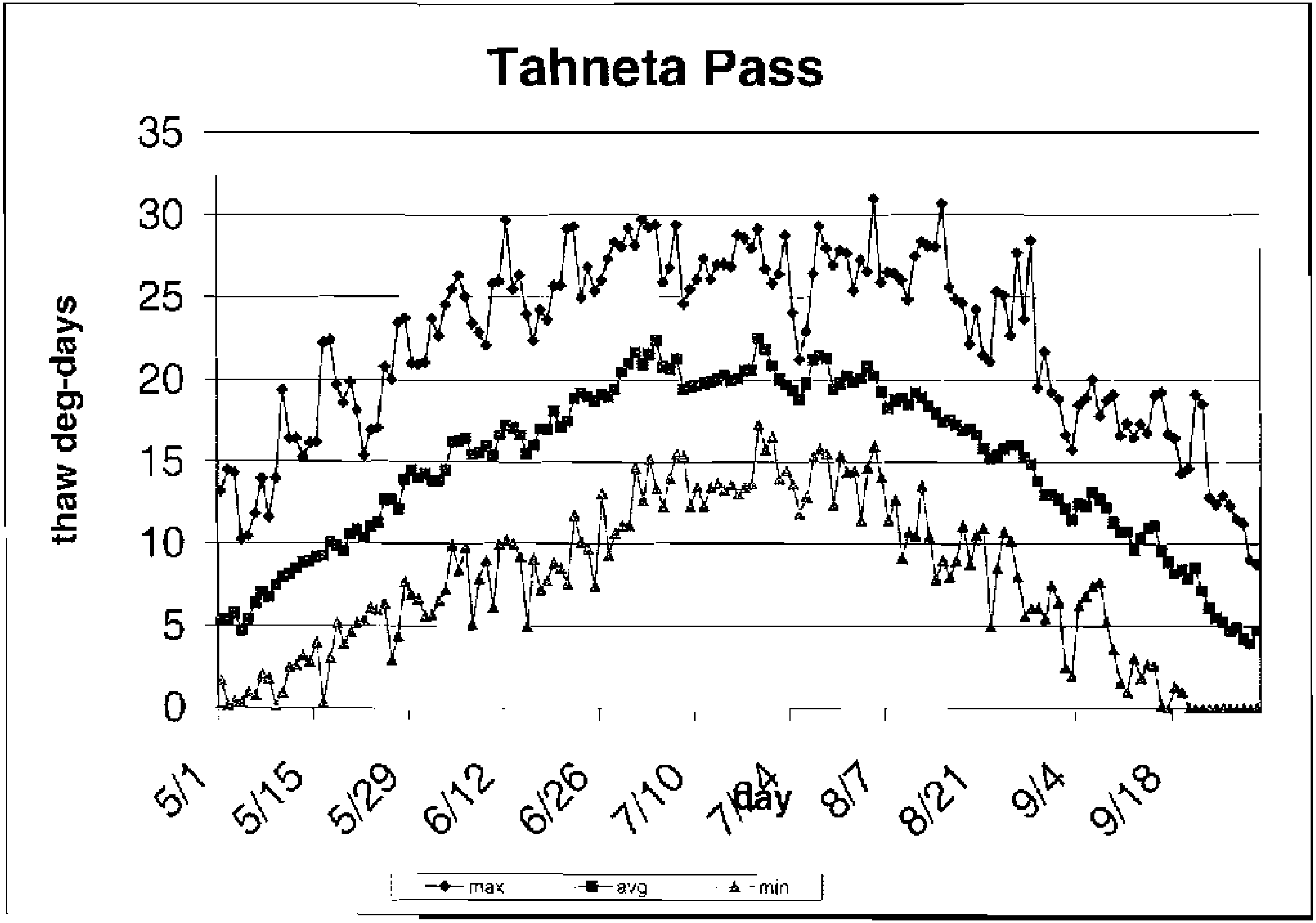

Lazy Mountain
thaw deg-days
0
5
10
15
20
25
30
35
40
5/1
5/15
5/29
6/12
6/26
7/10
7/24
8/7
8/21
9/4
9/18
day
max
avg
min

EL 2620



Tahneta Pass May-Sep deg days
thaw deg days
2700
2600
2500
2400
2300
2200
2100
2000
1900
1975
1980
1985
1990
1995
2000
year
May-Sep deg days
trend r2=6% r=17


Tahneta Pass July deg days
thaw deg days
730
710
690
670
650
630
610
590
570
550
1975
1980
1985
1990
1995
2000
2005
year
July deg days
trend r2=3% n=20


Tahneta Pass
thaw deg-days
35
30
25
20
15
10
5
0
5/1
5/15
5/29
6/12
6/26
7/10
7/24
8/7
8/21
9/4
9/18
day
max
avg
min

# APPENDIX C

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# APPENDIX E

*Hydraulic Analysis*

# MIKE-21 Model of the Matanuska River near Palmer, Alaska

## Technical Memorandum

8 September 2004

*Prepared for:*

**MWH Americas, Inc.**
Anchorage, Alaska

**United States Natural Resources Conservation Service**
Anchorage, Alaska

*Prepared by:*

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**nhc**

# MIKE-21 Model of the Matanuska River near Palmer, Alaska

## 1. Introduction

The objective of this numerical modeling study undertaken by Northwest Hydraulic Consultants (**nhc**) is to assess the feasibility and effectiveness of the proposed in-channel excavations as a means of controlling bank erosion hazards along the braided gravel-bed Matanuska River near Palmer, Alaska. The study reach of the river extends from Old Glenn Highway Bridge near Palmer to approximately 6 miles downstream of the bridge. An aerial photograph of the study reach is shown in Figure 1 and selected ground photographs are shown in Figures 2 and 3. The photographs show the multiple braided flow pattern and bank impingement and erosion that characterize this reach. The specific aim of this study was to estimate the effect of the channel excavations on flow pattern, hydraulic characteristics, and sediment transport in the study reach of the river during two flood events (2- and 10-year peak flows). The flood flow hydraulics was numerically simulated for both existing and project conditions using the Danish Hydraulic Institute (DHI) MIKE-21 2-dimensional (2-d) fixed bed computer model. The MIKE-21 model provides a well-tested tool for quantifying complex spatial flow hydraulics in braided channels characterized by irregular bed topography. Application of the MIKE-21 model provides a means to combine the computed hydrodynamic data with an understanding of geomorphic processes on the Matanuska River system to assess outcomes of gravel extraction alternatives. The MIKE-21 model also provides a means for quantifying the spatial distribution of depth and velocity for physical habitat analysis of existing and proposed gravel extraction alternatives.

Using the hydrodynamic solutions for the two flood events obtained from the MIKE-21 model, **nhc** calculated sediment transport capacities for each event for both existing and project conditions. The results of the sediment transport calculations were used to determine the relative difference in sediment transport capacities between the existing and project conditions, and to identify possible effect of the project excavations on sediment transport characteristics and patterns along the threatened banks of the river.

## 2. Description of Computer Model MIKE-21

MIKE-21 is an engineering software package containing a comprehensive modeling system for 2-d free-surface flows (DHI 2003). The model is applicable to the simulation of 2-d depth averaged hydrodynamic conditions in a wide range of environments including rivers, lakes, estuaries, bays, and coastal waters. MIKE-21 simulates unsteady depth-averaged 2-d flows in one-layer (vertically homogeneous) fluids. The computational procedure is based on the numerical approximation of the time-dependent non-linear equations of conservation of mass and momentum for 2-d free surface flow. The solution is obtained using an implicit finite difference scheme of second-order accuracy. The implicit scheme is used in such a way that numerical stability problems do not occur, provided that the input data are physically reasonable and that the time step used in the computations is limited only by accuracy requirements. The water surface elevation, velocity magnitude, and velocity direction are solved for on a rectangular grid covering the area of interest.

The main input parameters for the MIKE-21 model are channel surface topography (bathymetry), bed resistance, hydrographic boundary conditions (water levels or flow magnitude and flow direction), flow turbulence characteristic, and initial water surface elevation. The output parameters of a simulation include water depth and 2-d water flux components at each grid point in the computational domain for each time step. All output data can be post-processed, analyzed, and presented in various graphical formats. Discussed below are elements of the model setup. MIKE-21 manages the data and computations using metric units, so some of the graphic output from the model is presented in metric units in this report.

# 3. MIKE-21 Model Development

## 3.1. Surface Topography / Grid Geometry

A rectangular grid surface topography (bathymetry) of the Matanuska River near Palmer was developed using LiDAR mapping data collected by AeroMap U.S., Inc. on November 18, 2003. The LiDAR data were provided in feet in the NAD 27 Alaska State Plane (ASP) Zone 4 horizontal datum and Ellipsoid Heights vertical datum. Field surveys provided a correction for conversion of the LiDAR elevations to the NAVD 88 vertical datum. The MIKE-21 model required conversion of the site topography data to metric units for model grid development. The model grid cell size was set to 10 by 10 m (32.8 by 32.8 ft). This grid scale is sufficiently dense to describe the topographic features within the channel of the braided Matanuska River and at the same time provides manageable model run times. A graphical representation of the existing conditions grid geometry for the modeled reach of the river is shown in Figure 4. The model bathymetry occupies an area of 7,850 m (25,755 ft) by 11,800 m (38,714 ft). The horizontal and vertical coordinates of the lower left corner of the bathymetry area are 195,900 m (642,717 ft) and 836,900 m (2,745,735 ft), respectively. The location of the study area within the model computational domain is also shown in Figure 4. The model limits extend approximately 500 m (1,600 ft) upstream and 3,000 m (9,800 ft) downstream of the area of interest to eliminate any effects of the model boundaries on the solution in the study area.

The existing conditions geometry served as a base to create the project conditions grid geometry shown in Figure 5. The project conditions topography incorporates a pit trap and three trenches cut in the channel deposits as suggested in **nhc** (2004). The pit trap is located just downstream of Old Glenn Highway Bridge and is designed to intercept gravel inflow, while the trenches are intended to route flows into the pit trap and re-direct flows away from currently threatened banks. The pit trap in the model is approximated by a 350 by 350 m (1,150 by 1,150 ft) polygon with the excavation depth of 4.88 m (16 ft). The three trenches are 3 m (10 ft) deep and 150 m (500 ft) wide each, with the lengths of approximately 760 m (2,500 ft), 1,000 m (3,300 ft), and 1,980 m (6,500 ft), respectively. The location of the excavations was obtained from **nhc** (2004). Bed topography within the excavations was approximated by lowering grid cell elevations by the proposed excavation depths. The boundaries between the excavations and adjacent channel in the model were smoothed to obtain a more realistic transition of the bed surface topography and eliminate abrupt changes in flow conditions in the vicinity of the excavations (which is important for proper hydrodynamic modeling).

### 3.2. Boundary and Initial Conditions

MIKE-21 requires that water inflow/outflow and initial water surface elevations are specified within the computational domain. An isolated source term was specified at the upstream end of the model to simulate model inflows and sink terms at the downstream model extent to remove water mass from the model (see Figures 4 and 5). According to MWH (2004b), peak flows for the 2- and 10-year events in the study reach are 702 $m^3$/s (24,800 cfs) and 1,025 $m^3$/s (36,200 cfs), respectively. Since information on initial water surface elevations corresponding to the specified peak flows was originally unavailable, time-variant water inflows shown in Figure 6 were employed in the model for the simulation of the two flood events. For the simulation of the 2-year event, the initial water inflow and initial water depths were set to zero. The model was filled with water by gradually increasing inflow to 702 $m^3$/s (24,800 cfs), and the model was then run with the constant inflow during the next 12 hrs period to obtain steady flow conditions within the computational domain.

Hydrodynamic data simulated for the 2-year peak flow were then used as initial inflow and water surface conditions for subsequent simulation of the 10-year event. To obtain steady flow conditions corresponding to the 10-year peak flow, water inflow to the model was gradually increased from 702 $m^3$/s (24,800 cfs) to 1,025 $m^3$/s (36,200 cfs) and maintained constant during next 12 hrs.

### 3.3. Model Parameters

To perform hydrodynamic computations, MIKE-21 requires the user to specify certain parameters about the flow and physical characteristics of the stream channel. These parameters include a channel roughness factor (Manning's roughness coefficient), depth tolerances which turn computational grid cells on and off (flooding and drying depths), and a momentum diffusion coefficient (eddy viscosity). The modeler must also select the time step at which the model performs calculations over the computational domain, results output time step, and simulation time period.

Table 1 lists the model parameters used in this study to conduct the simulations of the two specified flood events. The channel roughness coefficient was adopted from Chow (1959) and was the same as that used in the HEC-RAS model developed by MWH Americas, Inc. Flooding and drying depths, as well as eddy viscosity were developed using procedures recommended by DHI. To maintain computational stability, the simulation time step was set using the computation cell size and the maximum velocity within the model domain. Model results were stored at 1 hrs increments and were compared with the previously stored time step to confirm numerical model convergence. The simulation period was set to assure convergence of the simulated hydrodynamic data with manageable model run times. Coriolis forcing, precipitation, evaporation, and wind were assumed to have negligible effect on the flow conditions in the relatively short study reach of the Matanuska River and therefore were not simulated.

Data extracted from the MIKE-21 model included water depths, flow velocities, flow direction, and water surface elevations. The computed data were post-processed using viewing tools of MIKE-ZERO (data editing system). Results of the hydrodynamic simulations are discussed below.

## 4. MIKE-21 Model Results

### 4.1. Existing Conditions Flood Simulations

Water depths in the study reach computed using the MIKE-21 model for the 2- and 10-year peak flows under existing conditions are shown in Figures 7 and 8, respectively. Velocities computed for the two flows are shown in Figures 9 and 10, respectively. Water surface elevations and velocity vectors computed for the 2- and 10-year events are shown in Figures 11 and 12, respectively. These figures indicate that flood flows through the study reach of the Matanuska River below the Old Glenn Highway Bridge have a complex, braided, and highly non-uniform pattern. The concentrated stream flow in the narrow, bedrock gorge at the bridge crossing has a depth of about 3-3.5 m (9.8-11.5 ft) and velocity of up to 5-5.5 m/s (16.4-18 ft/s) for the 2-year flow. For the 10-year flow, water depth in the gorge is within 3.5-4.5 m (11.5-14.8 ft) and velocity is up to 5.5-6 m/s (18-19.7 ft/s).

Downstream of the gorge, the stream flow spreads over the alluvial fan and forms two distinct wide paths flowing around a large mid-channel bar formed at the fan apex (see also Figure 1). The length of the bar is about 2,000 m (6,500 ft) and the width is about 600 m (2,000 ft). The bar is formed of sand and gravel deposits and represents a typical feature of a confined fan (**nhc** 2003). The bar deflects the stream flow towards each side of the channel thereby eroding its banks. Each flow path is composed of multiple, winding, narrow and relatively shallow sub-channels. Water depths west of the mid-channel bar range from a few centimeters up to 2-2.5 m (6.6-8.2 ft) for the both simulated flows. Water depths east of the bar are generally less than 1-1.5 m (3.3-4.9 ft). Flow velocities in this reach have a highly non-uniform spatial distribution and range from less than 0.5 m/s (1.6 ft/s) up to 2-3 m/s (6.6-9.8 ft/s). Higher velocities are mainly computed along the deeper sub-channels. Maximum flow velocities along the east bank are within 2-2.5 m/s (6.6-8.2 ft/s) for the both flood events. The model results indicate that average water surface slopes along the study reach range generally within 0.003-0.005 for both flow conditions.

Approximately 2,700 m (8,900 ft) downstream of the bridge, the two flow paths merge and form a single, more concentrated (but still braided) path flowing along the east bank of the river. For the simulated flows, local water depths in the middle and lower parts of the study reach are up to 2-3 m (6.6-9.8 ft) and flow velocities are up to 3-4 m/s (10-13 ft/s). Higher depths and velocities are computed in many locations along the east bank of the river where potentially significant bank and/or bed erosion can be expected under existing channel and flow conditions. The deepest flow and highest velocities are computed at spur dikes constructed in the vicinity of Circle View Estates, as well as at the locations where flow is directed against the river banks at steep angles and where bank irregularities (mainly bedrock) protrude far into the channel and confine the stream. The modeling results also indicate a shallow inundation (by 0.2-0.8 m, or 0.6-2.6 ft) of the low-elevation eastern floodplain areas along Old Glenn Highway in the vicinity of Bodenburg Butte. Existing dikes or berms whose characteristics were not measured in the LiDAR survey may preclude inundation of this small area. Flow into and out of this relatively small area is of low depth and relatively low velocity and does not affect the hydrodynamic characteristics of the primary Matanuska River braided channel system.

## 4.2. Project Conditions Flood Simulations

Project conditions water depths simulated for the 2- and 10-year peak flows are shown in Figures 13 and 14, respectively. Flow velocities computed for the two flows under project conditions are shown in Figures 15 and 16, respectively. Project conditions water surface elevations and velocity vectors simulated for the 2- and 10-year events are shown in Figures 17 and 18, respectively. It is seen from these figures that the proposed excavations effectively intercept the stream flow exiting the gorge and re-direct it downstream of the excavations. The greatest water depths are associated with the excavations, particularly with their downstream ponded portions. Maximum computed depths in the excavations during the simulated floods are within 5-7 m (16-23 ft). Flow velocities in the excavations range from less than 0.5 m/s (1.6 ft/s) in the downstream ponded portions up to 5-6 m/s (16-20 ft/s) for the 2-year event and up to 6-7 m/s (20-23 ft/s) for the 10-year event in the upstream water spill reaches.

The modeling results indicate that the project conditions water depths to the west of the mid-channel bar and along the east bank of the river immediately downstream of the bridge generally reduce to less than 1-1.5 m (3.3-4.9 ft) and flow velocities reduce to less than 1-1.5 m/s (3.3-4.9 ft/s) for the both simulated flood events. At the same time, significantly increased flows through the excavations located immediately downstream of the bridge results in increased stream depths and velocities adjacent to the 2,000 m (6,600 ft) long section of the east bank downstream of the pit trap. For the 2-year flood event, water depths in this reach increase under the project conditions up to 1.5-2 m (4.9-6.6 ft) and flow velocity up to 2.5-3 m/s (8.2-9.8 ft/s). For the 10-year event, depths increase up to 2-2.5 m (6.6-8.2 ft) and velocities increase up to 3-3.5 m/s (9.8-11.5 ft/s).

No significant changes in hydraulic conditions are simulated for project conditions along the approximately 1,300 m (4,300 ft) long section of the east bank downstream of the mid-channel bar. Further downstream, however, the excavations located in the vicinity of Bodenburg Butte and Circle View Estates intercept a significant portion of the flow and result in a noticeable reduction of flow depths and velocities along the eroded east bank. During the simulated events, water depths along the east bank in the vicinity of the two downstream excavations are reduced for project conditions to generally less than 1.5-2 m (4.9-6.6 ft) and flow velocities reduce to less than 2-2.5 m/s (6.6-8.2 ft/s).

### 4.3. Comparison of Existing Condition and Project Conditions Flood Events

Differences between the project and existing conditions water depths in the study reach computed for the 2- and 10-year peak flows are shown in Figures 19 and 20, respectively. Changes in flow velocities due to effect of the project excavations are shown for the 2- and 10-year events in Figures 21 and 22, respectively. In these figures, water depths/velocities computed for the existing conditions were subtracted from those computed for the project conditions. Blue colors indicate an increase of water depth or velocity while brown colors indicate a reduction of water depth or velocity caused by the proposed excavations. These figures indicate that stream flow to the west of the mid-channel bar at the fan apex is effectively reduced by the trench and the pit trap located immediately downstream of the bridge. For the simulated flows, water depths to the west of the bar are reduced under the project conditions by up to 1-1.5 m (3.3-4.9 ft) and flow velocities reduce by up to 1.5-2 m/s (4.9-6.6 ft/s). Also reduced under the project conditions are depths and velocities along the east bank immediately downstream of the bridge. The depth reduction at this location is approximately 0.5-1 m (1.6-3.3 ft). Flow velocities at the east bank immediately downstream of the bridge reduce by up to 1-2 m/s (3.3-6.6 ft/s) for the both events. At the same time, due to the conveyance of significant portions of floodwaters through the excavations, depths in the 2,000 m (6,600 ft) long reach immediately downstream of the pit trap increase by up to 0.5-1 m (1.6-3.3 ft) and flow velocities increase by up to 1-2 m/s (3.3-6.6 ft/s). This significant increase of flow along the east bank immediately downstream of the pit trap might have negative impact on the bank erosion in this reach. Therefore, a modified orientation of the upper excavations or additional trench cuts downstream of the pit trap should probably be considered in the final design to divert concentrated flows away from the east bank in the middle part of the study reach.

The hydrodynamic effects of the pit trap located downstream of the bridge become negligible downstream of the mid channel bar and upstream of the middle excavation trench. Thus, the upper pit trap excavation and lower reach excavation trenches can be viewed as independent project alternatives, as the flow effects of the upper pit trap are nullified at the location where the flow enters the lower reach excavation trenches. In the vicinity of the two excavations located in the lower part of the study reach, water depths during the simulated flood events are reduced by up to 1-1.7 m (3.3-5.6 ft) and flow velocities along the east bank are reduced by up to 1.5-2.5 m/s (4.9-8.2 ft/s). The lower reach excavation trenches effectively reduce flow depth and velocity in the vicinity of the existing locations of bank erosion near the Circle View Estates. These excavation trenches do not "steer" the flow toward banks downstream of the trenches as is computed for the modeled conditions of the upper reach pit trap.

## 5. Sediment Transport Capacity

The hydraulic data computed by the MIKE-21 models were used in the analysis of sediment transport characteristics in the study reach of the Matanuska River. The objective of this analysis was to estimate sediment transport capacity in the study area for the two specified flood events under the existing and proposed project conditions, determine the relative difference in sediment transport capacities between the existing and project conditions, and to identify potential effects of the project excavations on sediment transport characteristics and patterns along the eroded east bank of the river. Details and results of the sediment transport capacity assessment are provided in the following sections.

### 5.1. Sediment Assessment Approach

The hydrodynamic results of the MIKE-21 model consist of matrixes of flow depths and two components (in eastern and northern directions) of water flux. These output data were used to calculate various hydraulic variables (flow velocity, shear velocity, shear stress) at grid cell centers. Since in MIKE-21 computed flow depths are cell centered and water fluxes are computed at cell faces, all variables were interpolated to cell centers for use in the sediment transport capacity calculations. The calculated hydraulic variables were then used to calculate sediment flux for each cell of the bathymetry grid.

The sediment transport calculations were performed using the Ackers and White (1973) transport function as modified by Ackers (1993). This transport function predicts total bed material sediment transport load, which includes bed material sediment transported both in suspension and as bed load. The function is based on a large set of experimental data and is often used for calculation of sand and gravel transport.

A single sediment size of 12 mm, corresponding to the mean grain size of the bulk bed material in the study area (MWH 2004a), was used in the calculations. Although this approach does not account for possible sediment sorting effects, given the near-to-equal transport mobility of sediment mixtures observed in many natural fluvial systems (e.g. Parker et al., 1982; Andrews, 1983) the use of single grain size transport capacity procedures provides reasonable accuracy for the present generalized sedimentation assessment.

A computer program was written by **nhc** in FORTRAN to perform the sediment flux computations. The program reads hydrodynamic data from the MIKE-21 output file, computes hydraulic parameters, performs sediment transport computations, and creates an output file containing matrixes of sediment flux, velocity, and shear stress data for each grid cell. The format of the output file is arranged so that computed data can be viewed using MIKE-ZERO data viewing tools.

The sediment modeling approach used in this study does not couple the hydrodynamics with the sediment transport computations. In the present sediment model bed topography is fixed, water flow is steady, sediment is not routed between cells, and it is assumed that there is unlimited sediment supply to each cell. Therefore, the computed sediment fluxes represent capacity of the water flow to transport sediment, and not the actual sediment transport during a given hydrologic event. Results from the sediment transport computations presented in this technical memorandum can only be used to identify potential areas of erosion or deposition and provides an indication of the initial rate at which sediment transport will take place.

Sediment transport simulations were conducted for each of the two specified peak flows for both the existing and project conditions. Results of the sediment simulations are discussed below.

## 5.2. Existing Conditions Sediment Transport Capacities

Existing conditions sediment fluxes computed for the 2- and 10-year flows are shown in Figures 23 and 24, respectively. Sediment transport generally follows water flow patterns and occurs over large expanses (particularly in the upper portion of the study area) of the alluvial fan surface. The highest sediment transport capacities are calculated at the fan apex where stream flow is confined in the bedrock gorge and is characterized by extremely high depths and velocities. The flow downstream of the gorge spreads over the alluvial fan, which results in the reduction of the flow's sediment transport capacity. Sediment deposition can be expected in this area, and in fact occurs due to the presence of the confined alluvial fan in this reach. Sediments are transported further downstream around the mid-channel bar, although at an appreciably lower rate than at the gorge outlet. Downstream of the bar the floodwaters merge into a single stream, which results in more concentrated flows and higher sediment transport capacities in the middle and lower parts of the study area. Local increases of sediment flux are calculated for the fan reaches characterized by more concentrated flows and higher velocities compared to the adjacent areas characterized by shallower and lower velocity flows. These reaches of high sediment transport capacity include (in addition to the bedrock gorge): about 3,000 m (9,800 ft) long straight reach flowing in a southerly direction along the east bank parallel to Old Glenn Highway in the middle portion of the study area; approximately 700 m (2,300 ft) long reach in the vicinity of Bodenburg Butte where rock formations protrude into the river channel; about 1,000 m (3,300 ft) long reach near Circle View Estates where flow is forced against the east bank protected with spur dikes; and a river reach in the vicinity of bedrock outcrops to the west of Circle View Estates. In all these reaches with locally high sediment transport capacities and erodible bank materials, potentially significant bank and/or bed erosion can be expected [and were observed, see **nhc** (2004)] under existing channel and flow conditions.

Sediment fluxes computed for the two specified flood events in the confined gorge reach of the river are compared with measured sediment data in Figure 25. The sediment data plotted in this figure represents bed material load (sand, gravel, and cobbles). Wash load (silt and clay) does not contribute significantly to channel formation processes and is not considered in this analysis. The measured data shown in Figure 25 were collected by the U.S. Geological Survey (USGS) at Gage 15284000 (Matanuska River at Palmer) between 1953-2003. The considerable scatter of the measured data evident in Figure 25 is typical of natural rivers and reflects the natural variability in fluvial sediment transport processes. The majority of the sediment sampling occurred at flows below 22,000 cfs (600 $m^3/s$). A single measurement of suspended load was conducted at a higher flow of 33,400 cfs (946 $m^3/s$). Most of the measured data (56 data points) represent suspended bed material load only. Limited amount of data (13 data points) are available for total bed material load (suspended bed material load + bed load). However, according to the **nhc** (2004) estimates, the majority (more than 90%) of the total bed material load in the Matanuska River is transported in suspension, which allows the use of the suspended sediment data for verification of the computed results (representing total bed material load). Although no sediment data were measured at the two simulated flows, it is seen that the computed results from the MIKE-21 analysis follow general trends in the measured discharge-bed material load data and agree closely to the sediment rating curve fitted by **nhc** (2004) to the measured suspended bed material data. This provides assurance of the reasonableness and overall correctness of the computational sediment assessment approach and numerical modeling results obtained in this study.

## 5.3. Project Conditions Sediment Transport Capacities

Sediment fluxes calculated for the 2- and 10-year flows under the project conditions are shown in Figures 26 and 27, respectively. Changes in flow pattern due to the project excavations are reflected in the sediment transport pattern in the study area. Under the project conditions, flows are concentrated through and between the proposed trench cuts, which results in an increase of sediment transport activity upstream, along, and downstream of the trenches.

The highest sediment transport capacities are calculated for flows exiting the narrow gorge at the fan apex, as well as immediately upstream of the trenches where water spills into the excavations. Significant headcut erosion can be expected upstream of the project excavations. High sediment fluxes are also predicted for upper portions of the trenches and along the east bank where the flow is directed by the excavations located at the gorge outlet.

Practically no sediment transport is predicted to the west of the mid-channel bar under the project conditions. No sediment transport (i.e. depositional condition) is predicted for the pit trap and downstream, ponded portions of the two trenches located in the Bodenburg Butte and Circle View Estates reaches.

## 5.4. Comparison of Existing Conditions and Project Conditions Sediment Transport Capacities

Changes in sediment fluxes (sediment transport capacities) in the study reach of the Matanuska River due to the project excavations are shown for the 2- and 10-year flood events in Figures 28 and 29, respectively. These figures show the ratio of the sediment fluxes calculated for the project conditions to those calculated for the existing conditions. Blue colors indicate an increase of sediment transport capacity while brown colors indicate a reduction of sediment transport capacity under the project conditions relative to the existing conditions.

Under the project conditions, significantly reduced flows are predicted to the west of the mid-channel bar formed at the fan apex. Therefore, the project results in a reduction of sediment transport capacities in this area. Reduced flows, and therefore sediment transport, are also calculated along the east bank immediately downstream of the gorge. Most of the floodwaters exiting the gorge are intercepted by and conveyed through the trench and the pit trap in the southeastern direction, which increases flow and thereby sediment transport activity along the east bank downstream of the pit trap. A few-fold increase in sediment transport capacity is predicted for this area under the project conditions relative to the existing conditions. A slight increase of sediment transport is predicted along the east bank between the downstream extend of the mid-channel bar and the next trench cut due to the more concentrated flow here under the project conditions. On the contrary, significant reduction of sediment transport capacity is predicted along the east bank in the vicinity of the two downstream excavations conveying most of the floodwaters.

Figures 28 and 29 also indicate a significant increase of the sediment transport capacity at the locations where water spills into the project excavations (headcut zones) and reduction of sediment fluxes in the downstream, ponded portions of the excavations (depositional zones). The likely bed response is channel bed erosion and deposition at these two locations, respectively. The extent of the headcut zone for the uppermost trench, however, will be limited by the bedrock control in the gorge at the fan apex. Due to the deposition of the sediment load at the downstream end of the excavations, “sediment-hungry” waters exiting the excavations can be expected to erode the channel bed downstream of the excavations. Initial bed erosion upstream and downstream of the excavations will result in the armoring of the sand/gravel/cobble bed material with coarser particles, which will likely limit the vertical and spatial extent of the bed erosion in the vicinity of the excavations. **nhc** observed the maximum depth of abandoned primary flow channels to be on the order of 3 m (10 ft) with a surface layer of coarse gravel and cobbles during field reconnaissance activities completed in June 2004, indicating the effects of these channel armoring processes.

Shvidchenko and Kopaliani (1997) conducted field and laboratory studies of the effect of in-channel excavations on hydraulics and channel morphology of a large braided gravel-bed river similar to the Matanuska River. They found that 1,000-2,000 m (3,300-6,600 ft) long, 80-300 m (260-980 ft) wide, and 4 m (13 ft) deep excavations caused channel incision to a depth of up to about 2-3 m (7-10 ft) for a distance of around 1,000-2,000 m (3,300-6,600 ft) upstream and downstream of the excavations. The results presented by Shvidchenko and Kopaliani (1997) provide a preliminary and approximate estimate of the vertical and spatial extend of the channel scour in the vicinity of the proposed excavations in the Matanuska River.

## 6. Filling of Project Excavations

The volume of the proposed pit trap is 600,000 cubic yards, which is equivalent to the removal mass of roughly 900,000 tons of the bed material. The three proposed trenches have a total excavated volume of 2,200,000 cubic yards, or 3,300,000 tons. Thus, the total excavated volume would be 2,800,000 cubic yards, or about 4,200,000 tons. According to the modeling results, the excavations will intercept the majority of the floodwaters and, thus, will accumulate the majority of the bed material load transported by the river. The uppermost trench and the pit trap will be filled with sediment incoming from the gorge, while the two lowermost trenches will be filled with bed material derived from the middle part (undisturbed by the excavations) of the study area.

Due to the significant depth and longitudinal dimensions of the excavations, flows in the upper portions of the trenches are capable of transporting large amounts of sediment (see Figures 26 and 27). Coarser bed material (gravel and cobbles) will be actively transported as bed load through the upper portion of the trenches and then will form a deposition wedge gradually propagating along the excavations in the downstream direction and also building-up in the upstream direction. Finer suspended bed material load (primarily sand) will deposit below the coarse sediment front and in the ponded, downstream portions of the excavations. The filling of the excavations will be accompanied by the initial channel bed erosion immediately upstream and downstream of the excavations. In addition, flows through the initially straight excavations might erode their banks (especially during flood events when velocities are high) and eventually develop irregular excavated channel patterns with flow paths deviating from the constructed alignments.

According to the **nhc** (2004) estimates based on the measured sediment data, the average annual suspended bed material load in the Matanuska River at Palmer is approximately 1,630,000 tons and the average annual bed load is approximately 420,000 tons. This amounts to 2,050,000 tons of the average annual total bed material load in the study reach of the river. The total volume of the proposed excavations is approximately twice the average annual volume of the bed material transported. Assuming that sediment supply to the excavations will correspond to the maximum transporting capacity of the flow and that the excavations will intercept the majority of the total bed material load, the excavations would likely be completely filled and bed levels in the study reach restored in a few (i.e. 2-5) years, assuming stationarity in the hydrologic characteristics of the watershed. Thus, regular annual monitoring and maintenance of both the pit trap and trench channels would be necessary to ensure their long-term effectiveness and desired alignment.

## 7. Modeling Summary and Recommendations

The Matanuska River near Palmer is a wide, braided channel system characterized by highly non-uniform and complex flood flow patterns. Under the existing conditions, floodwaters exiting the narrow gorge are approximately evenly split into two general paths flowing around the mid-channel bar formed at the fan apex and then merge into a single, more concentrated stream flowing along and eroding the east bank. The proposed excavations effectively intercept and re-direct the floodwaters, which significantly alters flood flow dynamics and sediment transport patterns in the study area. Under the project conditions, the flow split at the fan apex is effectively reduced and the majority of the floodwater is directed from the gorge through the trench and the pit trap southeasterly towards the east bank, then in the southern direction along the east bank, and further downstream southwesterly through the remaining two excavations. The inundated area is significantly reduced under the project conditions, especially in the upper portion of the study reach, which reduces hydraulic stresses on the channel banks immediately downstream of the gorge. At the same time, the concentration of the flow under the project conditions in a single stream increases water depth, flow velocity, and sediment transport capacity along approximately a 2,000 m (6,600 ft) long section of the east bank immediately downstream of the pit trap. The concentration of flow would likely result in increased bank erosion in this reach, should the pit trap configuration of the project be implemented. Further downstream, in the Bodenburg Butte and Circle View Estates reaches, water depth, flow velocity, and sediment transport capacity along the east bank are reduced under the project conditions due to the concentration of the flows along the two downstream trenches.

Key findings from this hydrodynamic and sedimentation analysis of the Matanuska River are summarized below:

- Excavations significantly alter the flow patterns, and provide a means for reducing near bank velocity, depth, and sediment transport.

- The modeling results indicate that headcut bed erosion can be expected immediately upstream of the excavations and sediment deposition can be expected in the downstream, ponded portions of the excavations.

- Flows exiting the excavations at their downstream limit will likely erode channel bed downstream of the excavations. Armoring of the graded bed material with coarser particles will likely limit vertical and spatial extent of the bed erosion in the vicinity of the excavations.

- Excavations can reduce flow velocity, depth, and sediment transport capacity in the reach immediately adjacent to trenches, and can aid in reducing the propensity for bank erosion in these reaches.

- Excavations can increase flow depth and velocity downstream of the trench, as shown for the upper pit trap alternative, by capturing and focusing the flow downstream of the trench. This would likely result in an increase of bank erosion potential at this location, while simultaneously decreasing bank erosion potential immediately adjacent to the pit trap. Therefore, a modified orientation of the upper excavations or additional trench cuts in the middle part of the study area may be beneficial. These modifications should be developed prior to final design to incorporate the current braid patterns and river conditions.

- The Matanuska River can experience significant shifts in channel pattern in an individual high flow freshet season. Updated LiDAR surveys and hydraulic modeling are required to assess project alternatives prior to development of final grading plans and implementation of any gravel extraction alternative.

- Flows through the initially straight excavations will likely erode their banks and eventually develop irregular excavated channel patterns with flow paths deviating from the constructed alignment.

- Due to high sediment loads in the river, the extracted volumes will be replaced with the transported sediment in a few (i.e. 2-5) years. Therefore, regular monitoring and maintenance of the excavations are necessary to ensure their long-term effectiveness and desired performance.

An adaptive management approach for implementing and maintaining the gravel extraction trenches is highly recommended. Channel bed response in braided river systems is very unpredictable, and a high degree of uncertainty in predicted bed change and channel response exists. After implementation of a gravel extraction trench, observation of the locations and magnitude of channel bed deposition or erosion after a freshet season provide a means to assess project performance. This empirical observation of bed change should be combined with updated hydraulic modeling to develop a revised excavation plan that reduces the adverse effects of channel deposition and avulsion and reduces near bank velocity and depth. In summary, in spite of the dynamic characteristics of the Matanuska River, the gravel extraction excavations can reduce bank erosion but will not eliminate the need for bank erosion protection of key facilities, properties, and locations of direct flow impingement on bank locations.

## 8. References


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**Table 1. MIKE-21 model parameters.**

| Parameter | MIKE-21 model | |
|---|---|---|
| | 2-year flow | 10-year flow |
| Model grid | 10 by 10 m | 10 by 10 m |
| Initial water surface elevation | Dry bed | From 2-year flow run |
| Water inflow (initial and final) | 0-702 $m^3/s$ | 702-1025 $m^3/s$ |
| Manning's roughness coefficient | 0.035 | 0.035 |
| Flooding depth | 0.02 m | 0.02 m |
| Drying depth | 0.01 m | 0.01 m |
| Eddy viscosity (constant, flux based) | 2 $m^2/s$ | 2 $m^2/s$ |
| Simulation time step | 1 s | 1 s |
| Results output time step | 1 hr | 1 hr |
| Simulation period (total/constant inflow) | 27/12 hrs | 19/12 hrs |
| Coriolis forcing | not simulated | not simulated |
| Precipitation | not simulated | not simulated |
| Evaporation | not simulated | not simulated |
| Wind | not simulated | not simulated |

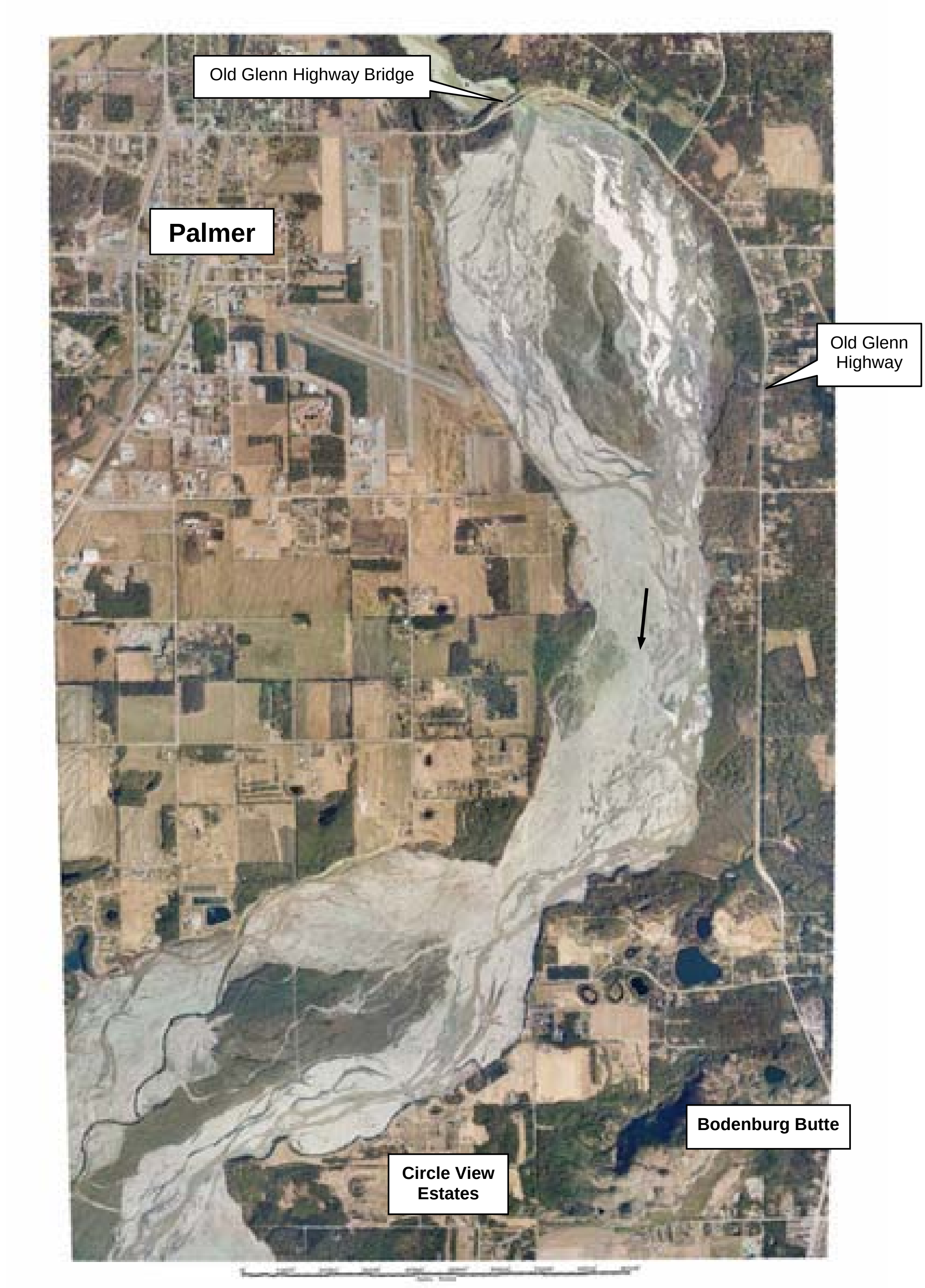



**Figure 1. Study reach of the Matanuska River near Palmer. Photo of May 9, 2000.**

**Figure 2. Matanuska River near Circle View Estates. View upstream. Photo of July 15, 2004.**

**Figure 3. Eroded bank of Matanuska River near Circle View Estates. View downstream. Photo of July 15, 2004.**

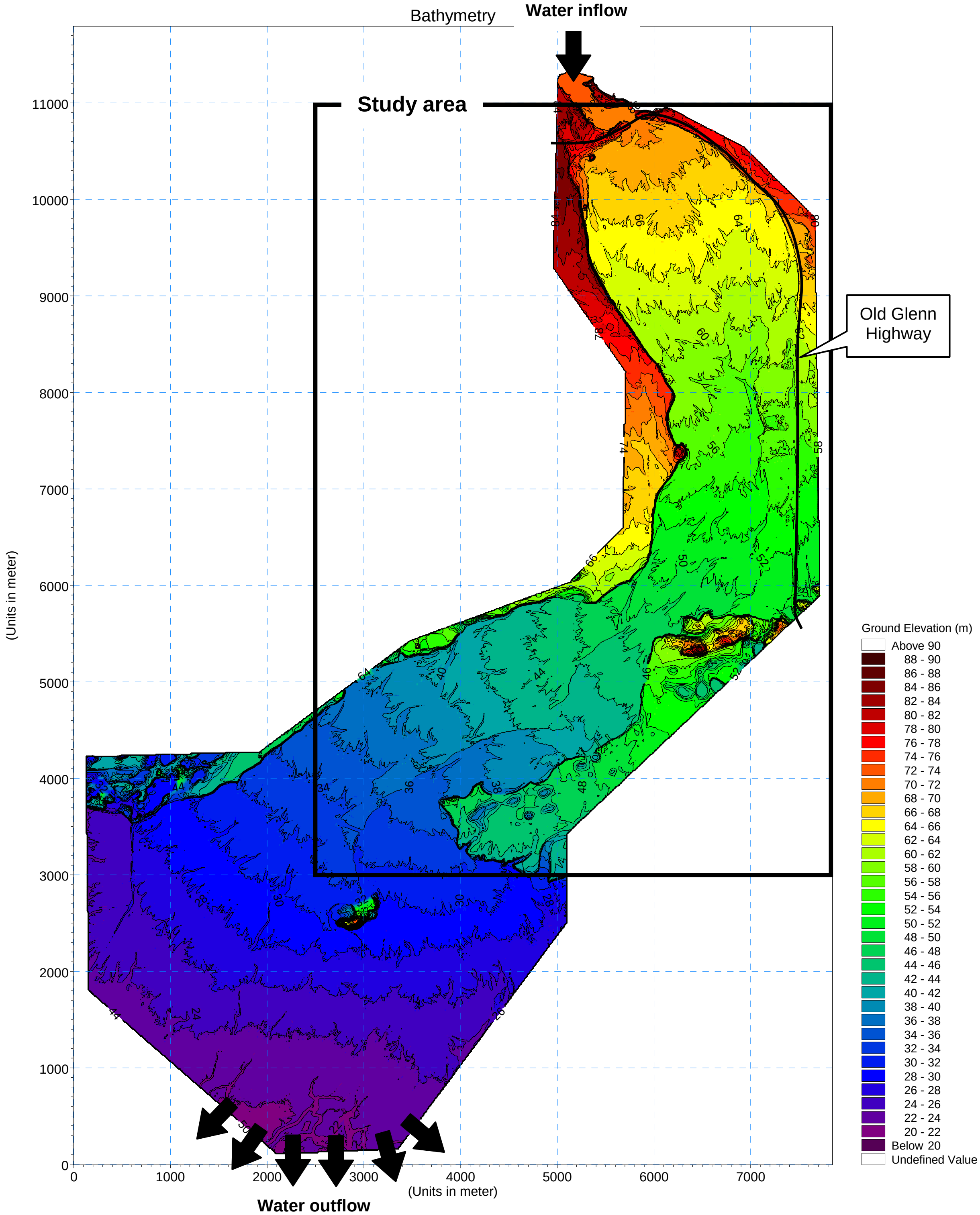



**Figure 4. Existing conditions model geometry.**

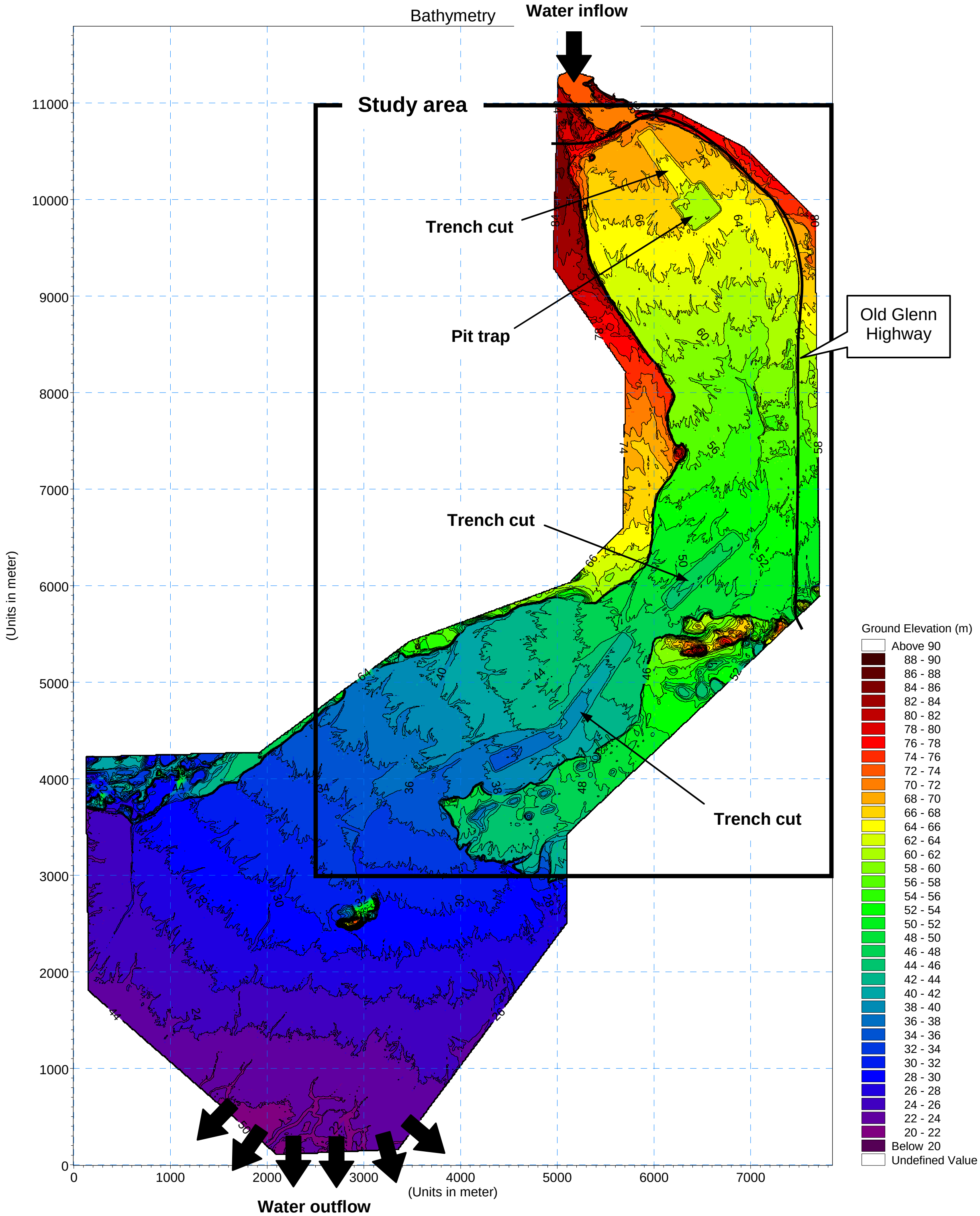



**Figure 5. Project conditions model geometry.**

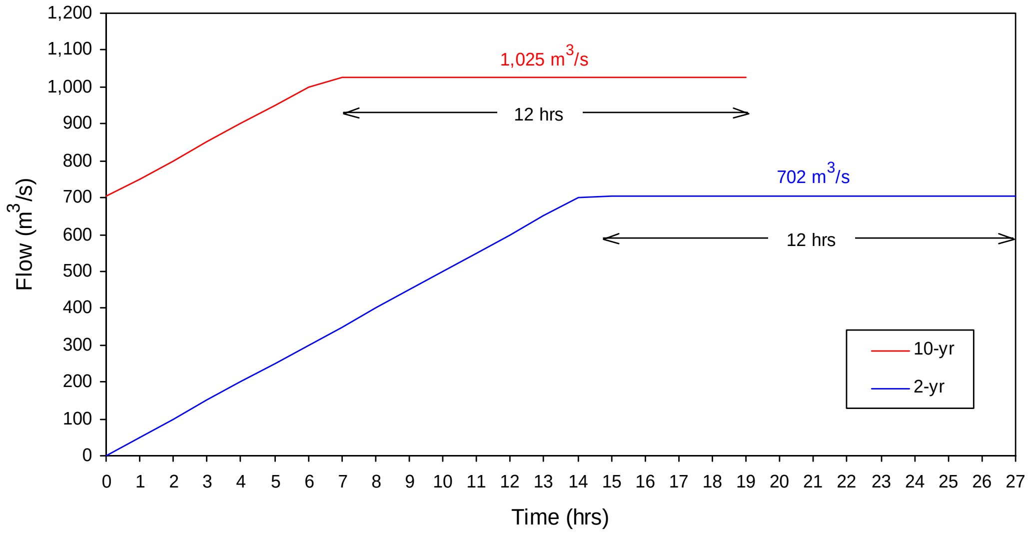



**Figure 6. Inflow hydrographs.**

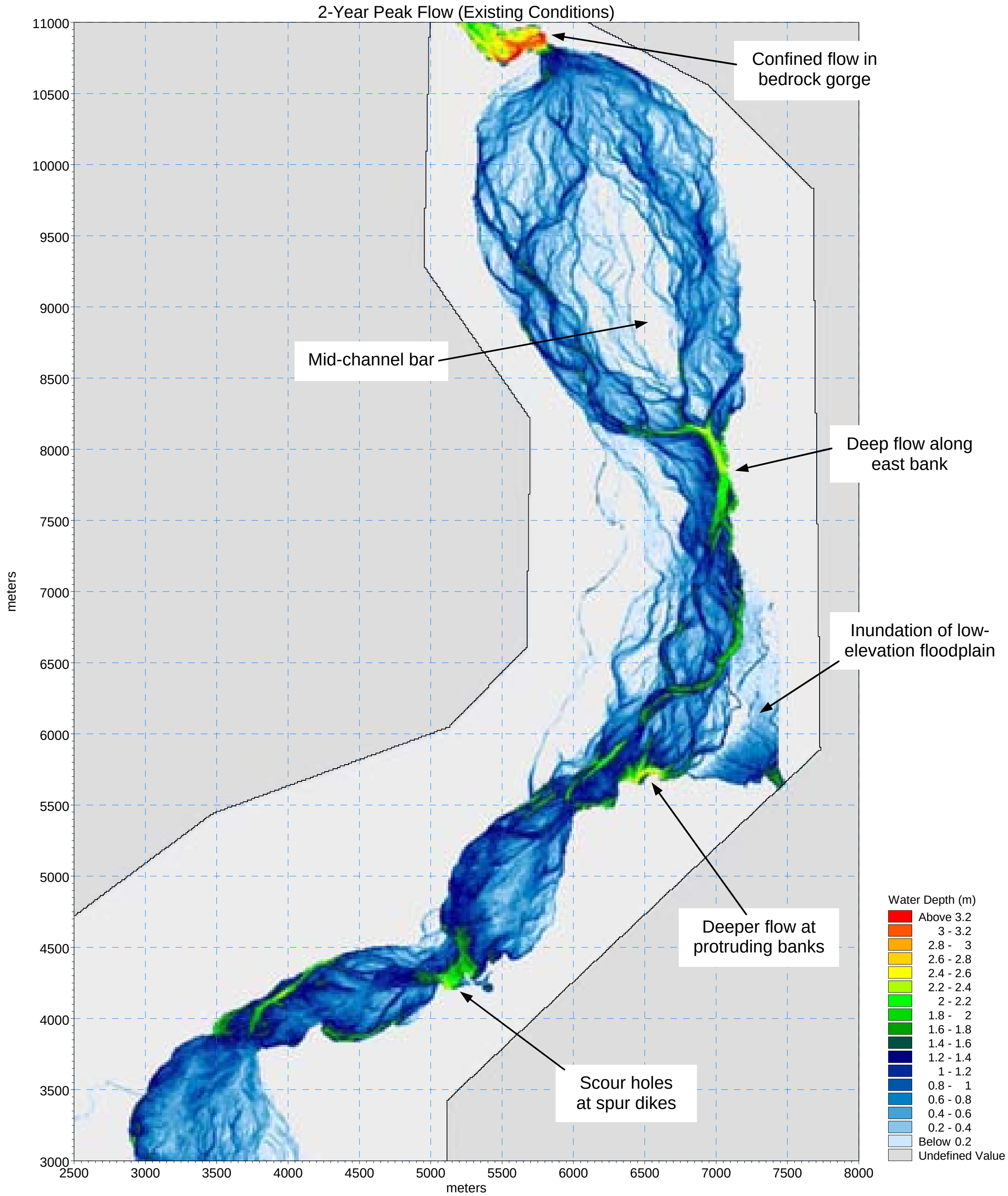



**Figure 7. Water depths simulated for 2-year peak flow under existing conditions.**

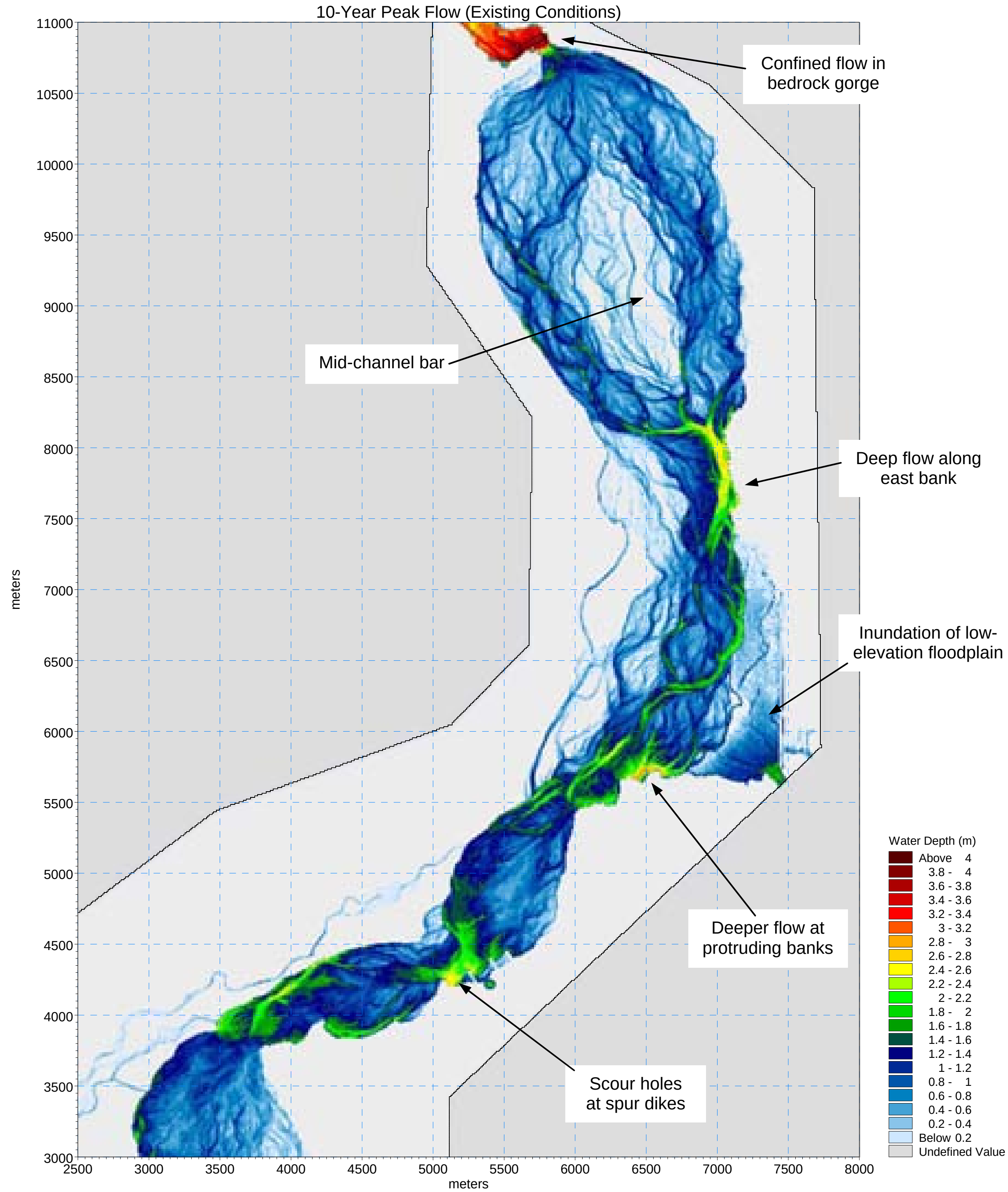



**Figure 8. Water depths simulated for 10-year peak flow under existing conditions.**

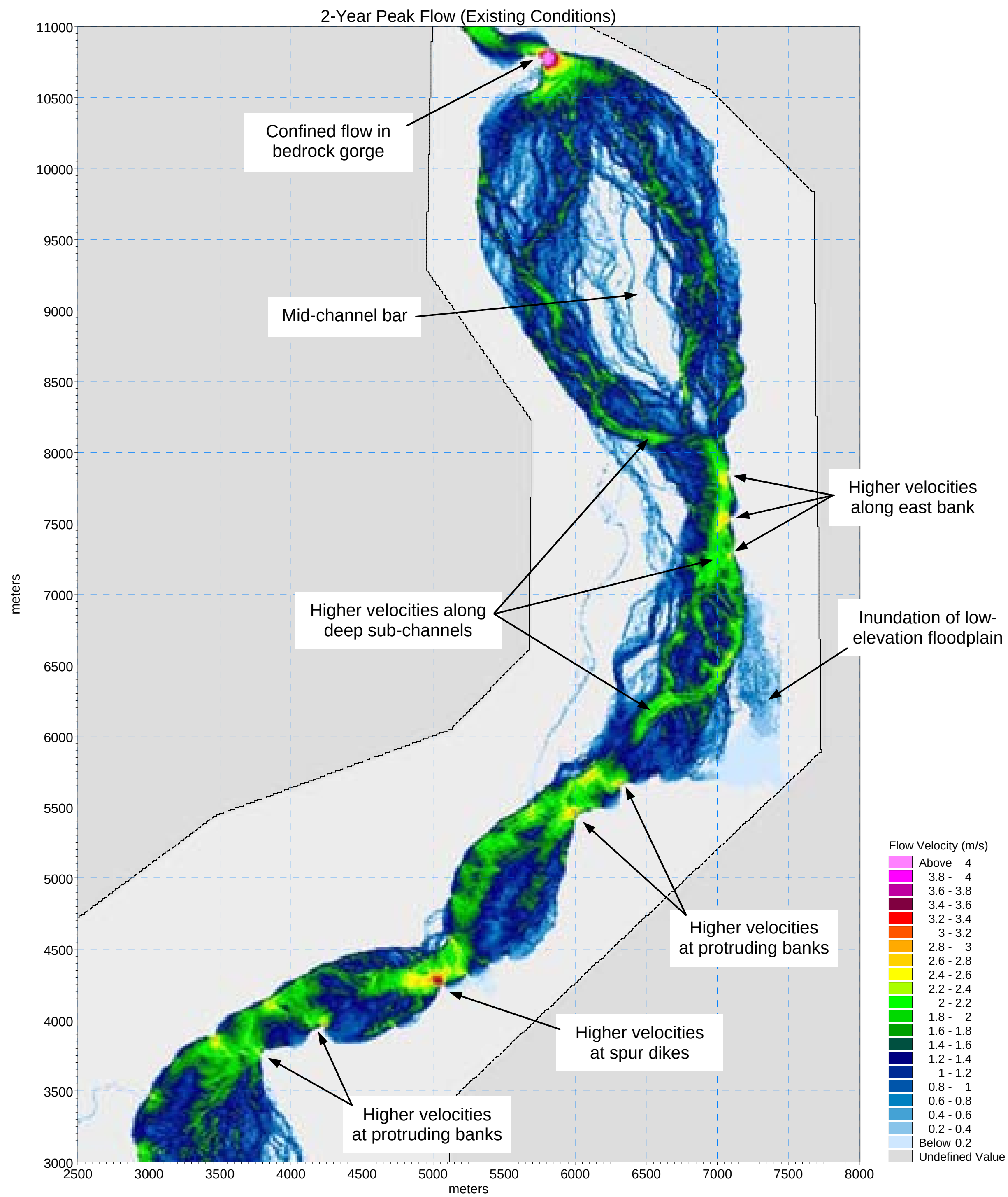



**Figure 9. Flow velocities simulated for 2-year peak flow under existing conditions.**

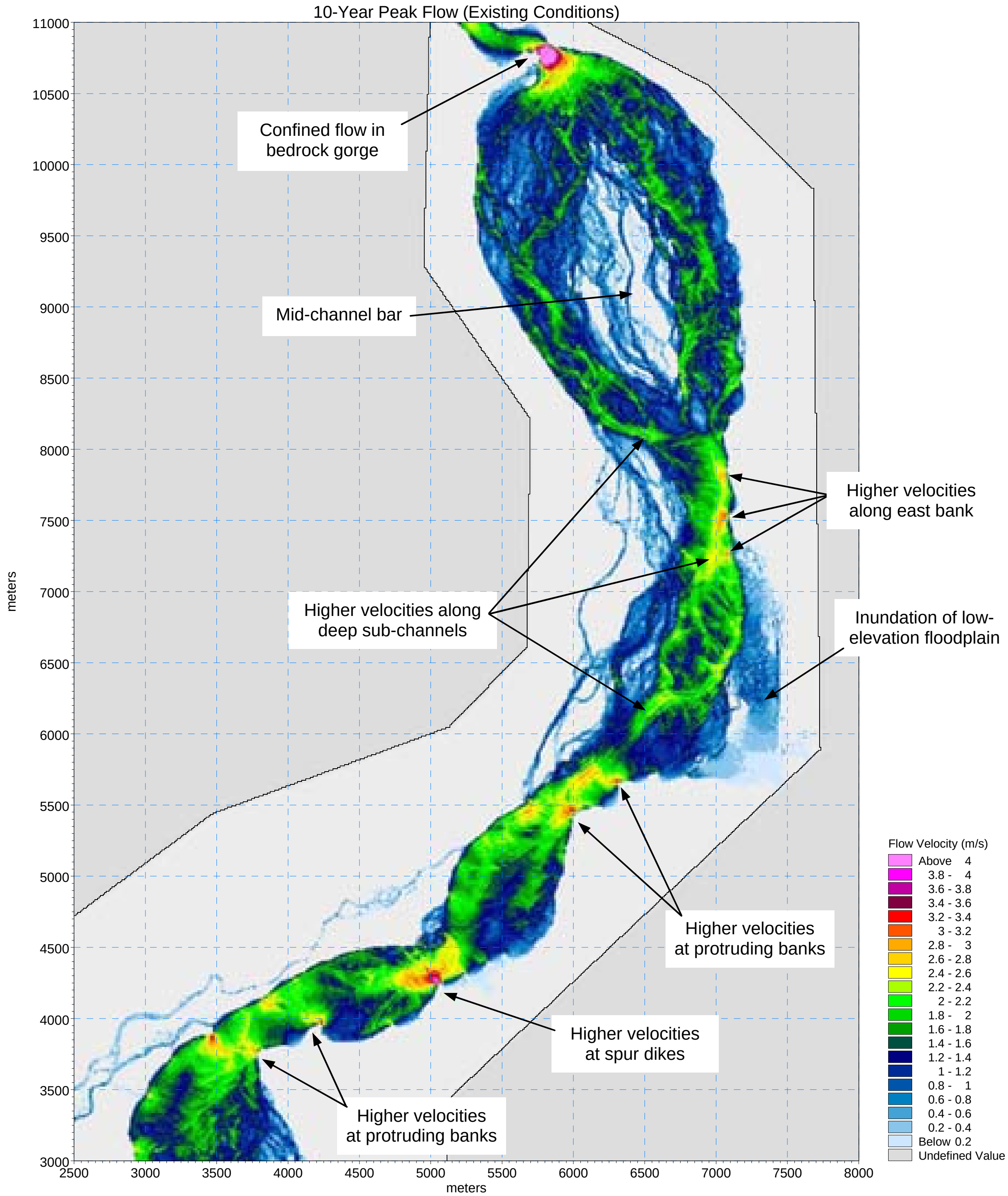



**Figure 10. Flow velocities simulated for 10-year peak flow under existing conditions.**

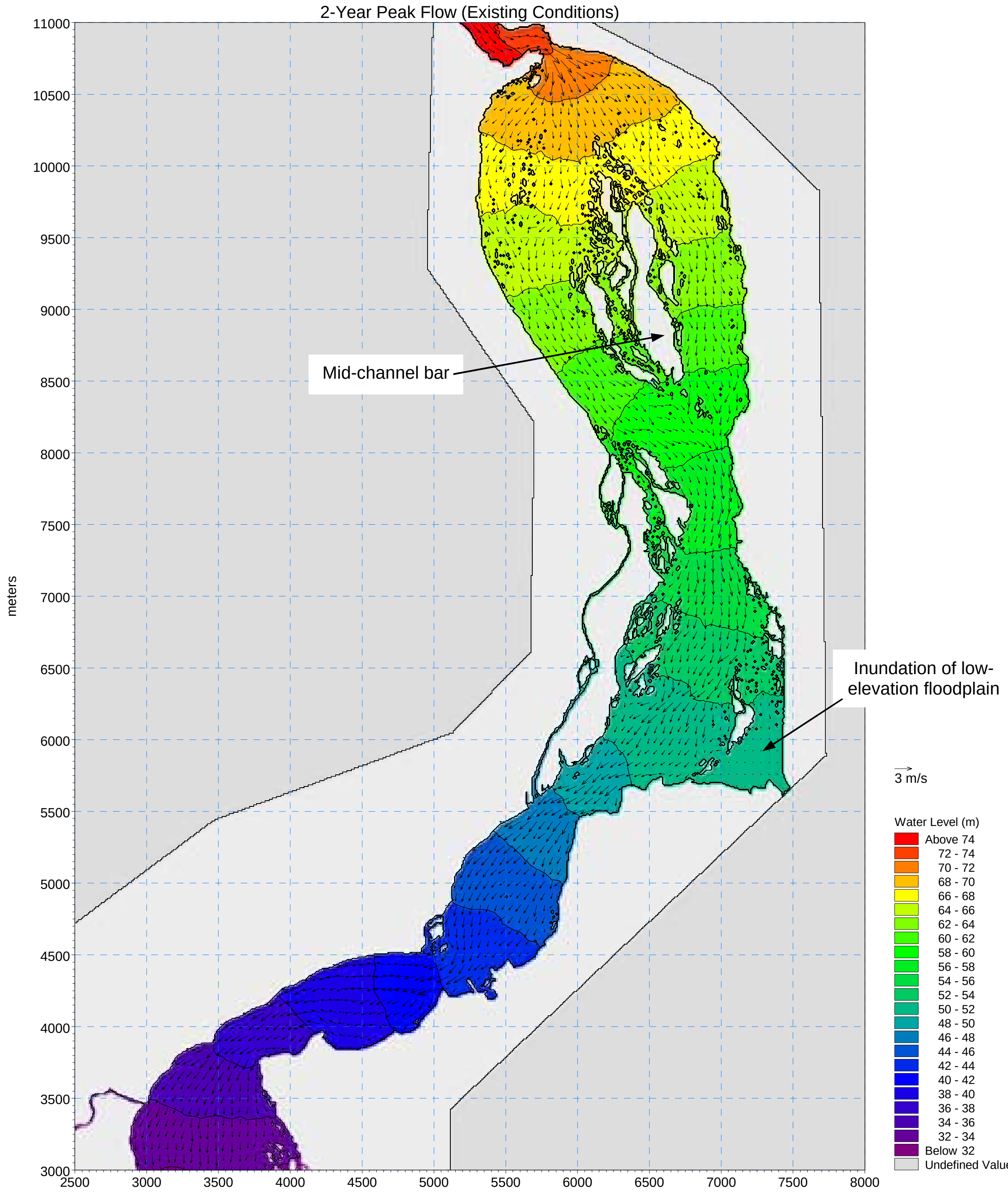



**Figure 11. Water surface elevations and velocity vectors simulated for 2-year peak flow under existing conditions.**

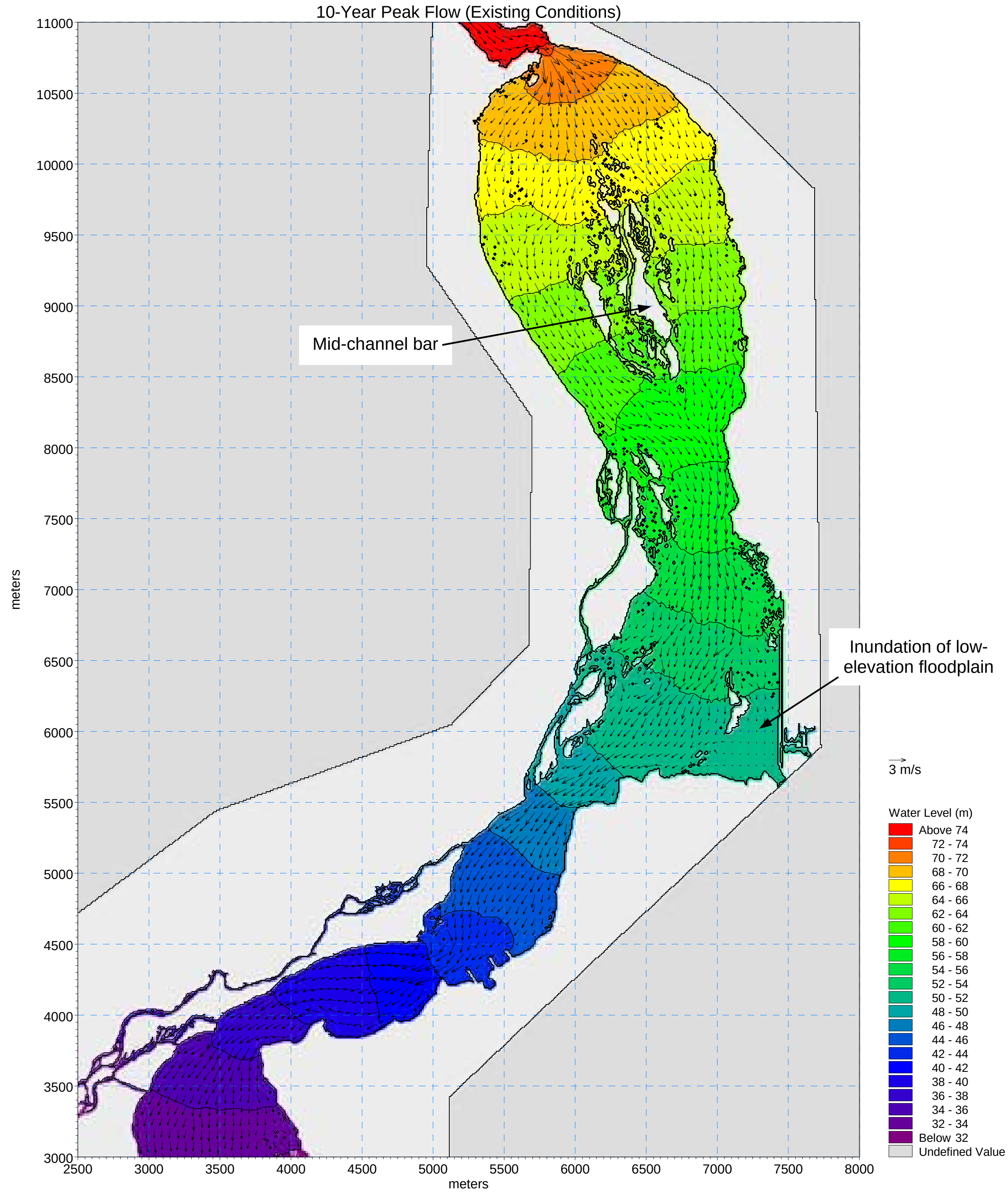



**Figure 12. Water surface elevations and velocity vectors simulated for 10-year peak flow under existing conditions.**

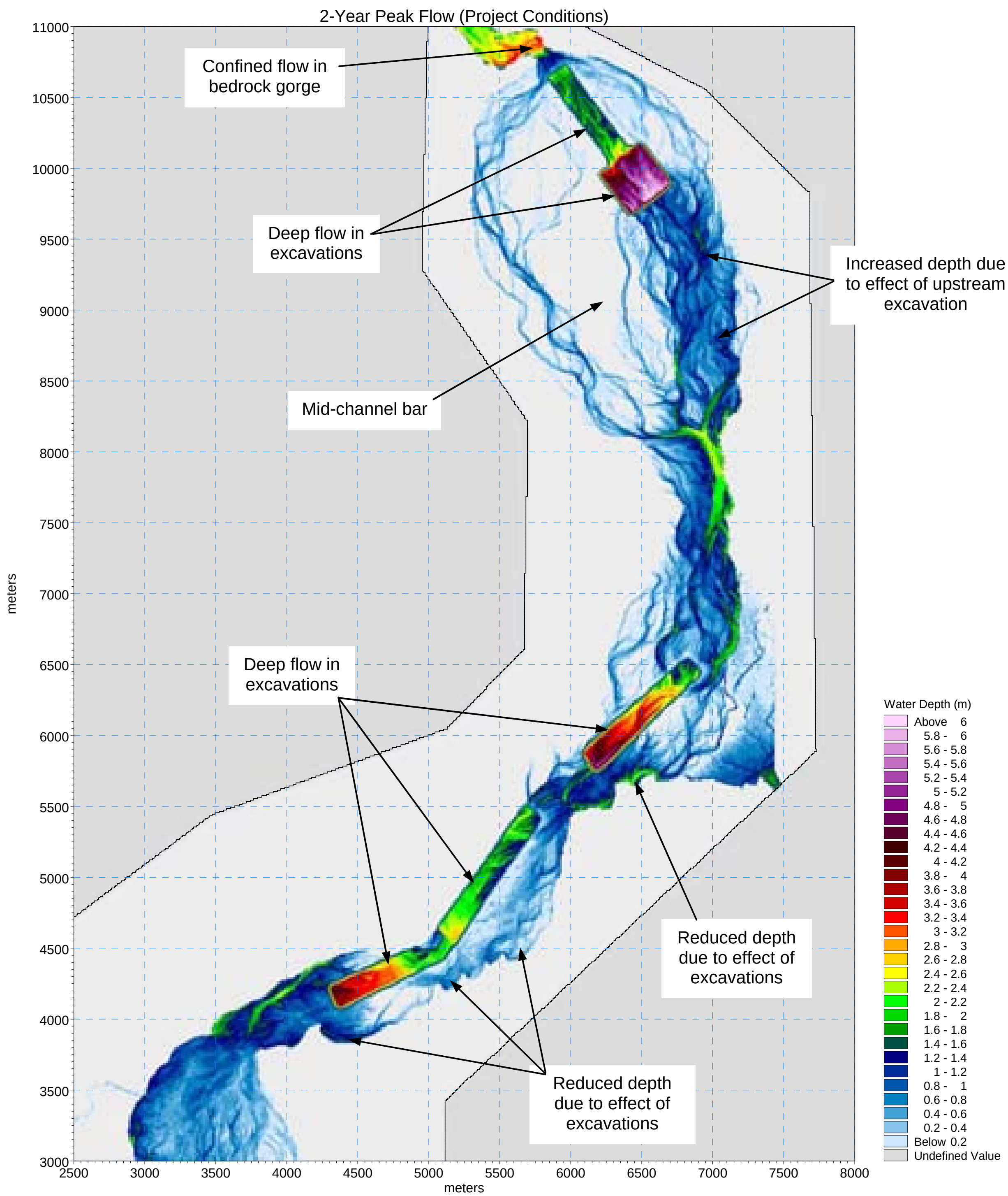



**Figure 13. Water depths simulated for 2-year peak flow under project conditions.**

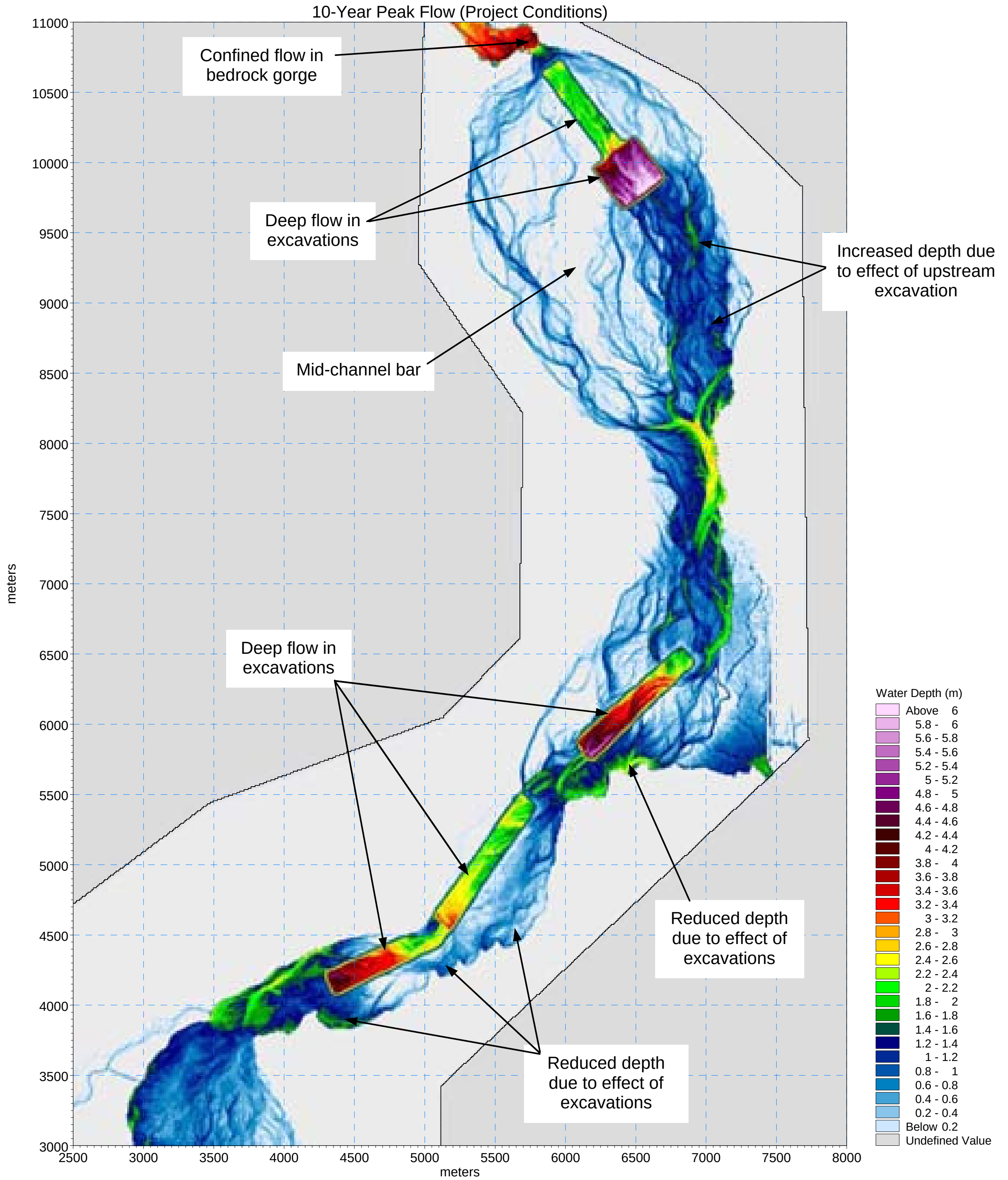



**Figure 14. Water depths simulated for 10-year peak flow under project conditions.**

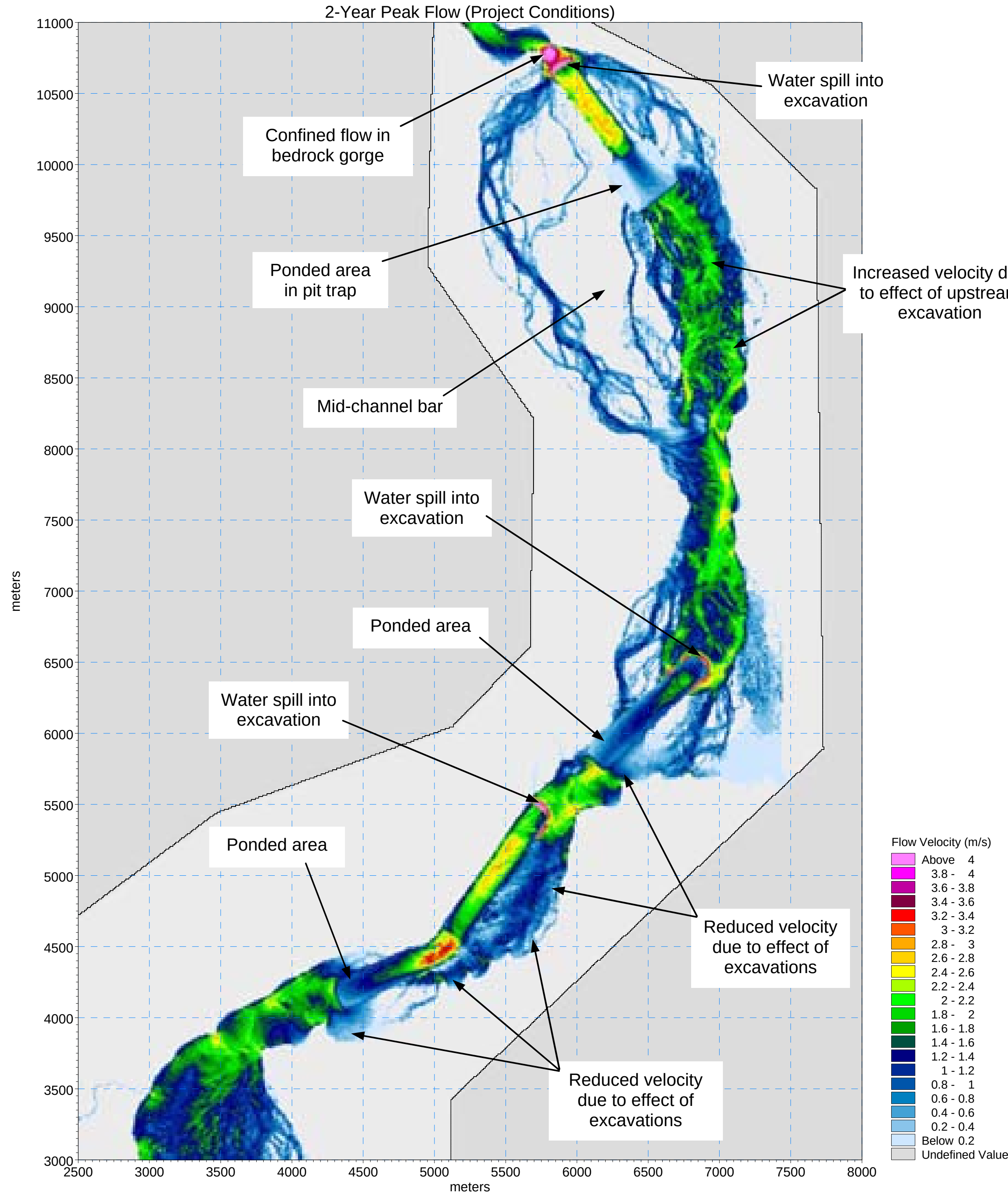



**Figure 15. Flow velocities simulated for 2-year peak flow under project conditions.**

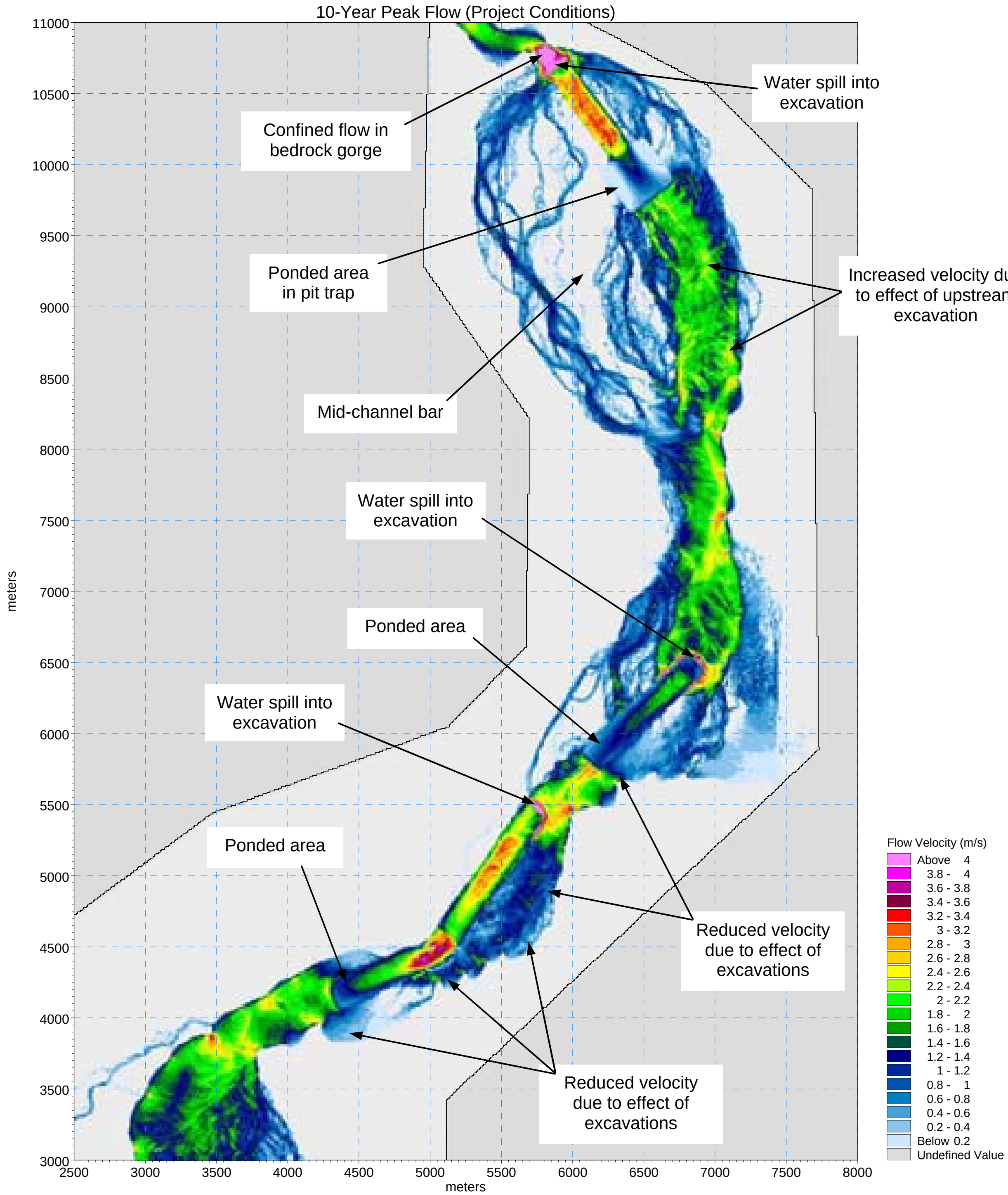



**Figure 16. Flow velocities simulated for 10-year peak flow under project conditions.**

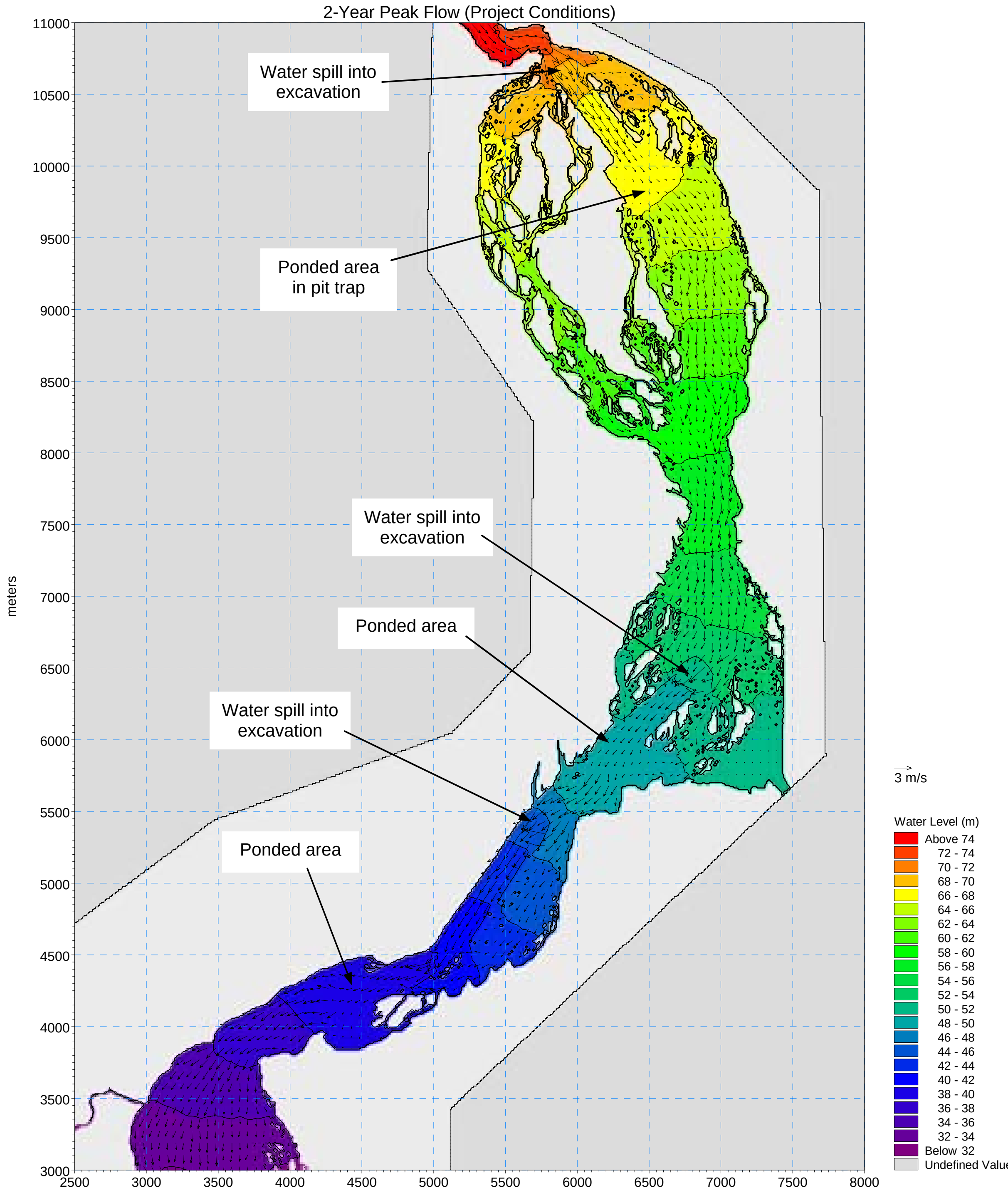



**Figure 17. Water surface elevations and velocity vectors simulated for 2-year peak flow under project conditions.**

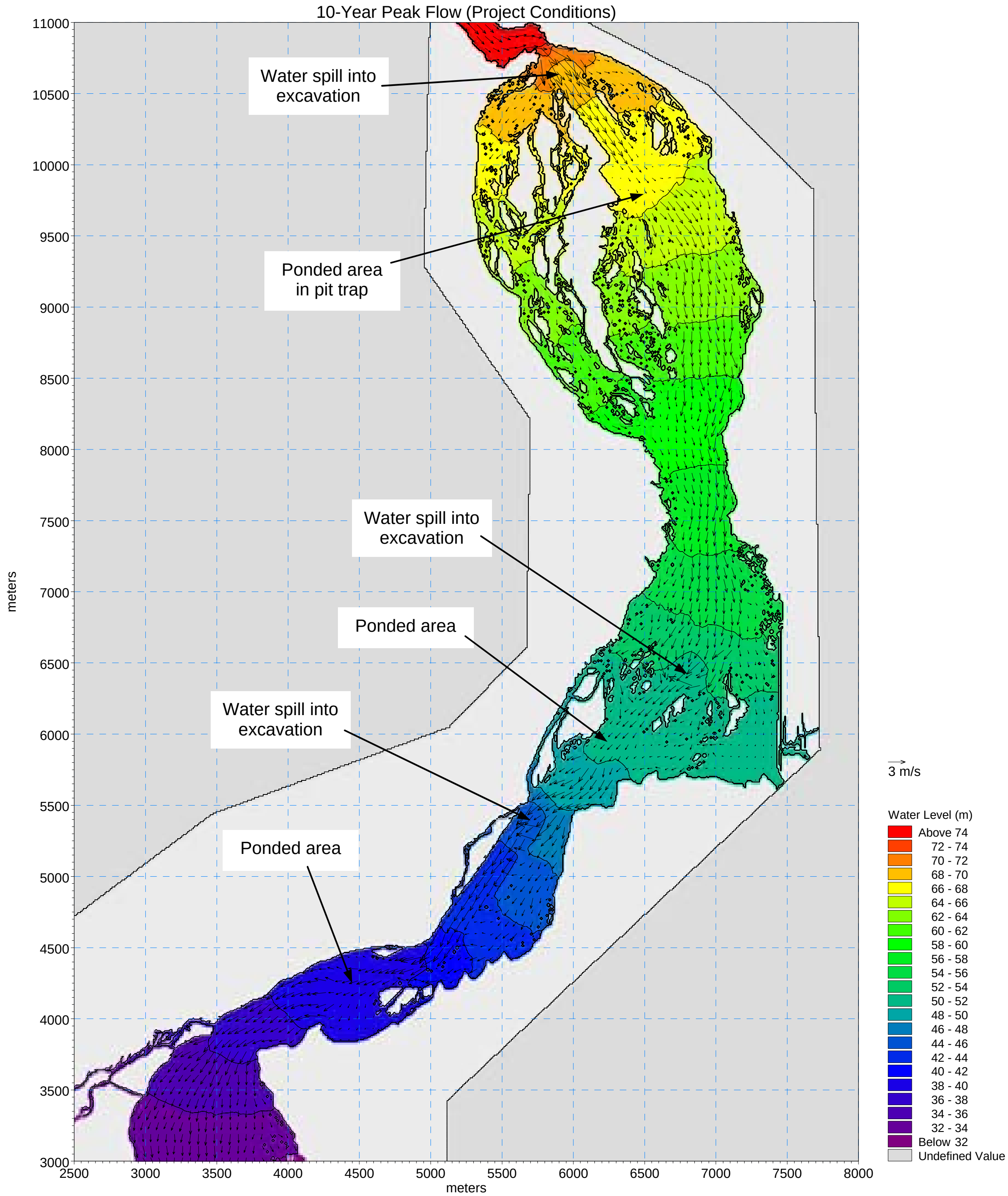



**Figure 18. Water surface elevations and velocity vectors simulated for 10-year peak flow under project conditions.**

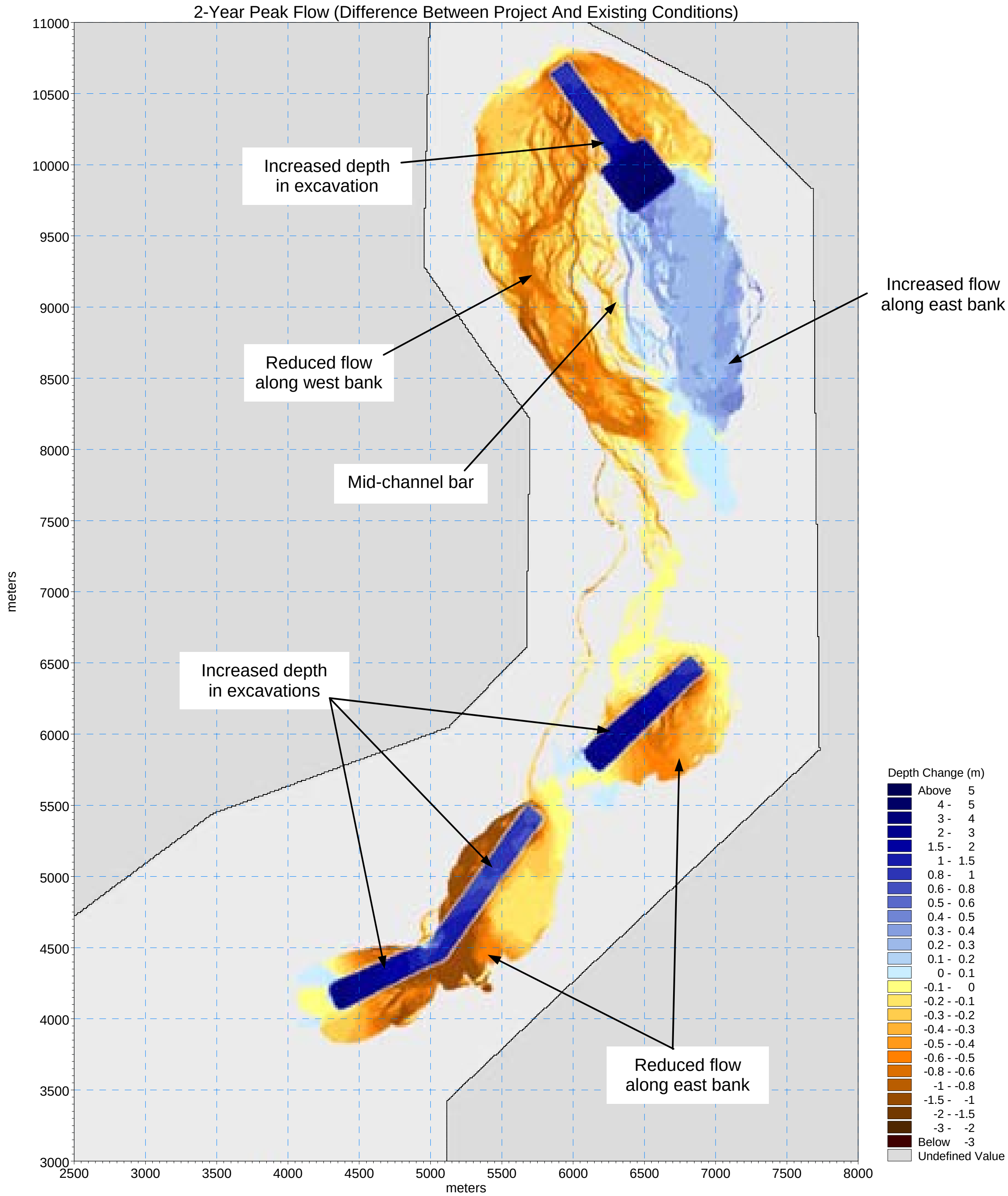



**Figure 19. Difference in water depths between project and existing conditions simulated for 2-year peak flow.**

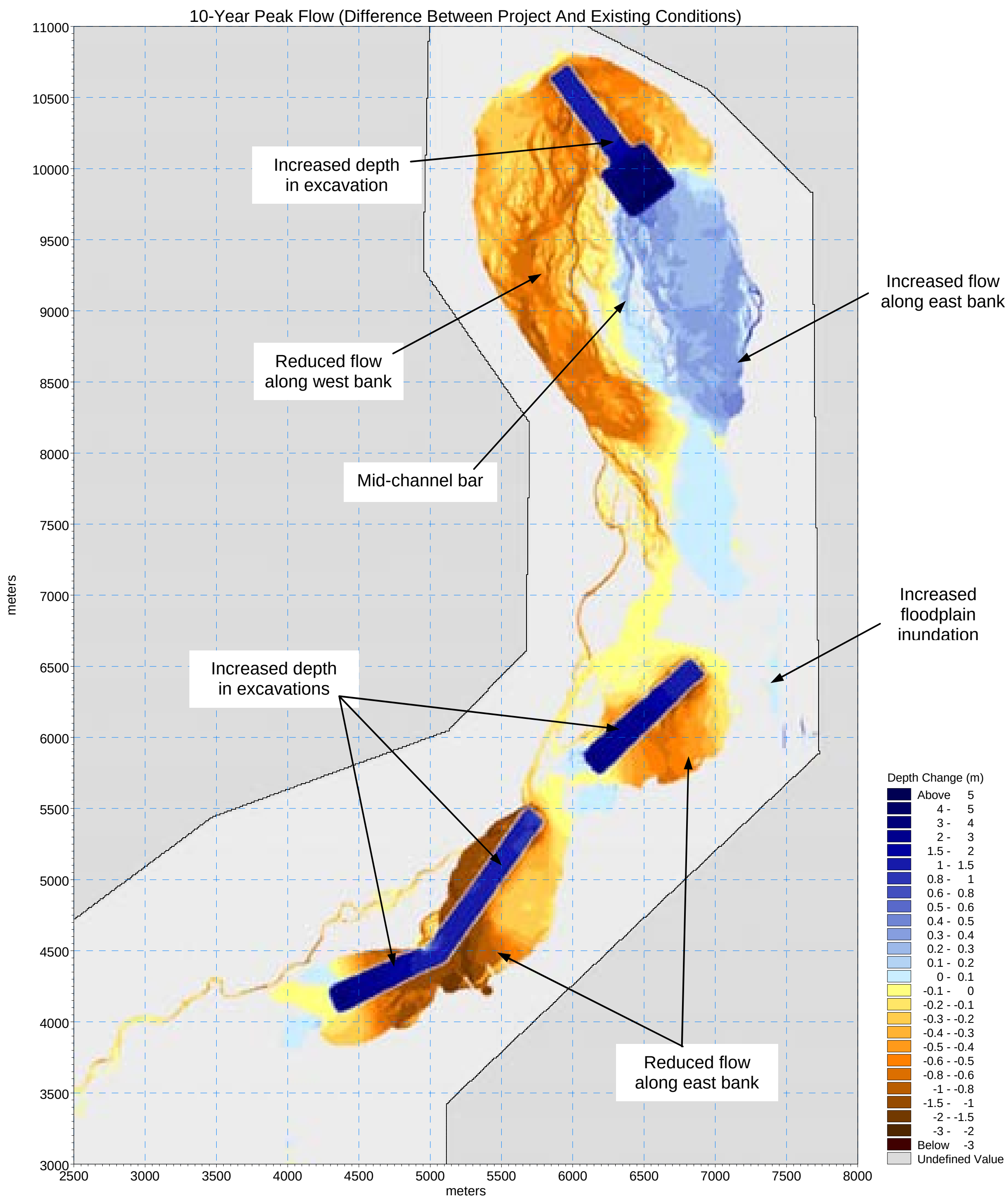



**Figure 20. Difference in water depths between project and existing conditions simulated for 10-year peak flow.**

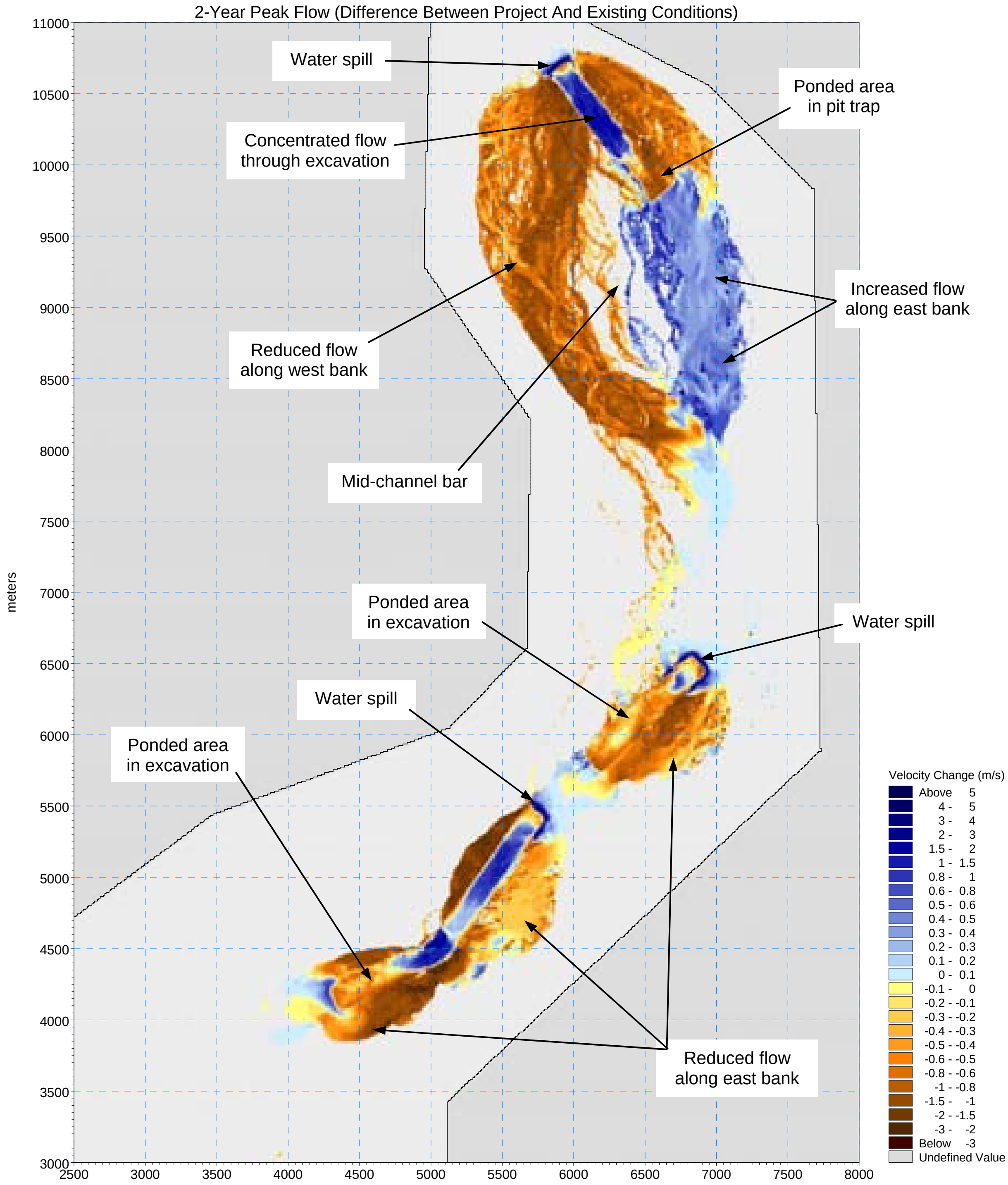



**Figure 21. Difference in flow velocities between project and existing conditions simulated for 2-year peak flow.**

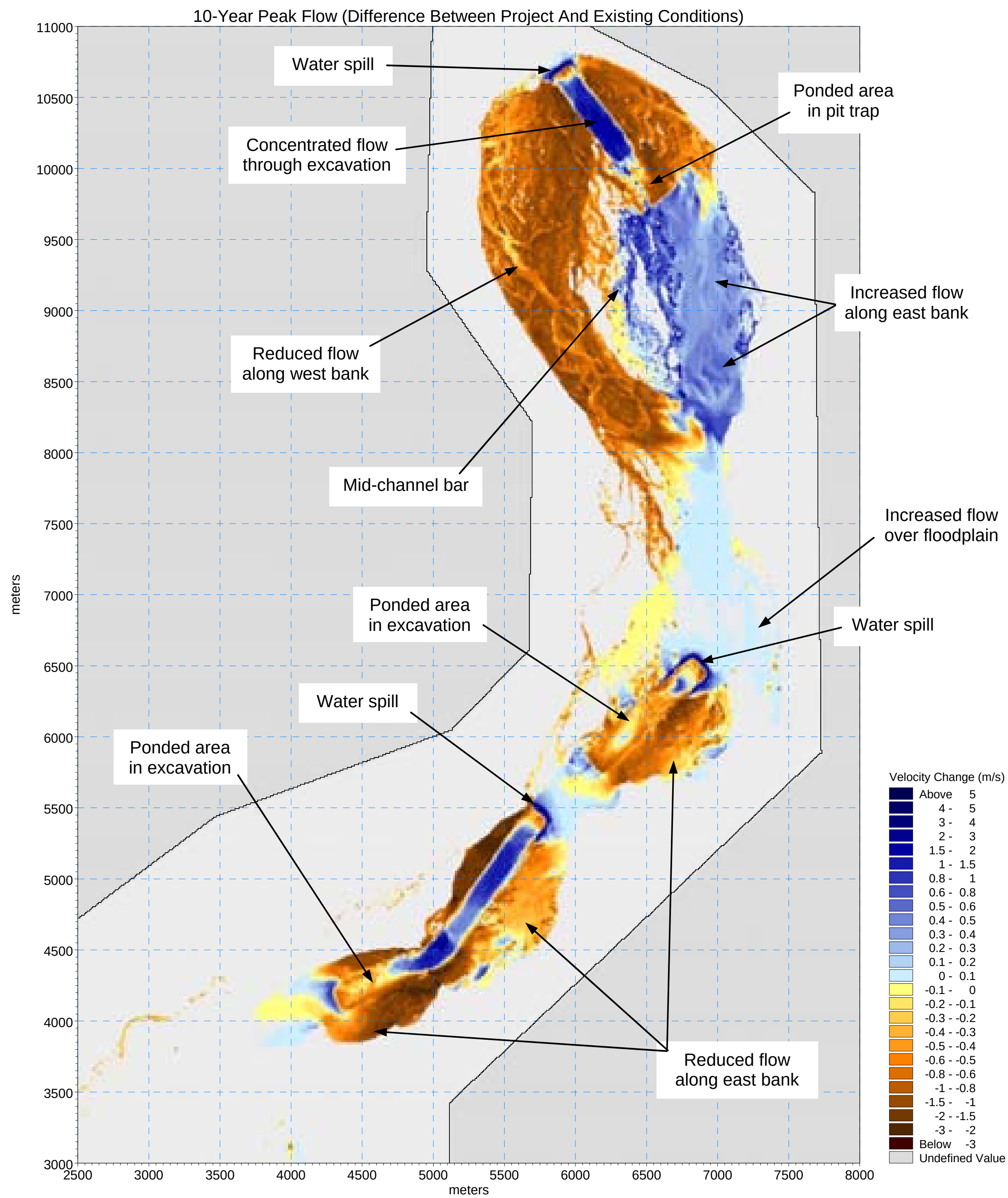



**Figure 22. Difference in flow velocities between project and existing conditions simulated for 10-year peak flow.**

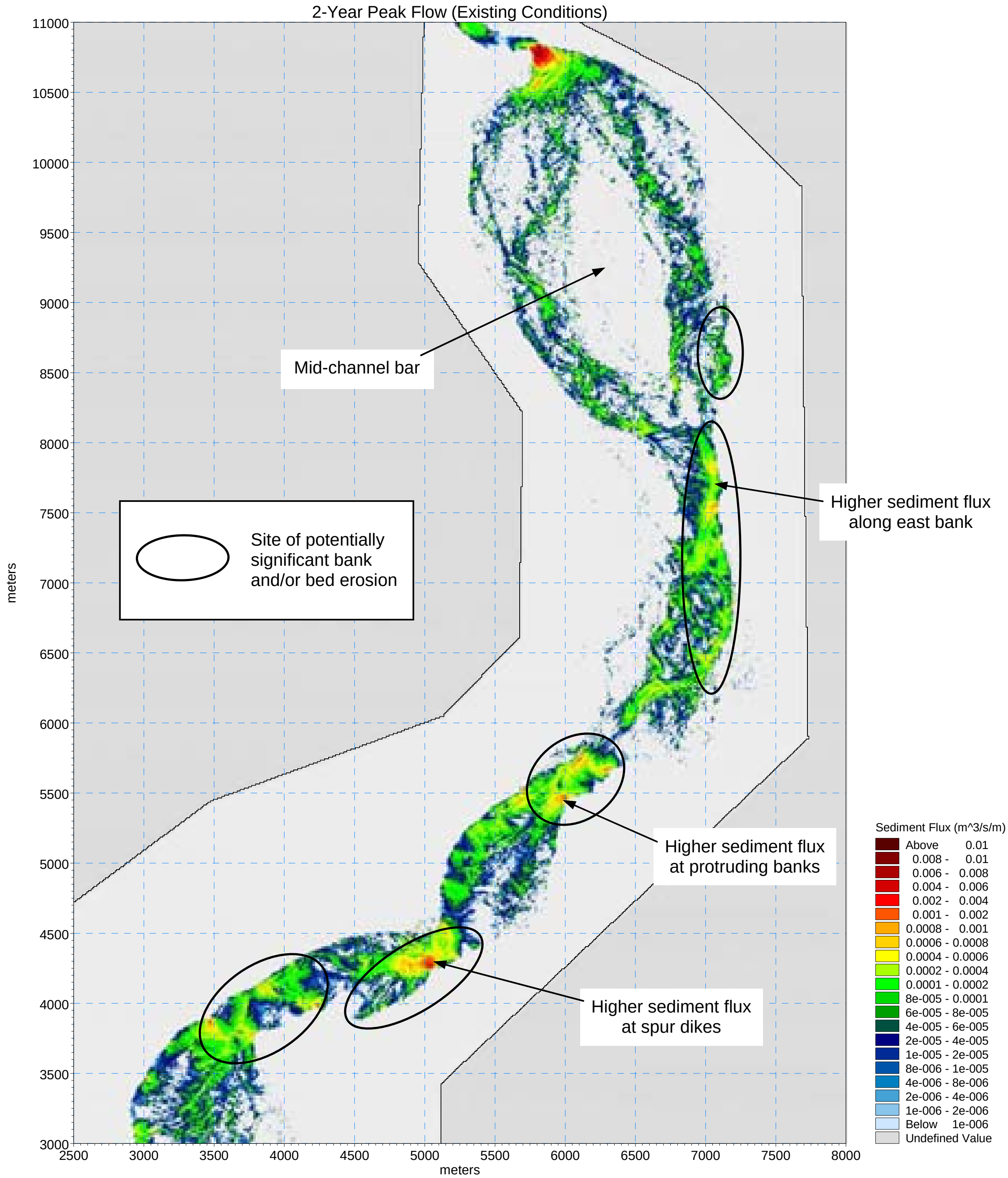



**Figure 23. Sediment fluxes simulated for 2-year peak flow under existing conditions.**

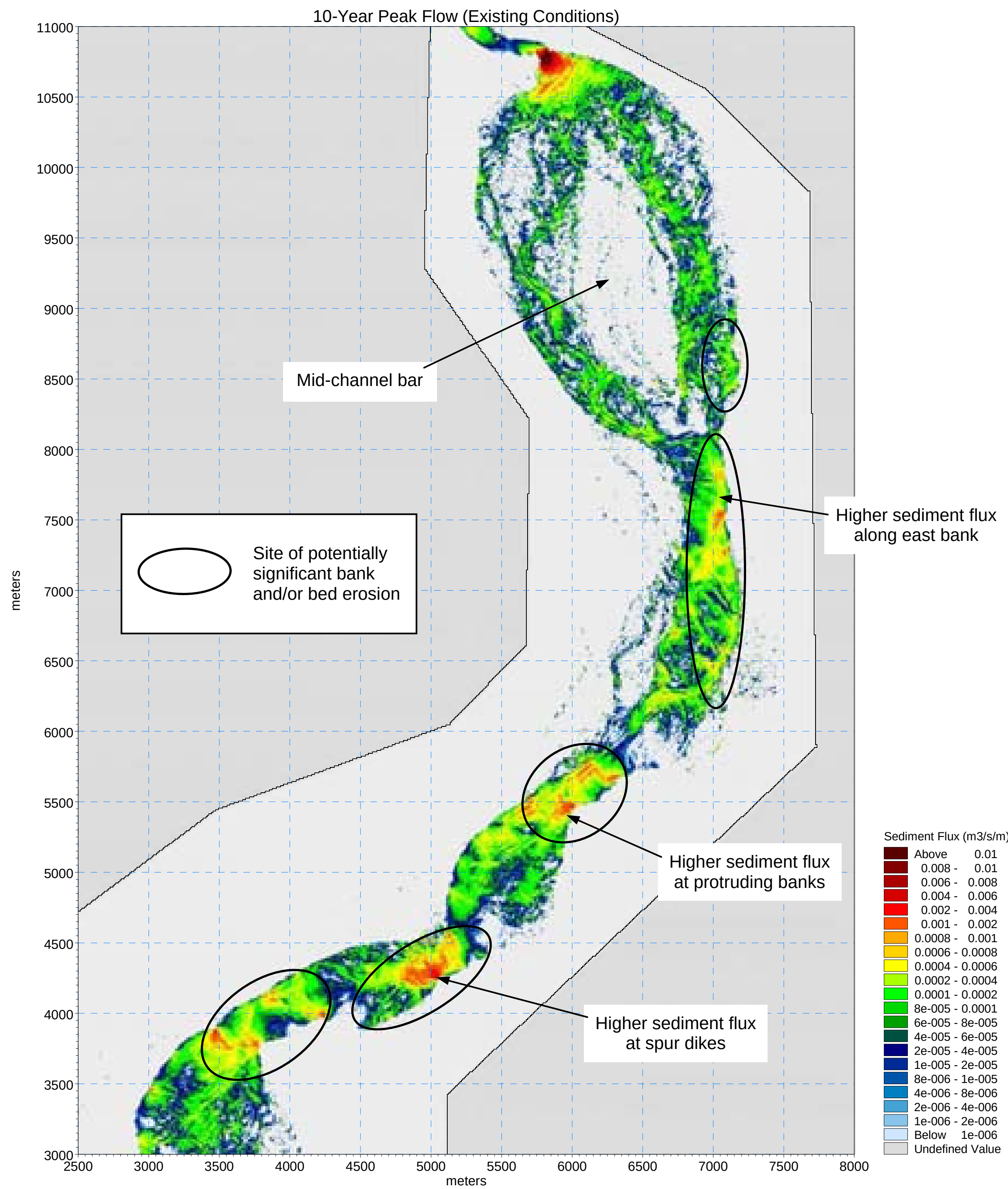



**Figure 24. Sediment fluxes simulated for 10-year peak flow under existing conditions.**

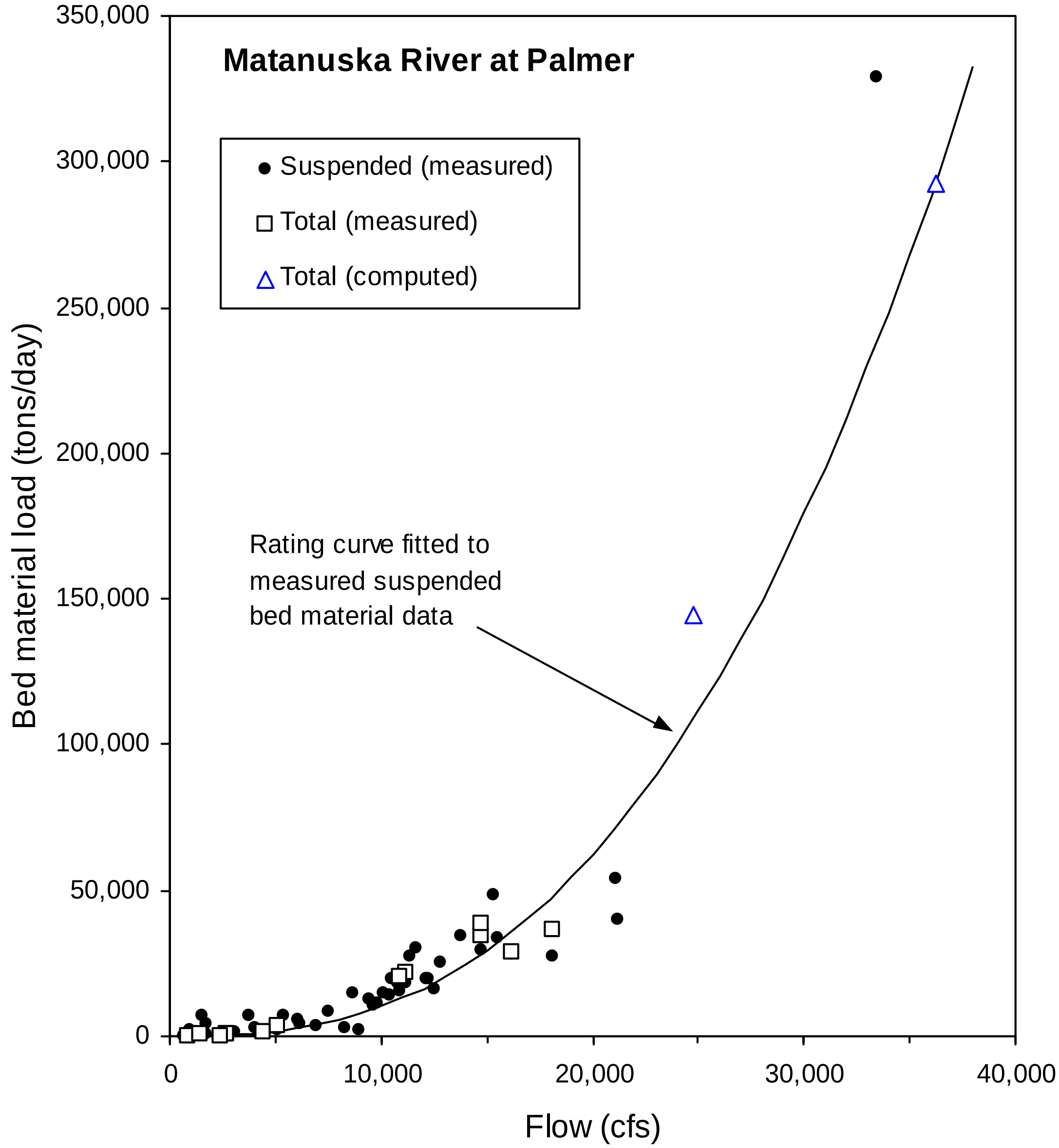



**Figure 25. Comparison of measured and computed sediment fluxes in Matanuska River at Palmer (gorge reach).**

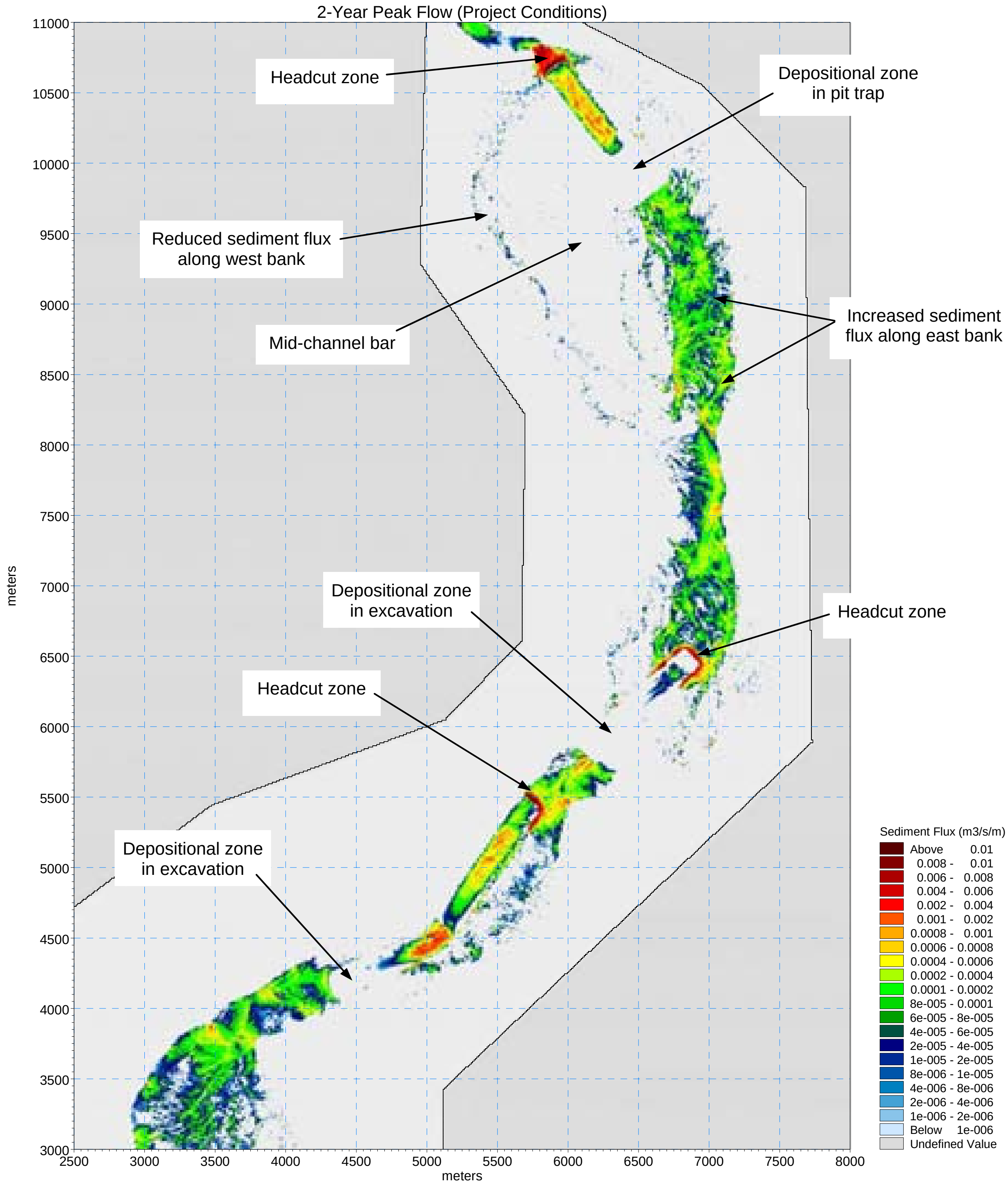



**Figure 26. Sediment fluxes simulated for 2-year peak flow under project conditions.**

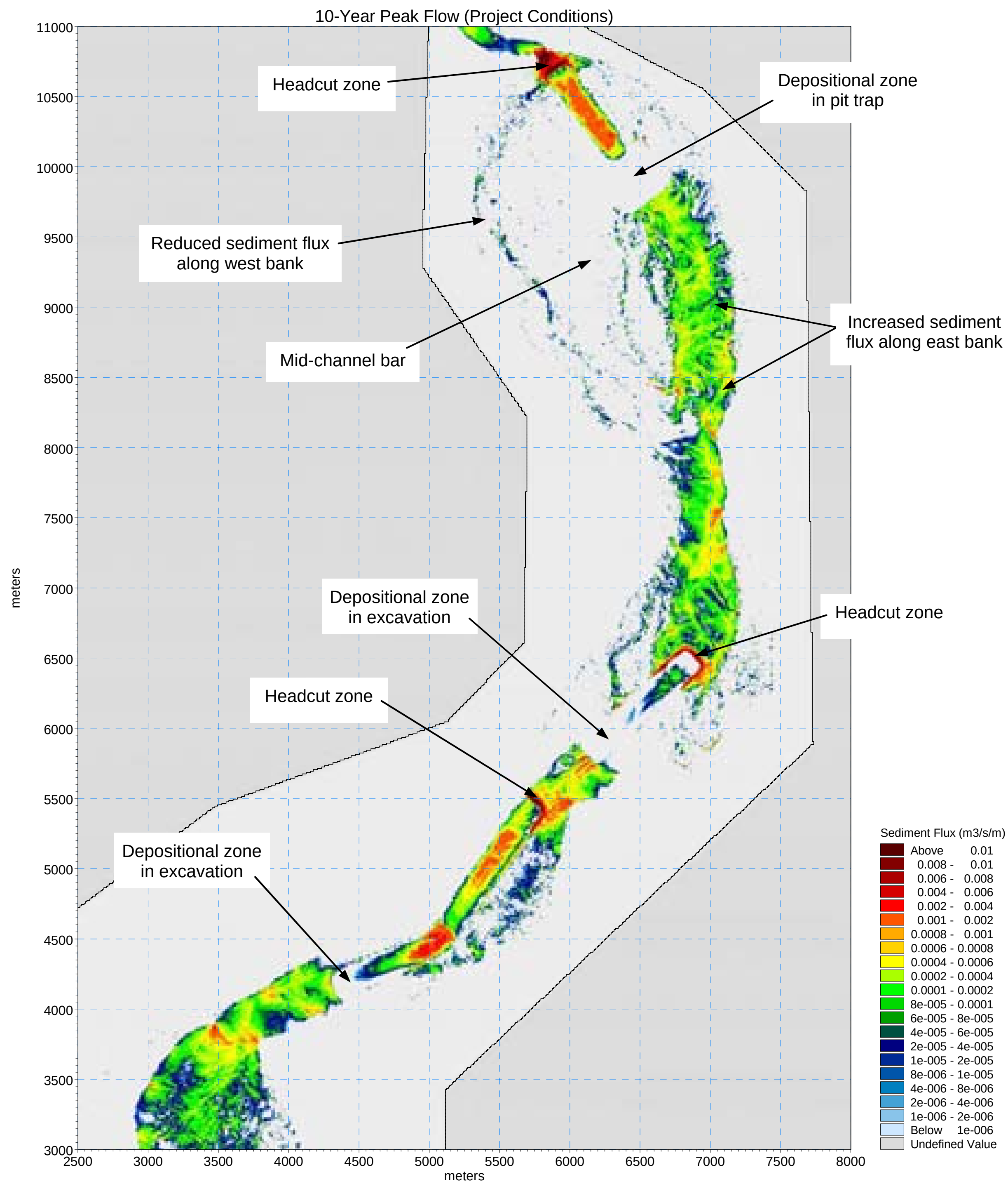



**Figure 27. Sediment fluxes simulated for 10-year peak flow under project conditions.**

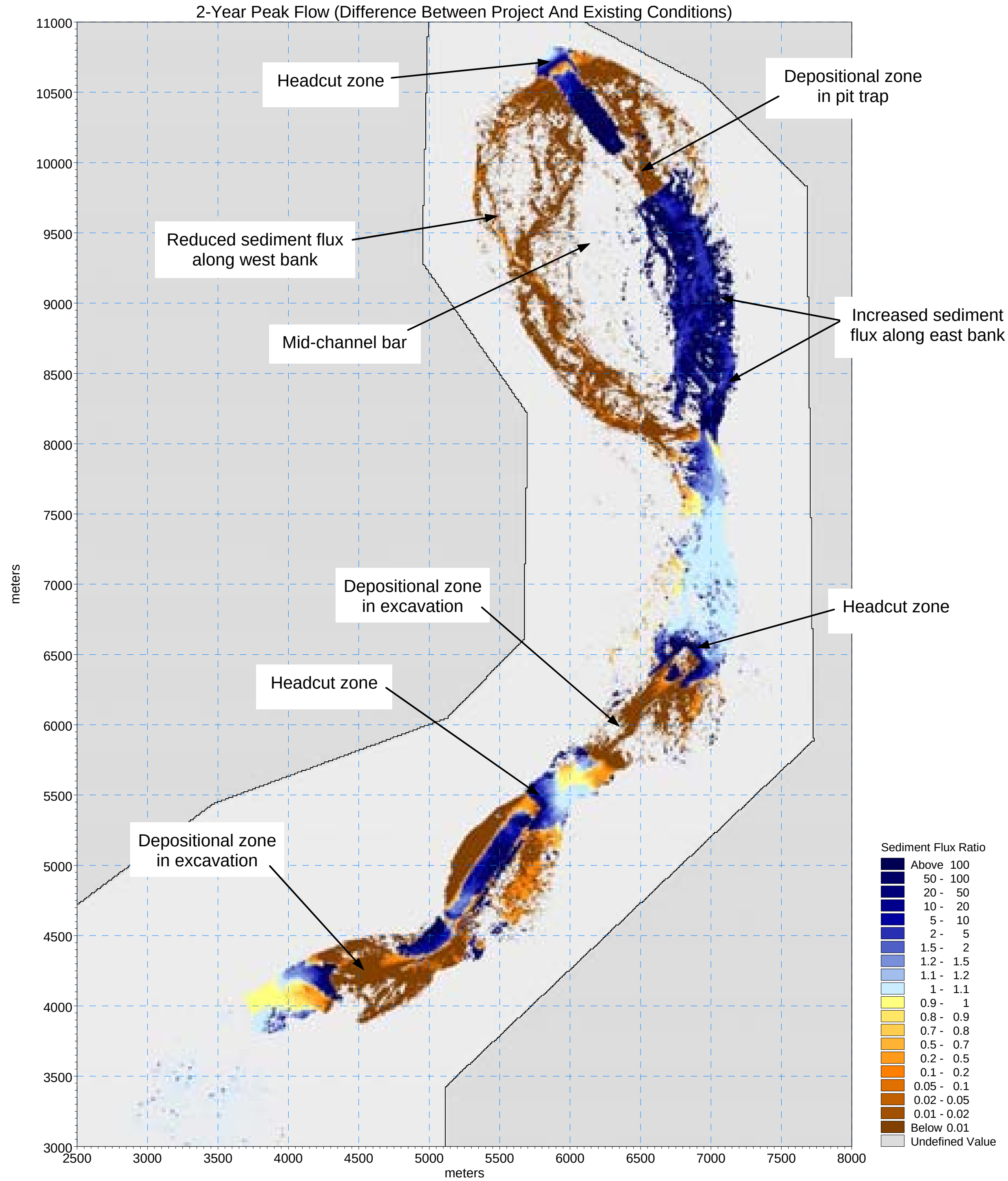



**Figure 28. Changes in sediment fluxes due to project excavations calculated for 2-year peak flow.**

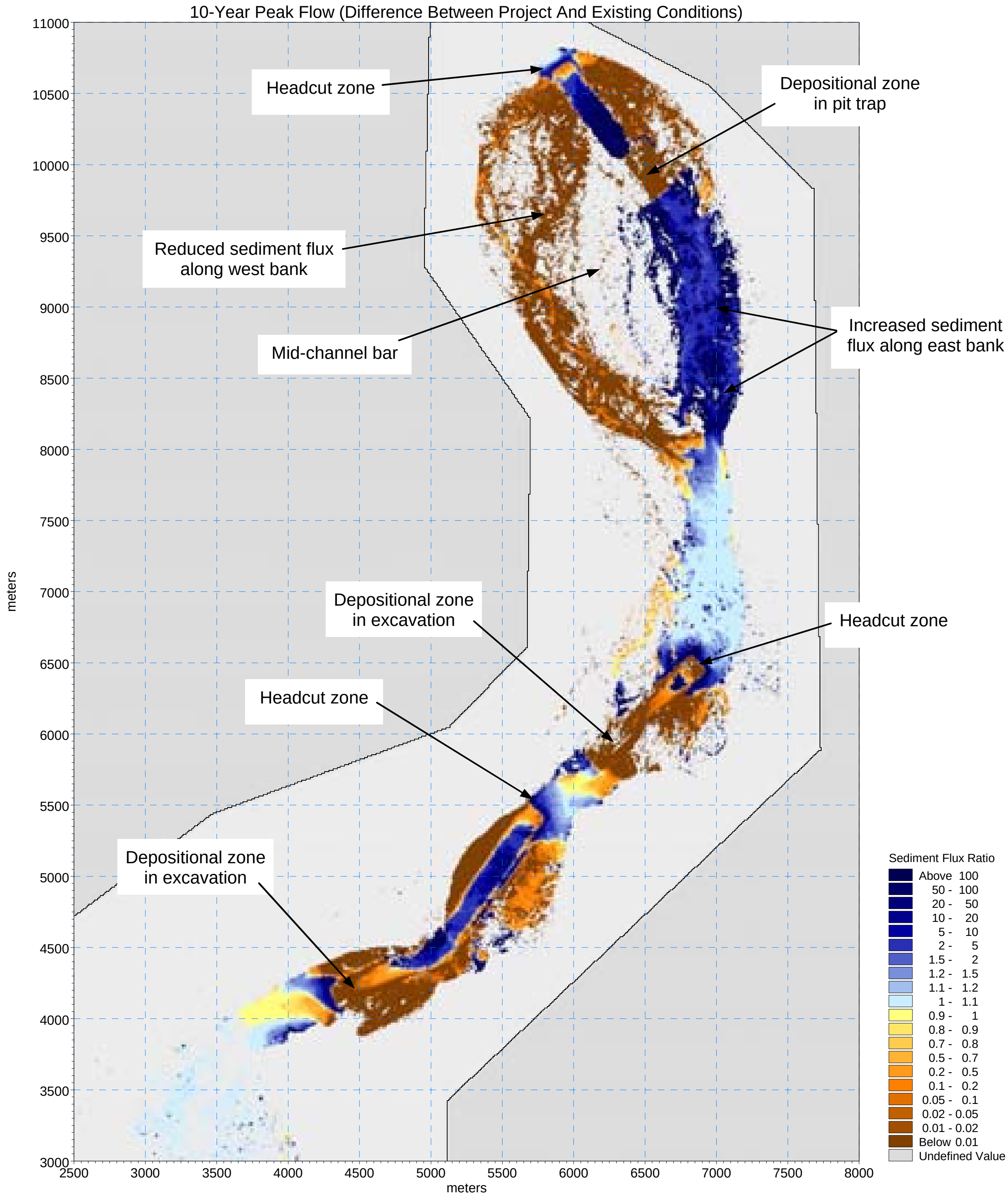



**Figure 29. Changes in sediment fluxes due to project excavations calculated for 10-year peak flow.**

**TECHNICAL MEMORANDUM**

MWH

**To:** File **Date:** October 5, 2004

**From:** Kris Ivarson **Reference:** 1851040.010107

**Subject:** **Matanuska River Erosion Project -**

**HEC-RAS MODELING: HYDRAULIC ANALYSIS**

## INTRODUCTION

Information on river hydraulics such as flood water levels, flow velocities, and water depths is required for assessing sediment transport and bank erosion processes, as well as for designing erosion protection measures and habitat impact assessment. The HEC-RAS 3.1 computer program, developed by the Hydrological Engineering Center, U.S. Army Corps of Engineers was used for this initial assessment of the Matanuska River study reach.

HEC-RAS creates an import file containing geometric attribute data from an existing digital terrain model (DTM) and complementary data sets. The import file contains: river, reach, and station identifiers; cross sectional cut lines; cross sectional surface lines; cross sectional bank stations; downstream reach lengths for the left overbank, main channel, and right overbank; and cross sectional roughness coefficients. Themes, such as "Ineffective Flow Areas," are then created that are pertinent to developing the geometric data. After running the model, water surface profile and velocity data can be exported from HEC-RAS for use in other analysis, such as the MIKE 21 modeling that was conducted by Northwest Hydraulics Consultants.

## HEC-RAS MODELING

Information on the hydrology of the watershed was collected, including water levels at the Palmer gage and other historical high-water mark information. Survey data was also collected and used as input for the HEC-RAS model. Details on the hydrology are presented in the Matanuska River Hydrology Technical Memorandum (Appendix D). Details on the survey data collection and methodology are presented in the Matanuska Survey Data Summary Technical Memorandum (Appendix B).

Channel field surveys and LiDAR data were used to prepare a standard step backwater model of the Matanuska River and DTM. The main input data for the model includes river channel cross section topography and information on channel roughness (Manning n-values), from the survey information.  The water level at the downstream end of the study reach was also determined from the available information on tidal levels in Knik Arm.

The model was calibrated using available historical water level information. A series of model runs were made for a range of flow conditions, ranging from bankfull discharge (typically around the 1.5-year flood) up to extreme events including the 100-year flood.  Estimates of channel water levels, velocities, hydraulic depth, and bed shear stresses were tabulated for each discharge condition.  An example of HEC-RAS output data is presented in Table 1, and portions of the actual HEC-RAS data output tables are included as an attachment.  This information was used as input for the two-dimensional model of critical sub-reaches to assess the hydraulic conditions in Phase 2.

**Table 1   Example HEC Output Data**

| Discharge Profile | Q Total (cfs) | Estimated Slope (ft/ft) | Velocity (ft/s) | Flow Area (sq ft) | Froude Number | Shear Stress of Channel (lb/sq ft) | Shear Stress Total (lb/sq ft) |
|---|---|---|---|---|---|---|---|
| Q - 50% | 1,320 | 0.004506 | 2.82 | 468 | 0.50 | 0.28 | 0.28 |
| Q – 2-yr | 24,800 | 0.007162 | 9.41 | 2,641 | 0.79 | 1.94 | 1.92 |
| Q – 100-yr | 49,990 | 0.009838 | 13.65 | 3,683 | 0.98 | 3.68 | 3.61 |

Key:
% – percent
cfs – cubic feet per second
ft/ft – feet per foot
ft/s – feet per second
sq ft – square foot/feet
lb – pounds
Q – Discharge
yr – year

Ms. Mel Langdon, P.E., conducted the HEC-RAS modeling.  Two model runs were made, one based on 2-foot contours and one based on “bare earth” point source data.  Output data ranges for selected parameters are shown in Table 2.

**Table 2   Range of Selected Values**

| Parameter | Low Value | High Value |
|---|---|---|
| Estimated Slope (ft/ft) | 0.001003 | 0.011543 |
| Velocity (ft/s) | 1.79 | 8.21 |
| Flow Area (sq ft) | 2436.82 | 11174.48 |
| Froude Number | 0.22 | 0.87 |
| Shear Stress Total (lb/sq ft) | 0.13 | 1.68 |

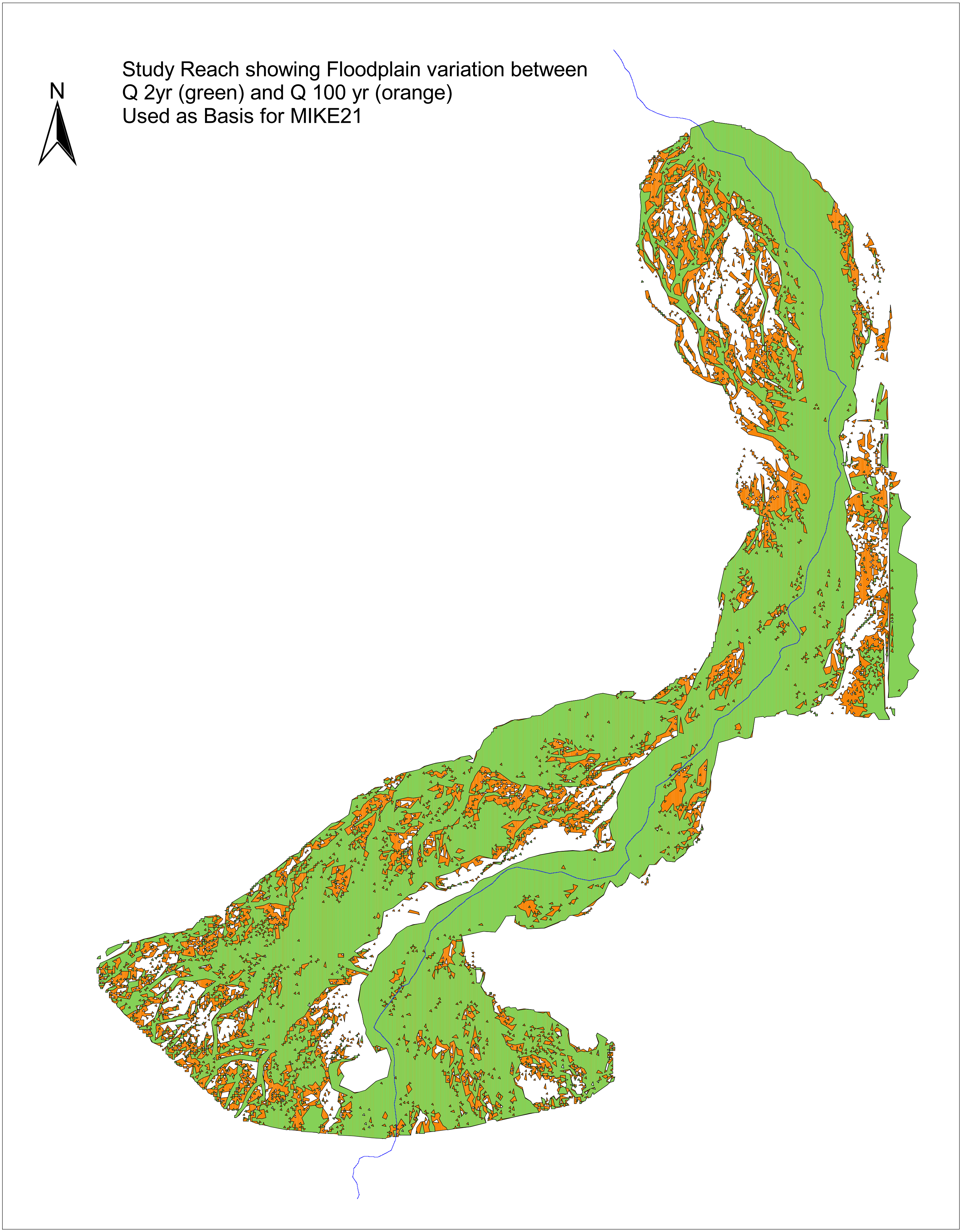
Key:
ft/ft – feet per foot
ft/s – feet per second
sq ft – square foot/feet
lb – pounds

## RESULTS

The results of the one-dimensional HEC-RAS model were used to develop boundary conditions for the two-dimensional model. Both existing and alternative conditions were examined using the Danish Hydraulic Institute MIKE-21 2-dimensional (2-d) fixed bed computer model for Phase 2 analysis.

The attached figure provides an example of the data used as a basis for the MIKE 21 modeling effort. The figure shows variation in floodplain width between discharges at an estimated 2-year interval and a 100-year interval. Variations in velocity and shear stress were also used; however, and are available in the MIKE 21 data tables.

KAI



N
Study Reach showing Floodplain variation between
Q 2yr (green) and Q 100 yr (orange)
Used as Basis for MIKE21

HEC-RAS Plan: ptsource River: Matanuska River Reach: studyarea

| Reach | River Sta | Profile | Q Total (cfs) | Min Ch El (ft) | W.S. Elev (ft) | Crit W.S. (ft) | E.G. Elev (ft) | E.G. Slope (ft/ft) |
|---|---|---|---|---|---|---|---|---|
| studyarea | 42443 | Q50% | 1320 | 229.03 | 232.01 | 231.52 | 232.13 | 0.004506 |
| studyarea | 42443 | Q2yr | 24800 | 229.03 | 235.8 | 235.15 | 237.18 | 0.007162 |
| studyarea | 42443 | Q100yr | 49990 | 229.03 | 237.49 | 237.42 | 240.38 | 0.009838 |
| | | | | | | | | |
| studyarea | 42345 | Q50% | 1320 | 227.98 | 231.6 | | 231.7 | 0.004147 |
| studyarea | 42345 | Q2yr | 24800 | 227.98 | 234.54 | 234.51 | 236.27 | 0.011005 |
| studyarea | 42345 | Q100yr | 49990 | 227.98 | 236.58 | 236.58 | 239.37 | 0.010103 |
| | | | | | | | | |
| studyarea | 42272 | Q50% | 1320 | 228.04 | 231.27 | | 231.38 | 0.004759 |
| studyarea | 42272 | Q2yr | 24800 | 228.04 | 234.11 | | 235.41 | 0.009281 |
| studyarea | 42272 | Q100yr | 49990 | 228.04 | 234.84 | 235.67 | 238.31 | 0.019536 |
| | | | | | | | | |
| studyarea | 42206 | Q50% | 1320 | 227.9 | 230.8 | | 230.95 | 0.008968 |
| studyarea | 42206 | Q2yr | 24800 | 227.9 | 233.54 | 233.36 | 234.75 | 0.009937 |
| studyarea | 42206 | Q100yr | 49990 | 227.9 | 234.83 | 235.01 | 237.16 | 0.012472 |
| | | | | | | | | |
| studyarea | 42122 | Q50% | 1320 | 228.08 | 230.21 | | 230.35 | 0.005745 |
| studyarea | 42122 | Q2yr | 24800 | 228.08 | 233.08 | | 233.93 | 0.007247 |
| studyarea | 42122 | Q100yr | 49990 | 228.08 | 234.44 | 234.06 | 235.99 | 0.008252 |
| | | | | | | | | |
| studyarea | 42017 | Q50% | 1320 | 226.62 | 229.64 | 229.29 | 229.74 | 0.005603 |
| studyarea | 42017 | Q2yr | 24800 | 226.62 | 232.86 | 231.71 | 233.3 | 0.003456 |
| studyarea | 42017 | Q100yr | 49990 | 226.62 | 234.34 | 232.98 | 235.2 | 0.004039 |
| | | | | | | | | |
| studyarea | 41929 | Q50% | 1320 | 225.36 | 229.11 | 228.8 | 229.22 | 0.006164 |
| studyarea | 41929 | Q2yr | 24800 | 225.36 | 232.62 | 231.36 | 233 | 0.002991 |
| studyarea | 41929 | Q100yr | 49990 | 225.36 | 234.09 | 232.58 | 234.83 | 0.003521 |
| | | | | | | | | |
| studyarea | 41774 | Q50% | 1320 | 224.61 | 228.64 | 227.96 | 228.69 | 0.002075 |
| studyarea | 41774 | Q2yr | 24800 | 224.61 | 232.25 | 230.83 | 232.56 | 0.002429 |
| studyarea | 41774 | Q100yr | 49990 | 224.61 | 233.69 | 232 | 234.3 | 0.002892 |
| | | | | | | | | |
| studyarea | 41632 | Q50% | 1320 | 224.54 | 228.37 | 227.73 | 228.42 | 0.001756 |
| studyarea | 41632 | Q2yr | 24800 | 224.54 | 231.87 | 230.62 | 232.2 | 0.002705 |
| studyarea | 41632 | Q100yr | 49990 | 224.54 | 233.24 | 231.74 | 233.87 | 0.003142 |
| | | | | | | | | |
| studyarea | 41343 | Q50% | 1320 | 224.3 | 227.85 | 226.9 | 227.9 | 0.001862 |
| studyarea | 41343 | Q2yr | 24800 | 224.3 | 231.09 | 229.92 | 231.39 | 0.002832 |
| studyarea | 41343 | Q100yr | 49990 | 224.3 | 232.36 | 230.99 | 232.93 | 0.003204 |
| | | | | | | | | |
| studyarea | 41070 | Q50% | 1320 | 224.06 | 227.12 | 226.55 | 227.19 | 0.003887 |
| studyarea | 41070 | Q2yr | 24800 | 224.06 | 230.23 | 229.2 | 230.54 | 0.003453 |
| studyarea | 41070 | Q100yr | 49990 | 224.06 | 231.41 | 230.27 | 231.99 | 0.003743 |
| | | | | | | | | |
| studyarea | 40885 | Q50% | 1320 | 223.01 | 226.5 | 225.89 | 226.56 | 0.002972 |
| studyarea | 40885 | Q2yr | 24800 | 223.01 | 229.62 | 228.55 | 229.9 | 0.003311 |
| studyarea | 40885 | Q100yr | 49990 | 223.01 | 230.76 | 229.61 | 231.29 | 0.00362 |
| | | | | | | | | |
| studyarea | 40729 | Q50% | 1320 | 222.74 | 225.9 | 225.36 | 225.99 | 0.00465 |

| Vel Chnl (ft/s) | Flow Area (sq ft) | Top Width (ft) | Froude # C | Shear Cha (lb/sq ft) | Shear Total (lb/sq ft) |
|---|---|---|---|---|---|
| 2.82 | 468.44 | 471.25 | 0.5 | 0.28 | 0.28 |
| 9.41 | 2641.34 | 611.88 | 0.79 | 1.94 | 1.92 |
| 13.65 | 3683.3 | 622.3 | 0.98 | 3.68 | 3.61 |
| | | | | | |
| 2.62 | 504.33 | 537.43 | 0.48 | 0.24 | 0.24 |
| 10.7 | 2409.42 | 692.14 | 0.97 | 2.57 | 2.38 |
| 13.66 | 3842.33 | 709.93 | 1 | 3.63 | 3.4 |
| | | | | | |
| 2.62 | 516.13 | 636.06 | 0.5 | 0.25 | 0.24 |
| 9.62 | 2883.92 | 899.92 | 0.89 | 2.09 | 1.85 |
| 15.8 | 3549.08 | 906.13 | 1.33 | 5.3 | 4.75 |
| | | | | | |
| 3.15 | 423.04 | 636.8 | 0.67 | 0.39 | 0.37 |
| 9.25 | 2983.24 | 1029.99 | 0.9 | 2.01 | 1.79 |
| 12.95 | 4328.66 | 1051.85 | 1.07 | 3.53 | 3.19 |
| | | | | | |
| 3.06 | 440.21 | 493.59 | 0.56 | 0.33 | 0.32 |
| 7.7 | 3523.21 | 1257.67 | 0.77 | 1.41 | 1.26 |
| 10.46 | 5249.88 | 1277.35 | 0.87 | 2.31 | 2.11 |
| | | | | | |
| 2.53 | 522.05 | 722.17 | 0.52 | 0.25 | 0.25 |
| 5.37 | 4614.74 | 1448.39 | 0.52 | 0.7 | 0.7 |
| 7.44 | 6724.23 | 1578.41 | 0.6 | 1.19 | 1.18 |
| | | | | | |
| 2.69 | 491.6 | 653.35 | 0.55 | 0.29 | 0.29 |
| 4.99 | 4975.29 | 1712.91 | 0.49 | 0.61 | 0.61 |
| 6.93 | 7230.48 | 1776.17 | 0.56 | 1.04 | 1.02 |
| | | | | | |
| 1.79 | 737.69 | 808.95 | 0.33 | 0.12 | 0.12 |
| 4.47 | 5544.87 | 1879.91 | 0.44 | 0.49 | 0.49 |
| 6.24 | 8031.91 | 2015.72 | 0.51 | 0.84 | 0.83 |
| | | | | | |
| 1.76 | 752.9 | 760.47 | 0.31 | 0.11 | 0.11 |
| 4.58 | 5427.85 | 2045.13 | 0.47 | 0.51 | 0.5 |
| 6.34 | 7917.29 | 2170.59 | 0.53 | 0.86 | 0.85 |
| | | | | | |
| 1.79 | 736.02 | 757.6 | 0.32 | 0.11 | 0.11 |
| 4.41 | 5620.26 | 2272.26 | 0.47 | 0.48 | 0.48 |
| 6.06 | 8294.69 | 2418.2 | 0.53 | 0.8 | 0.78 |
| | | | | | |
| 2.2 | 600.75 | 792.16 | 0.44 | 0.18 | 0.18 |
| 4.5 | 5509.19 | 2474.96 | 0.51 | 0.52 | 0.52 |
| 6.1 | 8199.14 | 2515.09 | 0.57 | 0.84 | 0.84 |
| | | | | | |
| 2.01 | 657.41 | 806.64 | 0.39 | 0.15 | 0.15 |
| 4.3 | 5763.08 | 2647.3 | 0.49 | 0.48 | 0.48 |
| 5.82 | 8597.64 | 2773.25 | 0.55 | 0.78 | 0.78 |
| | | | | | |
| 2.41 | 547.75 | 709.15 | 0.48 | 0.22 | 0.22 |

HEC-RAS Plan:

| Reach | River Sta | Profile | Q Total (cfs) | Min Ch El (ft) | W.S. Elev (ft) | Crit W.S. (ft) | E.G. Elev (ft) | E.G. Slope (ft/ft) |
|---|---|---|---|---|---|---|---|---|
| studyarea | 42443 | Q50% | 1320 | 230 | 232.88 | 232.38 | 232.97 | 0.002957 |
| studyarea | 42443 | Q2yr | 24800 | 230 | 236.5 | 235.81 | 237.82 | 0.006982 |
| studyarea | 42443 | Q100yr | 49900 | 230 | 238.13 | 238.02 | 240.97 | 0.010052 |
| studyarea | 42345 | Q50% | 1320 | 230 | 232.12 | 232.09 | 232.36 | 0.018668 |
| studyarea | 42345 | Q2yr | 24800 | 230 | 235.18 | 235.18 | 236.89 | 0.012141 |
| studyarea | 42345 | Q100yr | 49900 | 230 | 237.23 | 237.23 | 239.91 | 0.010546 |
| studyarea | 42272 | Q50% | 1320 | 229.49 | 231.41 | | 231.55 | 0.006934 |
| studyarea | 42272 | Q2yr | 24800 | 229.49 | 234.18 | 233.98 | 235.44 | 0.010214 |
| studyarea | 42272 | Q100yr | 49900 | 229.49 | 235.7 | 235.7 | 237.99 | 0.01119 |
| studyarea | 42206 | Q50% | 1320 | 230 | 231.11 | | 231.19 | 0.004017 |
| studyarea | 42206 | Q2yr | 24800 | 230 | 233.67 | 233.39 | 234.75 | 0.00916 |
| studyarea | 42206 | Q100yr | 49900 | 230 | 234.98 | 234.98 | 237.06 | 0.011145 |
| studyarea | 42122 | Q50% | 1320 | 229.18 | 230.59 | 230.42 | 230.7 | 0.008922 |
| studyarea | 42122 | Q2yr | 24800 | 229.18 | 233.14 | 232.7 | 233.97 | 0.007709 |
| studyarea | 42122 | Q100yr | 49900 | 229.18 | 234.46 | 234.09 | 235.99 | 0.008637 |
| studyarea | 42017 | Q50% | 1320 | 228 | 229.59 | 229.3 | 229.83 | 0.007668 |
| studyarea | 42017 | Q2yr | 24800 | 228 | 232.83 | 231.81 | 233.32 | 0.003837 |
| studyarea | 42017 | Q100yr | 49900 | 228 | 234.25 | 233.07 | 235.18 | 0.004516 |
| studyarea | 41929 | Q50% | 1320 | 226 | 229.25 | 228.69 | 229.33 | 0.003626 |
| studyarea | 41929 | Q2yr | 24800 | 226 | 232.64 | 231.27 | 233 | 0.002588 |
| studyarea | 41929 | Q100yr | 49900 | 226 | 234.1 | 232.48 | 234.78 | 0.003063 |
| studyarea | 41774 | Q50% | 1320 | 226 | 229 | 228.31 | 229.03 | 0.00111 |
| studyarea | 41774 | Q2yr | 24800 | 226 | 232.34 | 230.8 | 232.62 | 0.002055 |
| studyarea | 41774 | Q100yr | 49900 | 226 | 233.73 | 231.92 | 234.31 | 0.002639 |
| studyarea | 41632 | Q50% | 1320 | 226 | 228.79 | 228.24 | 228.83 | 0.0018 |
| studyarea | 41632 | Q2yr | 24800 | 226 | 231.93 | 230.79 | 232.27 | 0.002942 |
| studyarea | 41632 | Q100yr | 49900 | 226 | 233.25 | 231.88 | 233.88 | 0.003354 |
| studyarea | 41343 | Q50% | 1320 | 226 | 228.15 | 227.13 | 228.2 | 0.00269 |
| studyarea | 41343 | Q2yr | 24800 | 226 | 231.17 | 229.88 | 231.45 | 0.002639 |
| studyarea | 41343 | Q100yr | 49900 | 226 | 232.4 | 231.05 | 232.93 | 0.003059 |
| studyarea | 41070 | Q50% | 1320 | 226 | 227.1 | 226.74 | 227.23 | 0.004858 |
| studyarea | 41070 | Q2yr | 24800 | 226 | 230.19 | 229.29 | 230.55 | 0.004246 |
| studyarea | 41070 | Q100yr | 49900 | 226 | 231.3 | 230.4 | 231.92 | 0.004454 |
| studyarea | 40885 | Q50% | 1320 | 224 | 226.67 | 226.19 | 226.71 | 0.001721 |
| studyarea | 40885 | Q2yr | 24800 | 224 | 229.5 | 228.61 | 229.8 | 0.003651 |
| studyarea | 40885 | Q100yr | 49900 | 224 | 230.51 | 229.56 | 231.09 | 0.00432 |
| studyarea | 40729 | Q50% | 1320 | 224 | 225.75 | 225.69 | 226.06 | 0.016884 |

| Vel Chnl (ft/s) | Flow Area (sq ft) | Top Width (ft) | Froude # C | Shear Cha (lb/sq ft) | Shear Total (lb/sq ft) |
|---|---|---|---|---|---|
| 2.34 | 563.89 | 526.95 | 0.4 | 0.2 | 0.2 |
| 9.22 | 2690.32 | 612.52 | 0.77 | 1.91 | 1.91 |
| 13.53 | 3697.29 | 625.59 | 0.97 | 3.77 | 3.69 |
| | | | | | |
| 3.92 | 336.43 | 601.81 | 0.92 | 0.65 | 0.65 |
| 10.49 | 2366.91 | 697.65 | 1 | 2.59 | 2.57 |
| 13.17 | 3812.71 | 715 | 0.99 | 3.59 | 3.5 |
| | | | | | |
| 3.01 | 438.15 | 556.8 | 0.6 | 0.34 | 0.34 |
| 9.01 | 2752.21 | 896.72 | 0.91 | 1.96 | 1.96 |
| 12.13 | 4122.69 | 908.51 | 1 | 3.21 | 3.17 |
| | | | | | |
| 2.3 | 573.94 | 727.14 | 0.46 | 0.2 | 0.2 |
| 8.36 | 2970.36 | 1026.39 | 0.86 | 1.67 | 1.65 |
| 11.59 | 4330.55 | 1049.99 | 0.99 | 2.94 | 2.87 |
| | | | | | |
| 2.72 | 484.86 | 861.52 | 0.64 | 0.31 | 0.31 |
| 7.29 | 3408.43 | 1237.07 | 0.77 | 1.34 | 1.33 |
| 9.93 | 5056.88 | 1281.67 | 0.86 | 2.21 | 2.15 |
| | | | | | |
| 3.99 | 330.9 | 286.4 | 0.65 | 0.55 | 0.55 |
| 5.58 | 4450.02 | 1415.99 | 0.55 | 0.76 | 0.75 |
| 7.74 | 6463.48 | 1578.87 | 0.64 | 1.29 | 1.27 |
| | | | | | |
| 2.27 | 580.83 | 685.07 | 0.43 | 0.19 | 0.19 |
| 4.81 | 5163.35 | 1714.69 | 0.46 | 0.55 | 0.54 |
| 6.64 | 7824.71 | 1825.65 | 0.53 | 0.93 | 0.82 |
| | | | | | |
| 1.44 | 914.09 | 870.03 | 0.25 | 0.07 | 0.07 |
| 4.27 | 5807.59 | 1945.57 | 0.41 | 0.44 | 0.43 |
| 6.09 | 8240.88 | 2023.27 | 0.49 | 0.79 | 0.77 |
| | | | | | |
| 1.72 | 766.76 | 809.65 | 0.31 | 0.11 | 0.11 |
| 4.67 | 5320.48 | 1991.18 | 0.48 | 0.53 | 0.53 |
| 6.39 | 8003.25 | 2188.69 | 0.55 | 0.88 | 0.82 |
| | | | | | |
| 1.78 | 741.33 | 1019.1 | 0.37 | 0.12 | 0.12 |
| 4.29 | 5926.89 | 2280.32 | 0.46 | 0.45 | 0.43 |
| 5.9 | 8793.94 | 2421.4 | 0.52 | 0.76 | 0.69 |
| | | | | | |
| 2.86 | 461.68 | 485.91 | 0.52 | 0.29 | 0.29 |
| 4.78 | 5275.98 | 2495.2 | 0.56 | 0.6 | 0.56 |
| 6.37 | 8044.57 | 2513.48 | 0.61 | 0.94 | 0.89 |
| | | | | | |
| 1.59 | 832.63 | 970.73 | 0.3 | 0.09 | 0.09 |
| 4.43 | 5618.77 | 2596.92 | 0.52 | 0.52 | 0.51 |
| 6.12 | 8272.9 | 2770.96 | 0.6 | 0.88 | 0.83 |
| | | | | | |
| 4.51 | 292.89 | 386.42 | 0.91 | 0.8 | 0.8 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| studyarea | 40729 | Q2yr | 24800 | 222.74 | 229 | 228.03 | 229.28 | 0.00483 |
| studyarea | 40729 | Q100yr | 49990 | 222.74 | 230.13 | 229.04 | 230.62 | 0.005021 |
| | | | | | | | | |
| studyarea | 40608 | Q50% | 1320 | 222.74 | 225.29 | 224.73 | 225.4 | 0.005087 |
| studyarea | 40608 | Q2yr | 24800 | 222.74 | 228.35 | 227.54 | 228.68 | 0.005084 |
| studyarea | 40608 | Q100yr | 49990 | 222.74 | 229.44 | 228.56 | 229.99 | 0.00529 |
| | | | | | | | | |
| studyarea | 40459 | Q50% | 1320 | 222.32 | 224.61 | 224.03 | 224.71 | 0.004281 |
| studyarea | 40459 | Q2yr | 24800 | 222.32 | 227.42 | 226.73 | 227.81 | 0.006624 |
| studyarea | 40459 | Q100yr | 49990 | 222.32 | 228.54 | 227.84 | 229.13 | 0.006231 |
| | | | | | | | | |
| studyarea | 40308 | Q50% | 1320 | 221.19 | 224.04 | 223.48 | 224.1 | 0.003693 |
| studyarea | 40308 | Q2yr | 24800 | 221.19 | 226.53 | 225.83 | 226.95 | 0.004978 |
| studyarea | 40308 | Q100yr | 49990 | 221.19 | 227.62 | 227 | 228.25 | 0.005403 |
| | | | | | | | | |
| studyarea | 40211 | Q50% | 1320 | 221.56 | 223.7 | 223.34 | 223.75 | 0.00338 |
| studyarea | 40211 | Q2yr | 24800 | 221.56 | 226.11 | 225.42 | 226.45 | 0.004758 |
| studyarea | 40211 | Q100yr | 49990 | 221.56 | 227.21 | 226.42 | 227.71 | 0.004836 |
| | | | | | | | | |
| studyarea | 40130 | Q50% | 1320 | 221.4 | 223.34 | 223.03 | 223.42 | 0.005136 |
| studyarea | 40130 | Q2yr | 24800 | 221.4 | 225.71 | 225.11 | 226.05 | 0.005248 |
| studyarea | 40130 | Q100yr | 49990 | 221.4 | 226.82 | 225.98 | 227.32 | 0.004954 |
| | | | | | | | | |
| studyarea | 39997 | Q50% | 1320 | 220.51 | 222.41 | 222.14 | 222.55 | 0.008539 |
| studyarea | 39997 | Q2yr | 24800 | 220.51 | 225.09 | 224.38 | 225.4 | 0.004447 |
| studyarea | 39997 | Q100yr | 49990 | 220.51 | 226.26 | 225.3 | 226.7 | 0.004141 |
| | | | | | | | | |
| studyarea | 39936 | Q50% | 1320 | 220.11 | 222.01 | 221.72 | 222.1 | 0.005923 |
| studyarea | 39936 | Q2yr | 24800 | 220.11 | 224.83 | 224.04 | 225.13 | 0.004096 |
| studyarea | 39936 | Q100yr | 49990 | 220.11 | 226.03 | 225.02 | 226.46 | 0.003773 |
| | | | | | | | | |
| studyarea | 39855 | Q50% | 1320 | 219.79 | 221.58 | 221.21 | 221.66 | 0.00489 |
| studyarea | 39855 | Q2yr | 24800 | 219.79 | 224.32 | 223.74 | 224.74 | 0.00552 |
| studyarea | 39855 | Q100yr | 49990 | 219.79 | 225.43 | 224.74 | 226.07 | 0.005264 |
| | | | | | | | | |
| studyarea | 39690 | Q50% | 1320 | 218.78 | 220.96 | 220.44 | 221.02 | 0.003128 |
| studyarea | 39690 | Q2yr | 24800 | 218.78 | 223.56 | 222.83 | 223.92 | 0.004349 |
| studyarea | 39690 | Q100yr | 49990 | 218.78 | 224.77 | 223.85 | 225.29 | 0.003973 |
| | | | | | | | | |
| studyarea | 39559 | Q50% | 1320 | 218.35 | 220.4 | 220.02 | 220.48 | 0.005921 |
| studyarea | 39559 | Q2yr | 24800 | 218.35 | 222.96 | 222.19 | 223.33 | 0.004614 |
| studyarea | 39559 | Q100yr | 49990 | 218.35 | 224.22 | 223.26 | 224.75 | 0.00417 |
| | | | | | | | | |
| studyarea | 39425 | Q50% | 1320 | 217.2 | 219.56 | 219.26 | 219.65 | 0.006263 |
| studyarea | 39425 | Q2yr | 24800 | 217.2 | 222.18 | 221.53 | 222.62 | 0.005957 |
| studyarea | 39425 | Q100yr | 49990 | 217.2 | 223.41 | 222.65 | 224.04 | 0.006706 |
| | | | | | | | | |
| studyarea | 39316 | Q50% | 1320 | 216.38 | 218.88 | 218.54 | 218.99 | 0.005886 |
| studyarea | 39316 | Q2yr | 24800 | 216.38 | 221.64 | 220.92 | 222.03 | 0.004737 |
| studyarea | 39316 | Q100yr | 49990 | 216.38 | 222.82 | 221.99 | 223.43 | 0.004667 |
| | | | | | | | | |
| studyarea | 39229 | Q50% | 1320 | 216.21 | 218.49 | 218.07 | 218.57 | 0.003921 |

| | | | | | |
|---|---|---|---|---|---|
| 4.26 | 5819.04 | 2907.19 | 0.51 | 0.66 | 0.66 |
| 5.62 | 8908.55 | 3144.88 | 0.55 | 1.01 | 1 |
| | | | | | |
| 2.68 | 491.69 | 572.3 | 0.51 | 0.27 | 0.27 |
| 4.73 | 5493.18 | 2949.29 | 0.54 | 0.76 | 0.64 |
| 6.19 | 8639.83 | 3369.09 | 0.58 | 1.15 | 0.95 |
| | | | | | |
| 2.57 | 514.1 | 546 | 0.47 | 0.25 | 0.25 |
| 5.15 | 5095.6 | 2961.62 | 0.61 | 0.91 | 0.75 |
| 6.48 | 8585.02 | 3632.92 | 0.63 | 1.27 | 1.01 |
| | | | | | |
| 1.91 | 693.31 | 1045.47 | 0.41 | 0.15 | 0.15 |
| 5.21 | 4975.34 | 2734.88 | 0.62 | 0.68 | 0.57 |
| 6.59 | 8413.81 | 3785.87 | 0.65 | 1.06 | 0.81 |
| | | | | | |
| 1.81 | 728.91 | 1133.91 | 0.4 | 0.14 | 0.14 |
| 4.71 | 5354.08 | 3000.75 | 0.6 | 0.57 | 0.53 |
| 5.74 | 9113.3 | 3835.26 | 0.61 | 0.83 | 0.75 |
| | | | | | |
| 2.16 | 610.9 | 1005.84 | 0.49 | 0.19 | 0.19 |
| 4.7 | 5412.1 | 3089.77 | 0.6 | 0.61 | 0.57 |
| 5.75 | 9253.78 | 3856.3 | 0.6 | 0.89 | 0.74 |
| | | | | | |
| 2.9 | 454.69 | 706.83 | 0.64 | 0.34 | 0.34 |
| 4.48 | 5685.03 | 3131.99 | 0.56 | 0.55 | 0.5 |
| 5.46 | 9744.4 | 3894.31 | 0.55 | 0.78 | 0.65 |
| | | | | | |
| 2.49 | 529.9 | 775.19 | 0.53 | 0.25 | 0.25 |
| 4.42 | 5766.33 | 3185.23 | 0.55 | 0.52 | 0.47 |
| 5.34 | 10077.76 | 4220.51 | 0.53 | 0.73 | 0.59 |
| | | | | | |
| 2.33 | 567.33 | 802.92 | 0.49 | 0.22 | 0.22 |
| 5.19 | 4879.47 | 2937.83 | 0.63 | 0.72 | 0.66 |
| 6.54 | 8146.13 | 3954.4 | 0.67 | 0.98 | 0.8 |
| | | | | | |
| 1.95 | 675.19 | 882.4 | 0.39 | 0.15 | 0.15 |
| 4.79 | 5298.96 | 2962.78 | 0.58 | 0.58 | 0.52 |
| 5.88 | 9245.16 | 4388.65 | 0.58 | 0.78 | 0.62 |
| | | | | | |
| 2.22 | 595.23 | 994.36 | 0.51 | 0.22 | 0.22 |
| 4.89 | 5075.45 | 2827.23 | 0.59 | 0.61 | 0.61 |
| 5.86 | 8609.27 | 4307.91 | 0.61 | 0.74 | 0.7 |
| | | | | | |
| 2.39 | 551.33 | 908.72 | 0.54 | 0.24 | 0.24 |
| 5.29 | 4690.79 | 2617.89 | 0.64 | 0.78 | 0.77 |
| 6.36 | 7898.69 | 3946.18 | 0.68 | 1.13 | 1.08 |
| | | | | | |
| 2.66 | 495.5 | 668.05 | 0.55 | 0.27 | 0.27 |
| 5.04 | 4927.95 | 2586.03 | 0.6 | 0.64 | 0.63 |
| 6.28 | 8031.39 | 4041.69 | 0.67 | 0.81 | 0.78 |
| | | | | | |
| 2.27 | 581.84 | 741.01 | 0.45 | 0.19 | 0.19 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| studyarea | 40729 | Q2yr | 24800 | 224 | 228.85 | 228.24 | 229.16 | 0.004642 |
| studyarea | 40729 | Q100yr | 49900 | 224 | 229.83 | 229.05 | 230.38 | 0.00475 |
| studyarea | 40608 | Q50% | 1320 | 224 | 225.43 | 224.71 | 225.49 | 0.001811 |
| studyarea | 40608 | Q2yr | 24800 | 224 | 228.3 | 227.34 | 228.6 | 0.004602 |
| studyarea | 40608 | Q100yr | 49900 | 224 | 229.34 | 228.49 | 229.82 | 0.004178 |
| studyarea | 40459 | Q50% | 1320 | 223.68 | 224.99 | 224.61 | 225.08 | 0.004579 |
| studyarea | 40459 | Q2yr | 24800 | 223.68 | 227.51 | 226.89 | 227.86 | 0.005376 |
| studyarea | 40459 | Q100yr | 49900 | 223.68 | 228.46 | 227.8 | 229.05 | 0.006419 |
| studyarea | 40308 | Q50% | 1320 | 222 | 224.33 | 224.1 | 224.39 | 0.004355 |
| studyarea | 40308 | Q2yr | 24800 | 222 | 226.65 | 226.23 | 227 | 0.005953 |
| studyarea | 40308 | Q100yr | 49900 | 222 | 227.56 | 227.01 | 228.13 | 0.005667 |
| studyarea | 40211 | Q50% | 1320 | 222 | 223.6 | 223.49 | 223.73 | 0.01179 |
| studyarea | 40211 | Q2yr | 24800 | 222 | 226.01 | 225.42 | 226.41 | 0.006171 |
| studyarea | 40211 | Q100yr | 49900 | 222 | 227.03 | 226.5 | 227.6 | 0.00517 |
| studyarea | 40130 | Q50% | 1320 | 222 | 223.2 | 222.85 | 223.25 | 0.003304 |
| studyarea | 40130 | Q2yr | 24800 | 222 | 225.72 | 224.88 | 226 | 0.003584 |
| studyarea | 40130 | Q100yr | 49900 | 222 | 226.77 | 225.77 | 227.2 | 0.003872 |
| studyarea | 39997 | Q50% | 1320 | 222 | 222.83 | 222.42 | 222.87 | 0.002521 |
| studyarea | 39997 | Q2yr | 24800 | 222 | 225.25 | 224.5 | 225.51 | 0.003715 |
| studyarea | 39997 | Q100yr | 49900 | 222 | 226.15 | 225.31 | 226.65 | 0.004453 |
| studyarea | 39936 | Q50% | 1320 | 222 | 222.54 | 222.37 | 222.62 | 0.007403 |
| studyarea | 39936 | Q2yr | 24800 | 222 | 224.85 | 224.44 | 225.21 | 0.006315 |
| studyarea | 39936 | Q100yr | 49900 | 222 | 225.84 | 225.22 | 226.35 | 0.0052 |
| studyarea | 39855 | Q50% | 1320 | 220 | 221.37 | 221.37 | 221.63 | 0.022326 |
| studyarea | 39855 | Q2yr | 24800 | 220 | 224.21 | 223.65 | 224.69 | 0.006192 |
| studyarea | 39855 | Q100yr | 49900 | 220 | 225.36 | 224.82 | 225.94 | 0.004705 |
| studyarea | 39690 | Q50% | 1320 | 220 | 220.91 | 220.39 | 220.94 | 0.001449 |
| studyarea | 39690 | Q2yr | 24800 | 220 | 223.52 | 222.67 | 223.87 | 0.003757 |
| studyarea | 39690 | Q100yr | 49900 | 220 | 224.58 | 223.66 | 225.2 | 0.004347 |
| studyarea | 39559 | Q50% | 1320 | 219.82 | 220.61 | 220.33 | 220.66 | 0.003497 |
| studyarea | 39559 | Q2yr | 24800 | 219.82 | 222.99 | 222.28 | 223.35 | 0.004209 |
| studyarea | 39559 | Q100yr | 49900 | 219.82 | 223.98 | 223.31 | 224.6 | 0.004814 |
| studyarea | 39425 | Q50% | 1320 | 218 | 219.73 | 219.45 | 219.93 | 0.009112 |
| studyarea | 39425 | Q2yr | 24800 | 218 | 222.18 | 221.61 | 222.67 | 0.005867 |
| studyarea | 39425 | Q100yr | 49900 | 218 | 223.31 | 222.81 | 223.94 | 0.004922 |
| studyarea | 39316 | Q50% | 1320 | 218 | 219.12 | 218.72 | 219.21 | 0.004578 |
| studyarea | 39316 | Q2yr | 24800 | 218 | 221.62 | 221.01 | 222.05 | 0.005254 |
| studyarea | 39316 | Q100yr | 49900 | 218 | 222.69 | 221.99 | 223.38 | 0.00531 |
| studyarea | 39229 | Q50% | 1320 | 218 | 218.84 | 218.46 | 218.9 | 0.002803 |

| | | | | | |
|---|---|---|---|---|---|
| 4.52 | 5603.02 | 2993.21 | 0.57 | 0.57 | 0.54 |
| 5.99 | 8570.92 | 3053.33 | 0.62 | 0.87 | 0.83 |
| 2.03 | 650.08 | 544.93 | 0.33 | 0.13 | 0.13 |
| 4.42 | 5670.56 | 3315.05 | 0.56 | 0.55 | 0.51 |
| 5.62 | 9198.1 | 3373.4 | 0.58 | 0.76 | 0.71 |
| 2.46 | 537.26 | 662.14 | 0.48 | 0.23 | 0.23 |
| 4.77 | 5195.2 | 2744.18 | 0.61 | 0.65 | 0.65 |
| 6.15 | 8200.05 | 3651.9 | 0.69 | 0.99 | 0.93 |
| 1.86 | 710.77 | 1316.41 | 0.45 | 0.15 | 0.15 |
| 4.85 | 5312.05 | 3454.76 | 0.64 | 0.67 | 0.59 |
| 6.18 | 8476.16 | 3678.51 | 0.66 | 0.95 | 0.84 |
| 2.83 | 466.92 | 966.43 | 0.72 | 0.36 | 0.36 |
| 5.09 | 4875.25 | 3606.14 | 0.65 | 0.73 | 0.52 |
| 6.22 | 8663.9 | 3804.98 | 0.64 | 0.95 | 0.74 |
| 1.87 | 705.59 | 1027.73 | 0.4 | 0.14 | 0.14 |
| 4.21 | 5948.75 | 2874.05 | 0.51 | 0.48 | 0.46 |
| 5.36 | 9758.52 | 3967.47 | 0.55 | 0.71 | 0.59 |
| 1.66 | 795.49 | 1140.17 | 0.35 | 0.11 | 0.11 |
| 4.13 | 6126.7 | 3173.63 | 0.51 | 0.47 | 0.45 |
| 5.71 | 9257.97 | 4432.11 | 0.59 | 0.8 | 0.59 |
| 2.29 | 576.07 | 1137.54 | 0.57 | 0.23 | 0.23 |
| 4.85 | 5298.59 | 3477.32 | 0.65 | 0.69 | 0.6 |
| 5.92 | 8859.73 | 3720.65 | 0.63 | 0.88 | 0.77 |
| 4.13 | 319.92 | 609.63 | 1 | 0.73 | 0.73 |
| 5.61 | 4675.87 | 3526.88 | 0.67 | 0.85 | 0.51 |
| 6.47 | 8898.69 | 3819.66 | 0.62 | 0.98 | 0.68 |
| 1.48 | 894.67 | 1016.61 | 0.28 | 0.08 | 0.08 |
| 4.77 | 5281.44 | 2337.16 | 0.53 | 0.58 | 0.56 |
| 6.45 | 8736.21 | 4692.46 | 0.61 | 0.95 | 0.58 |
| 1.73 | 761.33 | 1309.23 | 0.4 | 0.13 | 0.13 |
| 4.89 | 5428.18 | 2869.84 | 0.56 | 0.63 | 0.5 |
| 6.56 | 8560.22 | 3362.96 | 0.63 | 1.01 | 0.76 |
| 3.52 | 375.2 | 463.65 | 0.69 | 0.46 | 0.46 |
| 5.64 | 4620.28 | 3256.41 | 0.66 | 0.84 | 0.54 |
| 6.74 | 8407.03 | 3763.94 | 0.64 | 1.05 | 0.72 |
| 2.52 | 523.31 | 635.7 | 0.49 | 0.24 | 0.24 |
| 5.3 | 4709.82 | 2174.49 | 0.62 | 0.74 | 0.72 |
| 6.84 | 8064.4 | 4291.08 | 0.66 | 1.09 | 0.7 |
| 1.82 | 725.42 | 995.56 | 0.38 | 0.13 | 0.13 |

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|---|---|---|---|---|---|---|---|---|
| studyarea | 39229 | Q2yr | 24800 | 216.21 | 221.24 | 220.52 | 221.62 | 0.004649 |
| studyarea | 39229 | Q100yr | 49990 | 216.21 | 222.46 | 221.53 | 223.03 | 0.004395 |
| studyarea | 39077 | Q50% | 1320 | 215.17 | 218 | 217.37 | 218.06 | 0.002867 |
| studyarea | 39077 | Q2yr | 24800 | 215.17 | 220.69 | 219.73 | 221 | 0.003302 |
| studyarea | 39077 | Q100yr | 49990 | 215.17 | 221.9 | 220.75 | 222.42 | 0.003499 |
| studyarea | 38898 | Q50% | 1320 | 215.1 | 217.41 | 216.88 | 217.48 | 0.003631 |
| studyarea | 38898 | Q2yr | 24800 | 215.1 | 219.89 | 219.23 | 220.28 | 0.004937 |
| studyarea | 38898 | Q100yr | 49990 | 215.1 | 221.12 | 220.24 | 221.69 | 0.004656 |
| studyarea | 38784 | Q50% | 1320 | 214.71 | 216.9 | 216.51 | 216.99 | 0.005298 |
| studyarea | 38784 | Q2yr | 24800 | 214.71 | 219.29 | 218.63 | 219.71 | 0.005058 |
| studyarea | 38784 | Q100yr | 49990 | 214.71 | 220.36 | 219.66 | 221.1 | 0.005554 |
| studyarea | 38690 | Q50% | 1320 | 214.39 | 216.43 | 215.98 | 216.51 | 0.00483 |
| studyarea | 38690 | Q2yr | 24800 | 214.39 | 218.85 | 218.15 | 219.23 | 0.004875 |
| studyarea | 38690 | Q100yr | 49990 | 214.39 | 219.95 | 219.16 | 220.57 | 0.004916 |
| studyarea | 38573 | Q50% | 1320 | 213.76 | 215.89 | 215.47 | 215.96 | 0.004641 |
| studyarea | 38573 | Q2yr | 24800 | 213.76 | 218.37 | 217.59 | 218.7 | 0.003992 |
| studyarea | 38573 | Q100yr | 49990 | 213.76 | 219.52 | 218.58 | 220.02 | 0.003984 |
| studyarea | 38424 | Q50% | 1320 | 213.09 | 215.08 | 214.8 | 215.17 | 0.006094 |
| studyarea | 38424 | Q2yr | 24800 | 213.09 | 217.64 | 217 | 218.03 | 0.005024 |
| studyarea | 38424 | Q100yr | 49990 | 213.09 | 218.87 | 218.05 | 219.4 | 0.004402 |
| studyarea | 38299 | Q50% | 1320 | 211.68 | 214.5 | 214.11 | 214.57 | 0.003861 |
| studyarea | 38299 | Q2yr | 24800 | 211.68 | 217.11 | 216.27 | 217.46 | 0.003998 |
| studyarea | 38299 | Q100yr | 49990 | 211.68 | 218.37 | 217.35 | 218.88 | 0.003758 |
| studyarea | 38183 | Q50% | 1320 | 211.98 | 214.02 | 213.63 | 214.09 | 0.004439 |
| studyarea | 38183 | Q2yr | 24800 | 211.98 | 216.61 | 215.72 | 217 | 0.003895 |
| studyarea | 38183 | Q100yr | 49990 | 211.98 | 217.83 | 216.94 | 218.42 | 0.004066 |
| studyarea | 38113 | Q50% | 1320 | 211.52 | 213.63 | 213.21 | 213.72 | 0.005871 |
| studyarea | 38113 | Q2yr | 24800 | 211.52 | 216.32 | 215.54 | 216.71 | 0.004225 |
| studyarea | 38113 | Q100yr | 49990 | 211.52 | 217.61 | 216.62 | 218.12 | 0.003747 |
| studyarea | 37982 | Q50% | 1320 | 210.59 | 213.04 | 212.57 | 213.11 | 0.003822 |
| studyarea | 37982 | Q2yr | 24800 | 210.59 | 215.71 | 214.92 | 216.15 | 0.004313 |
| studyarea | 37982 | Q100yr | 49990 | 210.59 | 216.89 | 216.18 | 217.56 | 0.004642 |
| studyarea | 37811 | Q50% | 1320 | 208.99 | 212.25 | 211.84 | 212.34 | 0.005246 |
| studyarea | 37811 | Q2yr | 24800 | 208.99 | 215 | 214.15 | 215.4 | 0.004262 |
| studyarea | 37811 | Q100yr | 49990 | 208.99 | 216.18 | 215.42 | 216.77 | 0.004296 |
| studyarea | 37577 | Q50% | 1320 | 208.43 | 211.07 | 210.5 | 211.18 | 0.004699 |
| studyarea | 37577 | Q2yr | 24800 | 208.43 | 214.06 | 213.26 | 214.41 | 0.004045 |
| studyarea | 37577 | Q100yr | 49990 | 208.43 | 215.4 | 214.38 | 215.83 | 0.003399 |
| studyarea | 37350 | Q50% | 1320 | 208.03 | 210.19 | 209.47 | 210.27 | 0.003382 |

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|---|---|---|---|---|---|
| 4.91 | 5047.62 | 3128.97 | 0.6 | 0.61 | 0.61 |
| 6.07 | 8285.45 | 4473.82 | 0.64 | 0.76 | 0.74 |
| | | | | | |
| 1.89 | 697.9 | 952.93 | 0.38 | 0.14 | 0.14 |
| 4.48 | 5589.22 | 2869.08 | 0.51 | 0.5 | 0.47 |
| 5.84 | 9008.28 | 4305.43 | 0.57 | 0.7 | 0.57 |
| | | | | | |
| 2.17 | 608.95 | 831.26 | 0.43 | 0.18 | 0.18 |
| 5.05 | 5005.96 | 2686.67 | 0.61 | 0.66 | 0.63 |
| 6.16 | 8476.43 | 3929.16 | 0.64 | 0.83 | 0.73 |
| | | | | | |
| 2.31 | 570.31 | 861.92 | 0.5 | 0.22 | 0.22 |
| 5.2 | 4807.84 | 2610.06 | 0.61 | 0.71 | 0.68 |
| 6.92 | 7490.92 | 3828.13 | 0.69 | 1.1 | 0.91 |
| | | | | | |
| 2.28 | 578.06 | 846.06 | 0.48 | 0.21 | 0.21 |
| 4.95 | 5068.15 | 2889.03 | 0.6 | 0.64 | 0.61 |
| 6.4 | 8246.13 | 4006.24 | 0.64 | 0.94 | 0.74 |
| | | | | | |
| 2.11 | 625.93 | 984.87 | 0.47 | 0.18 | 0.18 |
| 4.59 | 5460.15 | 3087.31 | 0.56 | 0.51 | 0.49 |
| 5.76 | 9095.28 | 4539.82 | 0.59 | 0.73 | 0.6 |
| | | | | | |
| 2.45 | 539.07 | 860.38 | 0.54 | 0.24 | 0.24 |
| 5.03 | 5029.93 | 2918.02 | 0.62 | 0.65 | 0.6 |
| 5.93 | 9095.51 | 4593.69 | 0.61 | 0.81 | 0.62 |
| | | | | | |
| 2.11 | 625.73 | 897.16 | 0.44 | 0.17 | 0.17 |
| 4.78 | 5304.5 | 2883.27 | 0.56 | 0.56 | 0.51 |
| 5.83 | 9344.9 | 4663.1 | 0.58 | 0.73 | 0.53 |
| | | | | | |
| 2.12 | 622.95 | 982.33 | 0.46 | 0.18 | 0.18 |
| 5.04 | 5042.22 | 2715.54 | 0.56 | 0.6 | 0.52 |
| 6.36 | 8795.04 | 4836.87 | 0.62 | 0.82 | 0.57 |
| | | | | | |
| 2.48 | 532.55 | 818.93 | 0.53 | 0.25 | 0.25 |
| 5.04 | 5185.34 | 3003.42 | 0.58 | 0.62 | 0.5 |
| 5.95 | 9794.84 | 5203.99 | 0.58 | 0.75 | 0.52 |
| | | | | | |
| 2.13 | 620.66 | 865.29 | 0.44 | 0.17 | 0.17 |
| 5.33 | 4811.68 | 3305.13 | 0.6 | 0.66 | 0.55 |
| 6.76 | 8328.27 | 4832.1 | 0.65 | 0.96 | 0.69 |
| | | | | | |
| 2.37 | 561.14 | 852.33 | 0.51 | 0.22 | 0.22 |
| 5.16 | 5116.78 | 3168.02 | 0.59 | 0.64 | 0.5 |
| 6.41 | 9061.94 | 4610.08 | 0.63 | 0.86 | 0.64 |
| | | | | | |
| 2.69 | 490.01 | 558.55 | 0.51 | 0.26 | 0.26 |
| 4.82 | 5361.72 | 2953.34 | 0.58 | 0.54 | 0.49 |
| 5.43 | 9813.99 | 4430.6 | 0.56 | 0.61 | 0.56 |
| | | | | | |
| 2.29 | 575.61 | 651.11 | 0.43 | 0.19 | 0.19 |

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|---|---|---|---|---|---|---|---|---|
| studyarea | 39229 | Q2yr | 24800 | 218 | 221.19 | 220.64 | 221.58 | 0.005326 |
| studyarea | 39229 | Q100yr | 49900 | 218 | 222.34 | 221.58 | 222.91 | 0.004728 |
| studyarea | 39077 | Q50% | 1320 | 216 | 218.29 | 218.11 | 218.33 | 0.005056 |
| studyarea | 39077 | Q2yr | 24800 | 216 | 220.68 | 219.62 | 220.96 | 0.002862 |
| studyarea | 39077 | Q100yr | 49900 | 216 | 221.84 | 220.67 | 222.3 | 0.003068 |
| studyarea | 38898 | Q50% | 1320 | 216 | 217.47 | 216.94 | 217.57 | 0.003636 |
| studyarea | 38898 | Q2yr | 24800 | 216 | 219.93 | 219.25 | 220.31 | 0.004574 |
| studyarea | 38898 | Q100yr | 49900 | 216 | 221.09 | 219.97 | 221.65 | 0.004245 |
| studyarea | 38784 | Q50% | 1320 | 216 | 216.92 | 216.65 | 217.01 | 0.006958 |
| studyarea | 38784 | Q2yr | 24800 | 216 | 219.23 | 218.79 | 219.69 | 0.006373 |
| studyarea | 38784 | Q100yr | 49900 | 216 | 220.25 | 219.73 | 221.03 | 0.006643 |
| studyarea | 38690 | Q50% | 1320 | 214.97 | 216.66 | 216.25 | 216.68 | 0.001893 |
| studyarea | 38690 | Q2yr | 24800 | 214.97 | 218.89 | 218.07 | 219.21 | 0.003612 |
| studyarea | 38690 | Q100yr | 49900 | 214.97 | 219.92 | 219.05 | 220.48 | 0.004129 |
| studyarea | 38573 | Q50% | 1320 | 214 | 216.27 | 216.11 | 216.32 | 0.00601 |
| studyarea | 38573 | Q2yr | 24800 | 214 | 218.42 | 217.63 | 218.76 | 0.004056 |
| studyarea | 38573 | Q100yr | 49900 | 214 | 219.49 | 218.72 | 219.99 | 0.003946 |
| studyarea | 38424 | Q50% | 1320 | 214 | 215.02 | 214.86 | 215.17 | 0.010152 |
| studyarea | 38424 | Q2yr | 24800 | 214 | 217.6 | 217.05 | 218.05 | 0.005599 |
| studyarea | 38424 | Q100yr | 49900 | 214 | 218.89 | 217.99 | 219.4 | 0.00392 |
| studyarea | 38299 | Q50% | 1320 | 212 | 214.72 | 214.27 | 214.74 | 0.001456 |
| studyarea | 38299 | Q2yr | 24800 | 212 | 217.21 | 216.18 | 217.52 | 0.002823 |
| studyarea | 38299 | Q100yr | 49900 | 212 | 218.19 | 217.24 | 218.87 | 0.004277 |
| studyarea | 38183 | Q50% | 1320 | 212.19 | 214.48 | 214.2 | 214.51 | 0.002695 |
| studyarea | 38183 | Q2yr | 24800 | 212.19 | 216.76 | 215.88 | 217.14 | 0.003747 |
| studyarea | 38183 | Q100yr | 49900 | 212.19 | 217.7 | 217.17 | 218.35 | 0.004585 |
| studyarea | 38113 | Q50% | 1320 | 212 | 213.71 | 213.71 | 214.08 | 0.02008 |
| studyarea | 38113 | Q2yr | 24800 | 212 | 216.23 | 215.71 | 216.79 | 0.006272 |
| studyarea | 38113 | Q100yr | 49900 | 212 | 217.5 | 217.01 | 218.01 | 0.003918 |
| studyarea | 37982 | Q50% | 1320 | 211.52 | 213.09 | 212.58 | 213.14 | 0.002256 |
| studyarea | 37982 | Q2yr | 24800 | 211.52 | 215.65 | 214.82 | 216.1 | 0.00413 |
| studyarea | 37982 | Q100yr | 49900 | 211.52 | 216.8 | 215.98 | 217.46 | 0.004288 |
| studyarea | 37811 | Q50% | 1320 | 210 | 212.39 | 212.25 | 212.47 | 0.008032 |
| studyarea | 37811 | Q2yr | 24800 | 210 | 215.03 | 214.24 | 215.38 | 0.003897 |
| studyarea | 37811 | Q100yr | 49900 | 210 | 216.18 | 215.29 | 216.72 | 0.003865 |
| studyarea | 37577 | Q50% | 1320 | 210 | 211.28 | 210.8 | 211.36 | 0.003161 |
| studyarea | 37577 | Q2yr | 24800 | 210 | 214.17 | 213.18 | 214.52 | 0.003469 |
| studyarea | 37577 | Q100yr | 49900 | 210 | 215.56 | 214.5 | 215.95 | 0.002551 |
| studyarea | 37350 | Q50% | 1320 | 208.01 | 210.39 | 210.17 | 210.45 | 0.005126 |

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|---|---|---|---|---|---|
| 5.1 | 5067.88 | 2750.59 | 0.61 | 0.72 | 0.61 |
| 6.3 | 9042.76 | 5058.81 | 0.61 | 0.96 | 0.58 |
| | | | | | |
| 1.73 | 771.21 | 1829.66 | 0.47 | 0.13 | 0.13 |
| 4.33 | 6018.48 | 2916.64 | 0.47 | 0.47 | 0.39 |
| 5.7 | 9647.5 | 3652.36 | 0.51 | 0.73 | 0.54 |
| | | | | | |
| 2.51 | 525.53 | 523.12 | 0.44 | 0.23 | 0.23 |
| 5.05 | 5096.24 | 2386.59 | 0.58 | 0.67 | 0.62 |
| 6.34 | 8865.03 | 4108.6 | 0.6 | 0.93 | 0.63 |
| | | | | | |
| 2.38 | 555.78 | 996.13 | 0.56 | 0.24 | 0.24 |
| 5.56 | 4620.12 | 2418.27 | 0.67 | 0.85 | 0.76 |
| 7.34 | 7500.01 | 4671.52 | 0.73 | 1.29 | 0.77 |
| | | | | | |
| 1.33 | 994.13 | 1605.16 | 0.3 | 0.07 | 0.07 |
| 4.58 | 5612.04 | 2851.01 | 0.52 | 0.54 | 0.47 |
| 6.13 | 8680.29 | 3363.07 | 0.59 | 0.87 | 0.71 |
| | | | | | |
| 1.83 | 722.27 | 1739.5 | 0.5 | 0.16 | 0.16 |
| 4.72 | 5563.12 | 3355.23 | 0.55 | 0.58 | 0.44 |
| 5.92 | 9365.66 | 4132.87 | 0.58 | 0.81 | 0.59 |
| | | | | | |
| 3.11 | 426.75 | 690.06 | 0.7 | 0.39 | 0.39 |
| 5.52 | 4722.61 | 2335 | 0.64 | 0.8 | 0.71 |
| 6.22 | 9895.6 | 4928.34 | 0.58 | 0.88 | 0.49 |
| | | | | | |
| 1.3 | 1015.62 | 1445.71 | 0.27 | 0.07 | 0.07 |
| 4.59 | 5695.72 | 2712.86 | 0.47 | 0.51 | 0.43 |
| 6.86 | 8419.66 | 5254.28 | 0.61 | 1.04 | 0.51 |
| | | | | | |
| 1.49 | 885.1 | 1621.05 | 0.35 | 0.09 | 0.09 |
| 5.09 | 5329.42 | 3320.2 | 0.54 | 0.63 | 0.42 |
| 6.84 | 8568.38 | 4288.97 | 0.63 | 1.04 | 0.63 |
| | | | | | |
| 4.86 | 271.69 | 373.93 | 1 | 0.91 | 0.91 |
| 6.06 | 4514.5 | 4004.52 | 0.69 | 0.95 | 0.48 |
| 6.34 | 9759.76 | 4951.41 | 0.58 | 0.9 | 0.54 |
| | | | | | |
| 1.73 | 763.17 | 960.42 | 0.34 | 0.11 | 0.11 |
| 5.37 | 4743.45 | 2335.42 | 0.57 | 0.71 | 0.62 |
| 6.88 | 8626.05 | 4974.53 | 0.61 | 1.04 | 0.56 |
| | | | | | |
| 2.25 | 585.65 | 1284.13 | 0.59 | 0.23 | 0.23 |
| 4.84 | 5422.95 | 3221.06 | 0.54 | 0.6 | 0.47 |
| 6.17 | 9224.23 | 5107.34 | 0.57 | 0.86 | 0.54 |
| | | | | | |
| 2.14 | 616.11 | 724.25 | 0.41 | 0.17 | 0.17 |
| 4.74 | 5523.66 | 3884.41 | 0.52 | 0.57 | 0.34 |
| 5.32 | 10637.67 | 4313.74 | 0.47 | 0.64 | 0.45 |
| | | | | | |
| 2.04 | 645.53 | 1200.41 | 0.49 | 0.18 | 0.18 |

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|---|---|---|---|---|---|---|---|---|
| studyarea | 37350 | Q2yr | 24800 | 208.03 | 213.29 | 212.19 | 213.6 | 0.003096 |
| studyarea | 37350 | Q100yr | 49990 | 208.03 | 214.64 | 213.35 | 215.09 | 0.003176 |
| | | | | | | | | |
| studyarea | 37225 | Q50% | 1320 | 207.32 | 209.85 | 209.26 | 209.91 | 0.002422 |
| studyarea | 37225 | Q2yr | 24800 | 207.32 | 212.96 | 211.72 | 213.24 | 0.002552 |
| studyarea | 37225 | Q100yr | 49990 | 207.32 | 214.29 | 212.88 | 214.72 | 0.002653 |
| | | | | | | | | |
| studyarea | 36985 | Q50% | 1320 | 206.38 | 208.96 | 208.53 | 209.07 | 0.005297 |
| studyarea | 36985 | Q2yr | 24800 | 206.38 | 212.17 | 211.16 | 212.51 | 0.003531 |
| studyarea | 36985 | Q100yr | 49990 | 206.38 | 213.51 | 212.36 | 213.99 | 0.003371 |
| | | | | | | | | |
| studyarea | 36719 | Q50% | 1320 | 205.44 | 207.93 | 207.25 | 208 | 0.003124 |
| studyarea | 36719 | Q2yr | 24800 | 205.44 | 211.18 | 210.14 | 211.56 | 0.003652 |
| studyarea | 36719 | Q100yr | 49990 | 205.44 | 212.46 | 211.41 | 213.03 | 0.003865 |
| | | | | | | | | |
| studyarea | 36575 | Q50% | 1320 | 205.35 | 207.49 | 206.89 | 207.56 | 0.002953 |
| studyarea | 36575 | Q2yr | 24800 | 205.35 | 210.65 | 209.62 | 211.02 | 0.003718 |
| studyarea | 36575 | Q100yr | 49990 | 205.35 | 211.95 | 210.94 | 212.45 | 0.003808 |
| | | | | | | | | |
| studyarea | 36440 | Q50% | 1320 | 204.99 | 207.15 | 206.39 | 207.21 | 0.002315 |
| studyarea | 36440 | Q2yr | 24800 | 204.99 | 210.19 | 209.09 | 210.52 | 0.003531 |
| studyarea | 36440 | Q100yr | 49990 | 204.99 | 211.48 | 210.38 | 211.95 | 0.003551 |
| | | | | | | | | |
| studyarea | 36245 | Q50% | 1320 | 204.28 | 206.49 | 206.1 | 206.58 | 0.004621 |
| studyarea | 36245 | Q2yr | 24800 | 204.28 | 209.31 | 208.6 | 209.71 | 0.004866 |
| studyarea | 36245 | Q100yr | 49990 | 204.28 | 210.59 | 209.72 | 211.14 | 0.004832 |
| | | | | | | | | |
| studyarea | 36163 | Q50% | 1320 | 203.62 | 206.02 | 205.76 | 206.13 | 0.006658 |
| studyarea | 36163 | Q2yr | 24800 | 203.62 | 208.92 | 208.19 | 209.32 | 0.004643 |
| studyarea | 36163 | Q100yr | 49990 | 203.62 | 210.17 | 209.32 | 210.75 | 0.004506 |
| | | | | | | | | |
| studyarea | 36046 | Q50% | 1320 | 203.25 | 205.62 | 205.1 | 205.67 | 0.002362 |
| studyarea | 36046 | Q2yr | 24800 | 203.25 | 208.47 | 207.51 | 208.82 | 0.003765 |
| studyarea | 36046 | Q100yr | 49990 | 203.25 | 209.74 | 208.75 | 210.24 | 0.003766 |
| | | | | | | | | |
| studyarea | 35870 | Q50% | 1320 | 203.16 | 205.07 | 204.53 | 205.14 | 0.004091 |
| studyarea | 35870 | Q2yr | 24800 | 203.16 | 207.83 | 206.92 | 208.14 | 0.003825 |
| studyarea | 35870 | Q100yr | 49990 | 203.16 | 209.16 | 207.99 | 209.6 | 0.003404 |
| | | | | | | | | |
| studyarea | 35611 | Q50% | 1320 | 202.07 | 204.09 | 203.63 | 204.16 | 0.003544 |
| studyarea | 35611 | Q2yr | 24800 | 202.07 | 206.62 | 205.88 | 207.05 | 0.004565 |
| studyarea | 35611 | Q100yr | 49990 | 202.07 | 207.93 | 207.01 | 208.57 | 0.004458 |
| | | | | | | | | |
| studyarea | 35386 | Q50% | 1320 | 201 | 203.26 | 202.88 | 203.32 | 0.003886 |
| studyarea | 35386 | Q2yr | 24800 | 201 | 205.68 | 204.89 | 206.06 | 0.004095 |
| studyarea | 35386 | Q100yr | 49990 | 201 | 206.98 | 205.92 | 207.59 | 0.004171 |
| | | | | | | | | |
| studyarea | 35154 | Q50% | 1320 | 200.49 | 202.06 | 201.78 | 202.15 | 0.006851 |
| studyarea | 35154 | Q2yr | 24800 | 200.49 | 204.73 | 203.9 | 205.12 | 0.004004 |
| studyarea | 35154 | Q100yr | 49990 | 200.49 | 206.1 | 205.01 | 206.66 | 0.003763 |
| | | | | | | | | |
| studyarea | 34992 | Q50% | 1320 | 198.8 | 201.26 | 200.85 | 201.33 | 0.003857 |

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|---|---|---|---|---|---|
| 4.48 | 5586.99 | 2627.56 | 0.51 | 0.47 | 0.45 |
| 5.44 | 9551.61 | 4179.77 | 0.54 | 0.61 | 0.55 |
| | | | | | |
| 1.87 | 707.07 | 844.73 | 0.36 | 0.13 | 0.13 |
| 4.24 | 6038.98 | 2850.12 | 0.46 | 0.42 | 0.38 |
| 5.35 | 10119.11 | 4542.12 | 0.51 | 0.56 | 0.45 |
| | | | | | |
| 2.66 | 496.59 | 621.5 | 0.52 | 0.26 | 0.26 |
| 4.73 | 5338.98 | 2595.94 | 0.54 | 0.53 | 0.49 |
| 5.66 | 9348.47 | 4531.93 | 0.59 | 0.61 | 0.53 |
| | | | | | |
| 2.24 | 589.3 | 641.66 | 0.41 | 0.18 | 0.18 |
| 4.94 | 5157.92 | 2366.59 | 0.54 | 0.58 | 0.52 |
| 6.18 | 8697.74 | 3968.84 | 0.62 | 0.74 | 0.62 |
| | | | | | |
| 2.22 | 594.8 | 629.4 | 0.4 | 0.17 | 0.17 |
| 4.91 | 5114.79 | 2347.98 | 0.57 | 0.54 | 0.51 |
| 5.76 | 9066.64 | 4009.28 | 0.61 | 0.66 | 0.6 |
| | | | | | |
| 1.91 | 692.91 | 778.44 | 0.36 | 0.13 | 0.13 |
| 4.63 | 5423.29 | 2593.75 | 0.54 | 0.5 | 0.48 |
| 5.56 | 9279.25 | 4053.34 | 0.57 | 0.64 | 0.59 |
| | | | | | |
| 2.39 | 551.46 | 729.3 | 0.49 | 0.22 | 0.22 |
| 5.11 | 4901.27 | 2581.5 | 0.62 | 0.64 | 0.62 |
| 5.99 | 8535.92 | 3698.94 | 0.63 | 0.84 | 0.79 |
| | | | | | |
| 2.62 | 503.72 | 766.95 | 0.57 | 0.27 | 0.27 |
| 5.1 | 4897.16 | 2552.28 | 0.62 | 0.61 | 0.6 |
| 6.16 | 8281.16 | 3766.66 | 0.63 | 0.82 | 0.77 |
| | | | | | |
| 1.81 | 729.78 | 903.93 | 0.36 | 0.12 | 0.12 |
| 4.77 | 5214.69 | 2584.2 | 0.57 | 0.52 | 0.52 |
| 5.71 | 8828.96 | 3850.9 | 0.59 | 0.67 | 0.65 |
| | | | | | |
| 2.2 | 598.68 | 819.95 | 0.45 | 0.19 | 0.19 |
| 4.5 | 5537.43 | 2893.38 | 0.55 | 0.5 | 0.49 |
| 5.36 | 9402.76 | 3828.4 | 0.54 | 0.65 | 0.64 |
| | | | | | |
| 2.08 | 635.29 | 851.61 | 0.42 | 0.16 | 0.16 |
| 5.24 | 4765.73 | 2460.9 | 0.61 | 0.64 | 0.62 |
| 6.46 | 7925.9 | 3444.56 | 0.65 | 0.86 | 0.79 |
| | | | | | |
| 1.94 | 679.96 | 1078.16 | 0.43 | 0.15 | 0.15 |
| 4.98 | 5023.05 | 2288.62 | 0.57 | 0.61 | 0.59 |
| 6.29 | 8171.83 | 3455.9 | 0.61 | 0.86 | 0.74 |
| | | | | | |
| 2.43 | 544.06 | 948.05 | 0.56 | 0.25 | 0.25 |
| 5.04 | 5014.36 | 2462.25 | 0.59 | 0.57 | 0.54 |
| 6.07 | 8615.18 | 3801.46 | 0.59 | 0.76 | 0.67 |
| | | | | | |
| 2.08 | 635.3 | 904.16 | 0.44 | 0.17 | 0.17 |

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|---|---|---|---|---|---|---|---|---|
| studyarea | 37350 | Q2yr | 24800 | 208.01 | 213.44 | 212.38 | 213.79 | 0.002988 |
| studyarea | 37350 | Q100yr | 49900 | 208.01 | 214.74 | 213.52 | 215.29 | 0.003155 |
| | | | | | | | | |
| studyarea | 37225 | Q50% | 1320 | 208 | 209.94 | 209.22 | 210.03 | 0.002378 |
| studyarea | 37225 | Q2yr | 24800 | 208 | 213.12 | 212.07 | 213.41 | 0.002756 |
| studyarea | 37225 | Q100yr | 49900 | 208 | 214.45 | 213.11 | 214.89 | 0.002754 |
| | | | | | | | | |
| studyarea | 36985 | Q50% | 1320 | 208 | 209.28 | 208.77 | 209.37 | 0.003234 |
| studyarea | 36985 | Q2yr | 24800 | 208 | 212.36 | 211.3 | 212.69 | 0.003181 |
| studyarea | 36985 | Q100yr | 49900 | 208 | 213.83 | 212.58 | 214.25 | 0.002533 |
| | | | | | | | | |
| studyarea | 36719 | Q50% | 1320 | 206 | 208.13 | 207.25 | 208.22 | 0.006077 |
| studyarea | 36719 | Q2yr | 24800 | 206 | 211.26 | 210.43 | 211.73 | 0.004018 |
| studyarea | 36719 | Q100yr | 49900 | 206 | 212.35 | 211.66 | 213.26 | 0.005336 |
| | | | | | | | | |
| studyarea | 36575 | Q50% | 1320 | 206 | 207.63 | 206.86 | 207.73 | 0.002143 |
| studyarea | 36575 | Q2yr | 24800 | 206 | 210.81 | 209.7 | 211.15 | 0.003578 |
| studyarea | 36575 | Q100yr | 49900 | 206 | 211.97 | 211.01 | 212.51 | 0.003745 |
| | | | | | | | | |
| studyarea | 36440 | Q50% | 1320 | 206 | 207.3 | 206.78 | 207.37 | 0.003199 |
| studyarea | 36440 | Q2yr | 24800 | 206 | 210.23 | 209.29 | 210.62 | 0.004098 |
| studyarea | 36440 | Q100yr | 49900 | 206 | 211.51 | 210.66 | 212.01 | 0.003479 |
| | | | | | | | | |
| studyarea | 36245 | Q50% | 1320 | 205.81 | 206.78 | 206.39 | 206.82 | 0.002453 |
| studyarea | 36245 | Q2yr | 24800 | 205.81 | 209.29 | 208.68 | 209.74 | 0.005017 |
| studyarea | 36245 | Q100yr | 49900 | 205.81 | 210.53 | 209.75 | 211.21 | 0.004704 |
| | | | | | | | | |
| studyarea | 36163 | Q50% | 1320 | 204.95 | 206.23 | 206.2 | 206.38 | 0.01965 |
| studyarea | 36163 | Q2yr | 24800 | 204.95 | 208.93 | 208.23 | 209.34 | 0.004413 |
| studyarea | 36163 | Q100yr | 49900 | 204.95 | 210.17 | 209.31 | 210.82 | 0.004515 |
| | | | | | | | | |
| studyarea | 36046 | Q50% | 1320 | 204 | 205.56 | 204.96 | 205.64 | 0.002918 |
| studyarea | 36046 | Q2yr | 24800 | 204 | 208.49 | 207.51 | 208.85 | 0.003735 |
| studyarea | 36046 | Q100yr | 49900 | 204 | 209.84 | 208.77 | 210.32 | 0.00326 |
| | | | | | | | | |
| studyarea | 35870 | Q50% | 1320 | 204 | 205.15 | 204.59 | 205.2 | 0.002111 |
| studyarea | 35870 | Q2yr | 24800 | 204 | 207.83 | 207 | 208.19 | 0.003789 |
| studyarea | 35870 | Q100yr | 49900 | 204 | 209.25 | 207.94 | 209.76 | 0.003192 |
| | | | | | | | | |
| studyarea | 35611 | Q50% | 1320 | 202 | 204.31 | 204.13 | 204.37 | 0.005512 |
| studyarea | 35611 | Q2yr | 24800 | 202 | 206.84 | 205.88 | 207.23 | 0.003541 |
| studyarea | 35611 | Q100yr | 49900 | 202 | 208.1 | 207.1 | 208.8 | 0.004118 |
| | | | | | | | | |
| studyarea | 35386 | Q50% | 1320 | 202 | 203.6 | 202.99 | 203.64 | 0.002098 |
| studyarea | 35386 | Q2yr | 24800 | 202 | 205.85 | 205.13 | 206.31 | 0.004708 |
| studyarea | 35386 | Q100yr | 49900 | 202 | 207.09 | 206.36 | 207.81 | 0.004701 |
| | | | | | | | | |
| studyarea | 35154 | Q50% | 1320 | 201.77 | 202.29 | 202.29 | 202.43 | 0.027511 |
| studyarea | 35154 | Q2yr | 24800 | 201.77 | 204.75 | 204.18 | 205.2 | 0.004897 |
| studyarea | 35154 | Q100yr | 49900 | 201.77 | 206.02 | 205.2 | 206.72 | 0.004664 |
| | | | | | | | | |
| studyarea | 34992 | Q50% | 1320 | 200 | 201.22 | 200.77 | 201.28 | 0.002684 |

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|---|---|---|---|---|---|
| 4.82 | 5395.67 | 2439.9 | 0.49 | 0.56 | 0.47 |
| 6.26 | 9157.91 | 4702.35 | 0.53 | 0.84 | 0.5 |
| | | | | | |
| 2.37 | 557.2 | 455.24 | 0.38 | 0.18 | 0.18 |
| 4.4 | 5951.19 | 2862.18 | 0.46 | 0.48 | 0.39 |
| 5.64 | 10203.53 | 5929.54 | 0.49 | 0.71 | 0.42 |
| | | | | | |
| 2.42 | 546.36 | 545.72 | 0.43 | 0.2 | 0.2 |
| 4.75 | 5584.67 | 3172 | 0.51 | 0.55 | 0.39 |
| 5.53 | 10220.29 | 4115.24 | 0.47 | 0.67 | 0.47 |
| | | | | | |
| 2.36 | 560.2 | 983.55 | 0.54 | 0.23 | 0.23 |
| 5.6 | 4661.5 | 2354.14 | 0.57 | 0.75 | 0.61 |
| 7.93 | 7231.3 | 4304.73 | 0.69 | 1.36 | 0.77 |
| | | | | | |
| 2.53 | 520.73 | 355.35 | 0.37 | 0.2 | 0.2 |
| 4.7 | 5573.86 | 2836.59 | 0.52 | 0.56 | 0.45 |
| 6.09 | 8983.24 | 3313.68 | 0.56 | 0.86 | 0.67 |
| | | | | | |
| 2.22 | 593.34 | 660.97 | 0.41 | 0.18 | 0.18 |
| 5.15 | 5166.69 | 3181.55 | 0.58 | 0.63 | 0.43 |
| 6 | 9350.26 | 3607.42 | 0.55 | 0.81 | 0.59 |
| | | | | | |
| 1.75 | 755.56 | 997.03 | 0.35 | 0.12 | 0.12 |
| 5.5 | 4788.61 | 2371.13 | 0.61 | 0.78 | 0.66 |
| 6.94 | 8309.89 | 4009.8 | 0.63 | 1.1 | 0.68 |
| | | | | | |
| 3.06 | 432.19 | 1176 | 0.89 | 0.45 | 0.45 |
| 5.29 | 5107.28 | 2581.65 | 0.58 | 0.72 | 0.57 |
| 6.76 | 8526.32 | 4771.77 | 0.62 | 1.05 | 0.63 |
| | | | | | |
| 2.4 | 551.03 | 516.05 | 0.41 | 0.19 | 0.19 |
| 4.91 | 5488.29 | 2937.86 | 0.54 | 0.61 | 0.46 |
| 5.89 | 9435.27 | 3580.9 | 0.53 | 0.78 | 0.63 |
| | | | | | |
| 1.88 | 703.21 | 744.66 | 0.34 | 0.12 | 0.12 |
| 4.92 | 5315.16 | 2354.03 | 0.54 | 0.61 | 0.54 |
| 5.99 | 9421.88 | 4060.22 | 0.53 | 0.8 | 0.6 |
| | | | | | |
| 1.9 | 693.87 | 1483.34 | 0.49 | 0.16 | 0.16 |
| 5.08 | 5190.51 | 2475.33 | 0.53 | 0.64 | 0.51 |
| 6.95 | 8225.52 | 4572.8 | 0.6 | 1.07 | 0.57 |
| | | | | | |
| 1.6 | 825.76 | 1114.06 | 0.33 | 0.1 | 0.1 |
| 5.53 | 4626.28 | 2131.86 | 0.6 | 0.77 | 0.7 |
| 7.05 | 7771.07 | 3590.25 | 0.64 | 1.1 | 0.82 |
| | | | | | |
| 3.07 | 430.61 | 1511.07 | 1.01 | 0.49 | 0.49 |
| 5.42 | 4743.1 | 2467.8 | 0.63 | 0.71 | 0.61 |
| 6.86 | 8037.38 | 4683.1 | 0.64 | 1.05 | 0.61 |
| | | | | | |
| 1.93 | 682.88 | 828.58 | 0.38 | 0.14 | 0.14 |

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|---|---|---|---|---|---|---|---|---|---|
| studyarea | 34992 | Q2yr | 24800 | 198.8 | 204.06 | 203.14 | 204.47 | 0.00408 |
| studyarea | 34992 | Q100yr | 49990 | 198.8 | 205.33 | 204.35 | 206 | 0.004283 |
| studyarea | 34839 | Q50% | 1320 | 197.77 | 200.68 | 200.19 | 200.76 | 0.003615 |
| studyarea | 34839 | Q2yr | 24800 | 197.77 | 203.34 | 202.55 | 203.8 | 0.004565 |
| studyarea | 34839 | Q100yr | 49990 | 197.77 | 204.59 | 203.75 | 205.31 | 0.004699 |
| studyarea | 34659 | Q50% | 1320 | 197.49 | 199.99 | 199.59 | 200.05 | 0.004207 |
| studyarea | 34659 | Q2yr | 24800 | 197.49 | 202.53 | 201.81 | 202.98 | 0.004472 |
| studyarea | 34659 | Q100yr | 49990 | 197.49 | 203.92 | 203.06 | 204.5 | 0.003863 |
| studyarea | 34432 | Q50% | 1320 | 195.19 | 198.58 | 198.34 | 198.71 | 0.008937 |
| studyarea | 34432 | Q2yr | 24800 | 195.19 | 201.51 | 200.68 | 201.97 | 0.004398 |
| studyarea | 34432 | Q100yr | 49990 | 195.19 | 202.9 | 202.03 | 203.59 | 0.004114 |
| studyarea | 34239 | Q50% | 1320 | 195.34 | 197.19 | 196.81 | 197.34 | 0.005813 |
| studyarea | 34239 | Q2yr | 24800 | 195.34 | 200.66 | 199.79 | 201.15 | 0.004162 |
| studyarea | 34239 | Q100yr | 49990 | 195.34 | 202.09 | 201.15 | 202.8 | 0.003989 |
| studyarea | 34095 | Q50% | 1320 | 192.61 | 196.81 | 195.96 | 196.87 | 0.001887 |
| studyarea | 34095 | Q2yr | 24800 | 192.61 | 200.19 | 199.12 | 200.6 | 0.003227 |
| studyarea | 34095 | Q100yr | 49990 | 192.61 | 201.67 | 200.45 | 202.27 | 0.003055 |
| studyarea | 33776 | Q50% | 1320 | 191.7 | 196.04 | 195.26 | 196.12 | 0.003055 |
| studyarea | 33776 | Q2yr | 24800 | 191.7 | 198.97 | 198.08 | 199.44 | 0.004104 |
| studyarea | 33776 | Q100yr | 49990 | 191.7 | 200.22 | 199.22 | 201.04 | 0.004739 |
| studyarea | 33560 | Q50% | 1320 | 191.25 | 195.02 | 194.21 | 195.17 | 0.006551 |
| studyarea | 33560 | Q2yr | 24800 | 191.25 | 198.01 | 197.36 | 198.48 | 0.004787 |
| studyarea | 33560 | Q100yr | 49990 | 191.25 | 199.19 | 198.52 | 199.96 | 0.00513 |
| studyarea | 33307 | Q50% | 1320 | 190.13 | 193.37 | 192.79 | 193.53 | 0.006432 |
| studyarea | 33307 | Q2yr | 24800 | 190.13 | 196.8 | 196.16 | 197.24 | 0.004958 |
| studyarea | 33307 | Q100yr | 49990 | 190.13 | 197.95 | 197.24 | 198.66 | 0.005009 |
| studyarea | 33086 | Q50% | 1320 | 189.5 | 192.54 | 191.89 | 192.63 | 0.002686 |
| studyarea | 33086 | Q2yr | 24800 | 189.5 | 195.79 | 195.02 | 196.16 | 0.004604 |
| studyarea | 33086 | Q100yr | 49990 | 189.5 | 196.93 | 196.07 | 197.55 | 0.004815 |
| studyarea | 32883 | Q50% | 1320 | 189.74 | 191.15 | 191.09 | 191.5 | 0.016225 |
| studyarea | 32883 | Q2yr | 24800 | 189.74 | 194.47 | 194.01 | 194.98 | 0.00742 |
| studyarea | 32883 | Q100yr | 49990 | 189.74 | 195.89 | 195.08 | 196.51 | 0.005445 |
| studyarea | 32669 | Q50% | 1320 | 187.53 | 190.1 | 189.54 | 190.18 | 0.002944 |
| studyarea | 32669 | Q2yr | 24800 | 187.53 | 193.94 | 192.36 | 194.16 | 0.001994 |
| studyarea | 32669 | Q100yr | 49990 | 187.53 | 195.41 | 193.5 | 195.78 | 0.001983 |
| studyarea | 32462 | Q50% | 1320 | 186.49 | 189.44 | 188.79 | 189.54 | 0.003218 |
| studyarea | 32462 | Q2yr | 24800 | 186.49 | 193.11 | 192.15 | 193.53 | 0.004567 |
| studyarea | 32462 | Q100yr | 49990 | 186.49 | 194.64 | 193.47 | 195.22 | 0.003484 |
| studyarea | 32242 | Q50% | 1320 | 186 | 188.77 | 188.14 | 188.85 | 0.003039 |

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|---|---|---|---|---|---|
| 5.21 | 4958.91 | 2282.17 | 0.55 | 0.72 | 0.6 |
| 6.82 | 8400.32 | 4139.41 | 0.6 | 1.09 | 0.7 |
| | | | | | |
| 2.14 | 618.65 | 793.67 | 0.43 | 0.18 | 0.18 |
| 5.58 | 4691.94 | 2548.14 | 0.61 | 0.74 | 0.61 |
| 7.13 | 8146.37 | 4230.91 | 0.65 | 1.11 | 0.71 |
| | | | | | |
| 2.08 | 638.05 | 980.96 | 0.45 | 0.17 | 0.17 |
| 5.55 | 4816.68 | 2720.72 | 0.6 | 0.74 | 0.59 |
| 6.51 | 8941.1 | 4780.86 | 0.6 | 0.87 | 0.59 |
| | | | | | |
| 2.88 | 460.45 | 736.92 | 0.64 | 0.35 | 0.35 |
| 5.6 | 4737.85 | 2522.89 | 0.58 | 0.79 | 0.61 |
| 7.04 | 8493.65 | 4614.95 | 0.6 | 1.09 | 0.64 |
| | | | | | |
| 3.09 | 427.04 | 457.02 | 0.56 | 0.34 | 0.34 |
| 5.72 | 4596.75 | 2690.74 | 0.58 | 0.78 | 0.59 |
| 7.2 | 8184.13 | 4196.98 | 0.61 | 1.09 | 0.67 |
| | | | | | |
| 2.05 | 646.01 | 567.98 | 0.33 | 0.14 | 0.14 |
| 5.28 | 5058.15 | 2884.51 | 0.52 | 0.65 | 0.49 |
| 6.6 | 8814.21 | 4510.54 | 0.53 | 0.9 | 0.57 |
| | | | | | |
| 2.22 | 595.59 | 641.21 | 0.41 | 0.18 | 0.18 |
| 5.54 | 4630.78 | 2419.91 | 0.57 | 0.75 | 0.66 |
| 7.54 | 7405.93 | 3883.51 | 0.65 | 1.23 | 0.79 |
| | | | | | |
| 3.15 | 418.99 | 520.84 | 0.59 | 0.36 | 0.36 |
| 5.65 | 4684.85 | 2658.26 | 0.61 | 0.8 | 0.66 |
| 7.45 | 7504.39 | 3405.78 | 0.67 | 1.23 | 0.91 |
| | | | | | |
| 3.25 | 406.37 | 431.87 | 0.59 | 0.38 | 0.38 |
| 5.57 | 4866.7 | 2689.81 | 0.61 | 0.79 | 0.64 |
| 7.17 | 7764.37 | 3110.99 | 0.65 | 1.16 | 0.89 |
| | | | | | |
| 2.46 | 537.06 | 579.85 | 0.4 | 0.2 | 0.2 |
| 4.95 | 5173.3 | 2569.1 | 0.58 | 0.65 | 0.62 |
| 6.46 | 8263.57 | 3218.62 | 0.63 | 0.98 | 0.81 |
| | | | | | |
| 4.79 | 275.31 | 448.85 | 0.92 | 0.85 | 0.85 |
| 5.71 | 4351.85 | 2407.79 | 0.72 | 0.9 | 0.88 |
| 6.36 | 7959.85 | 3124.74 | 0.66 | 0.98 | 0.93 |
| | | | | | |
| 2.33 | 566.62 | 659.09 | 0.41 | 0.19 | 0.19 |
| 3.76 | 6607.98 | 2586.44 | 0.4 | 0.35 | 0.34 |
| 4.86 | 10508.07 | 3089.4 | 0.42 | 0.51 | 0.46 |
| | | | | | |
| 2.63 | 502.45 | 443.15 | 0.43 | 0.23 | 0.23 |
| 5.24 | 4870.87 | 2535.99 | 0.58 | 0.72 | 0.63 |
| 6.26 | 8670.31 | 3130.88 | 0.55 | 0.87 | 0.67 |
| | | | | | |
| 2.28 | 578.04 | 631.04 | 0.41 | 0.18 | 0.18 |

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|---|---|---|---|---|---|---|---|---|
| studyarea | 34992 | Q2yr | 24800 | 200 | 204.06 | 203.1 | 204.49 | 0.00387 |
| studyarea | 34992 | Q100yr | 49900 | 200 | 205.4 | 204.42 | 206.02 | 0.003711 |
| studyarea | 34839 | Q50% | 1320 | 200 | 200.88 | 200.41 | 200.92 | 0.001998 |
| studyarea | 34839 | Q2yr | 24800 | 200 | 203.45 | 202.56 | 203.89 | 0.003836 |
| studyarea | 34839 | Q100yr | 49900 | 200 | 204.62 | 203.73 | 205.38 | 0.004559 |
| studyarea | 34659 | Q50% | 1320 | 198 | 200.26 | 200.1 | 200.33 | 0.006443 |
| studyarea | 34659 | Q2yr | 24800 | 198 | 202.56 | 201.91 | 203.08 | 0.005289 |
| studyarea | 34659 | Q100yr | 49900 | 198 | 203.81 | 203.18 | 204.53 | 0.004741 |
| studyarea | 34432 | Q50% | 1320 | 196 | 198.55 | 198.35 | 198.66 | 0.008278 |
| studyarea | 34432 | Q2yr | 24800 | 196 | 201.35 | 200.71 | 201.88 | 0.00522 |
| studyarea | 34432 | Q100yr | 49900 | 196 | 202.74 | 201.9 | 203.48 | 0.004496 |
| studyarea | 34239 | Q50% | 1320 | 196 | 197.32 | 196.9 | 197.45 | 0.004941 |
| studyarea | 34239 | Q2yr | 24800 | 196 | 200.7 | 199.55 | 201.08 | 0.003058 |
| studyarea | 34239 | Q100yr | 49900 | 196 | 202.07 | 200.93 | 202.71 | 0.003343 |
| studyarea | 34095 | Q50% | 1320 | 194 | 197.05 | 196.3 | 197.1 | 0.00129 |
| studyarea | 34095 | Q2yr | 24800 | 194 | 200.18 | 199.15 | 200.61 | 0.003508 |
| studyarea | 34095 | Q100yr | 49900 | 194 | 201.65 | 200.58 | 202.23 | 0.003063 |
| studyarea | 33776 | Q50% | 1320 | 192 | 196.39 | 195.25 | 196.44 | 0.003826 |
| studyarea | 33776 | Q2yr | 24800 | 192 | 199.12 | 198.03 | 199.52 | 0.003294 |
| studyarea | 33776 | Q100yr | 49900 | 192 | 200.27 | 199.29 | 201.05 | 0.004389 |
| studyarea | 33560 | Q50% | 1320 | 192 | 195.3 | 194.58 | 195.44 | 0.005527 |
| studyarea | 33560 | Q2yr | 24800 | 192 | 198.08 | 197.44 | 198.61 | 0.005318 |
| studyarea | 33560 | Q100yr | 49900 | 192 | 199.16 | 198.75 | 199.97 | 0.005632 |
| studyarea | 33307 | Q50% | 1320 | 192 | 193.85 | 193.39 | 194 | 0.005908 |
| studyarea | 33307 | Q2yr | 24800 | 192 | 196.81 | 196.4 | 197.28 | 0.005097 |
| studyarea | 33307 | Q100yr | 49900 | 192 | 197.92 | 197.35 | 198.61 | 0.004891 |
| studyarea | 33086 | Q50% | 1320 | 190 | 192.88 | 192.43 | 192.98 | 0.003602 |
| studyarea | 33086 | Q2yr | 24800 | 190 | 195.74 | 195.13 | 196.15 | 0.004898 |
| studyarea | 33086 | Q100yr | 49900 | 190 | 196.83 | 195.91 | 197.49 | 0.005114 |
| studyarea | 32883 | Q50% | 1320 | 190 | 191.78 | 191.37 | 192.01 | 0.006419 |
| studyarea | 32883 | Q2yr | 24800 | 190 | 194.5 | 193.95 | 194.99 | 0.006667 |
| studyarea | 32883 | Q100yr | 49900 | 190 | 195.8 | 195.06 | 196.47 | 0.004941 |
| studyarea | 32669 | Q50% | 1320 | 188 | 190.49 | 190.23 | 190.58 | 0.006654 |
| studyarea | 32669 | Q2yr | 24800 | 188 | 193.89 | 192.6 | 194.13 | 0.002329 |
| studyarea | 32669 | Q100yr | 49900 | 188 | 195.31 | 193.63 | 195.7 | 0.002255 |
| studyarea | 32462 | Q50% | 1320 | 188 | 189.72 | 189.01 | 189.82 | 0.002364 |
| studyarea | 32462 | Q2yr | 24800 | 188 | 193.18 | 192.33 | 193.52 | 0.00379 |
| studyarea | 32462 | Q100yr | 49900 | 188 | 194.64 | 193.31 | 195.15 | 0.003088 |
| studyarea | 32242 | Q50% | 1320 | 188 | 189.12 | 188.65 | 189.19 | 0.003395 |

| | | | | | |
|---|---|---|---|---|---|
| 5.23 | 4836.88 | 2898.29 | 0.56 | 0.66 | 0.48 |
| 6.59 | 8682.04 | 4160.53 | 0.58 | 0.94 | 0.62 |
| 1.57 | 842.63 | 1125.78 | 0.32 | 0.09 | 0.09 |
| 5.39 | 4746.9 | 2129.58 | 0.56 | 0.7 | 0.62 |
| 7.32 | 7995.93 | 5172.61 | 0.64 | 1.16 | 0.62 |
| 2.06 | 644 | 1383.65 | 0.53 | 0.19 | 0.19 |
| 5.9 | 4555.6 | 2988.78 | 0.64 | 0.86 | 0.61 |
| 7.21 | 7944.79 | 3714.03 | 0.65 | 1.14 | 0.77 |
| 2.74 | 481.24 | 803.97 | 0.62 | 0.31 | 0.31 |
| 5.93 | 4331.05 | 2059.48 | 0.64 | 0.87 | 0.76 |
| 7.24 | 8071.19 | 4852.33 | 0.63 | 1.14 | 0.64 |
| 2.91 | 454.19 | 472.44 | 0.52 | 0.3 | 0.3 |
| 5.08 | 5176.09 | 3077.22 | 0.52 | 0.57 | 0.45 |
| 6.64 | 8445.77 | 4967.33 | 0.56 | 0.91 | 0.55 |
| 1.74 | 757.51 | 620 | 0.28 | 0.1 | 0.1 |
| 5.32 | 4976.67 | 3566.51 | 0.54 | 0.67 | 0.45 |
| 6.41 | 8781.28 | 4101.24 | 0.53 | 0.86 | 0.6 |
| 1.77 | 747.04 | 1346.63 | 0.42 | 0.13 | 0.13 |
| 5.12 | 4998.62 | 2527.74 | 0.51 | 0.63 | 0.55 |
| 7.26 | 7629.16 | 4518.46 | 0.63 | 1.14 | 0.63 |
| 3.06 | 431.21 | 450.36 | 0.55 | 0.33 | 0.33 |
| 5.94 | 4490.47 | 3309.96 | 0.64 | 0.88 | 0.58 |
| 7.66 | 7378.7 | 3606.5 | 0.7 | 1.31 | 0.92 |
| 3.15 | 419.35 | 441.77 | 0.57 | 0.35 | 0.35 |
| 5.73 | 4845.65 | 2812.49 | 0.63 | 0.83 | 0.57 |
| 7.1 | 7941.67 | 2944.09 | 0.65 | 1.13 | 0.86 |
| 2.54 | 519.23 | 642.99 | 0.45 | 0.22 | 0.22 |
| 5.3 | 4933.25 | 2520.58 | 0.6 | 0.73 | 0.64 |
| 6.9 | 8042.9 | 3229.07 | 0.66 | 1.09 | 0.84 |
| 3.92 | 336.5 | 398.68 | 0.62 | 0.5 | 0.5 |
| 5.7 | 4497.33 | 2545.66 | 0.69 | 0.88 | 0.78 |
| 6.76 | 7788.72 | 2795.54 | 0.64 | 1.05 | 0.91 |
| 2.5 | 527.56 | 942.9 | 0.56 | 0.26 | 0.26 |
| 4 | 6256.42 | 2455.16 | 0.43 | 0.4 | 0.39 |
| 5.1 | 10101.35 | 2983.23 | 0.45 | 0.57 | 0.51 |
| 2.48 | 533.28 | 405.84 | 0.38 | 0.19 | 0.19 |
| 4.7 | 5341.48 | 2600.49 | 0.53 | 0.58 | 0.56 |
| 5.79 | 9036.7 | 3199.63 | 0.52 | 0.75 | 0.61 |
| 2.17 | 608.24 | 760.77 | 0.42 | 0.18 | 0.18 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| studyarea | 32242 | Q2yr | 24800 | 186 | 192.34 | 191.1 | 192.68 | 0.003141 |
| studyarea | 32242 | Q100yr | 49990 | 186 | 194.07 | 192.38 | 194.56 | 0.002426 |
| | | | | | | | | |
| studyarea | 32000 | Q50% | 1320 | 183.84 | 186.89 | 186.89 | 187.3 | 0.019825 |
| studyarea | 32000 | Q2yr | 24800 | 183.84 | 191.59 | 190.26 | 191.97 | 0.002794 |
| studyarea | 32000 | Q100yr | 49990 | 183.84 | 193.56 | 191.69 | 194.02 | 0.001983 |
| | | | | | | | | |
| studyarea | 31833 | Q50% | 1320 | 182.92 | 185.96 | 184.48 | 185.98 | 0.000543 |
| studyarea | 31833 | Q2yr | 24800 | 182.92 | 191.7 | 187.32 | 191.77 | 0.000266 |
| studyarea | 31833 | Q100yr | 49990 | 182.92 | 193.65 | 188.66 | 193.8 | 0.000388 |
| | | | | | | | | |
| studyarea | 31686 | Q50% | 1320 | 182.96 | 185.68 | 184.88 | 185.81 | 0.002933 |
| studyarea | 31686 | Q2yr | 24800 | 182.96 | 191.44 | 189.06 | 191.68 | 0.001551 |
| studyarea | 31686 | Q100yr | 49990 | 182.96 | 193.25 | 190.72 | 193.68 | 0.001605 |
| | | | | | | | | |
| studyarea | 31524 | Q50% | 1320 | 182.97 | 185.08 | 184.44 | 185.26 | 0.004024 |
| studyarea | 31524 | Q2yr | 24800 | 182.97 | 190.99 | 188.91 | 191.34 | 0.002666 |
| studyarea | 31524 | Q100yr | 49990 | 182.97 | 192.75 | 190.86 | 193.34 | 0.002503 |
| | | | | | | | | |
| studyarea | 31287 | Q50% | 1320 | 180.86 | 184.54 | 183.68 | 184.63 | 0.001765 |
| studyarea | 31287 | Q2yr | 24800 | 180.86 | 190.36 | 188.43 | 190.73 | 0.002517 |
| studyarea | 31287 | Q100yr | 49990 | 180.86 | 192.09 | 190.22 | 192.73 | 0.002599 |
| | | | | | | | | |
| studyarea | 31042 | Q50% | 1320 | 180.67 | 183.99 | 183.05 | 184.13 | 0.002321 |
| studyarea | 31042 | Q2yr | 24800 | 180.67 | 189.58 | 188.06 | 190.04 | 0.003083 |
| studyarea | 31042 | Q100yr | 49990 | 180.67 | 191.31 | 189.78 | 192.04 | 0.003016 |
| | | | | | | | | |
| studyarea | 30805 | Q50% | 1320 | 180.75 | 183.55 | 182.35 | 183.67 | 0.001576 |
| studyarea | 30805 | Q2yr | 24800 | 180.75 | 188.8 | 187.59 | 189.26 | 0.003524 |
| studyarea | 30805 | Q100yr | 49990 | 180.75 | 190.58 | 188.97 | 191.3 | 0.00315 |
| | | | | | | | | |
| studyarea | 30599 | Q50% | 1320 | 180.62 | 183.21 | 182.12 | 183.32 | 0.001822 |
| studyarea | 30599 | Q2yr | 24800 | 180.62 | 188.12 | 186.63 | 188.59 | 0.002959 |
| studyarea | 30599 | Q100yr | 49990 | 180.62 | 190 | 188.32 | 190.7 | 0.002678 |
| | | | | | | | | |
| studyarea | 30327 | Q50% | 1320 | 180.2 | 182.72 | 181.78 | 182.81 | 0.001906 |
| studyarea | 30327 | Q2yr | 24800 | 180.2 | 187.28 | 185.95 | 187.76 | 0.00312 |
| studyarea | 30327 | Q100yr | 49990 | 180.2 | 189.09 | 187.41 | 189.9 | 0.003119 |
| | | | | | | | | |
| studyarea | 30112 | Q50% | 1320 | 179.78 | 182.29 | 181.36 | 182.39 | 0.001967 |
| studyarea | 30112 | Q2yr | 24800 | 179.78 | 186.34 | 185.33 | 186.96 | 0.004443 |
| studyarea | 30112 | Q100yr | 49990 | 179.78 | 188.04 | 186.84 | 189.08 | 0.004436 |
| | | | | | | | | |
| studyarea | 29897 | Q50% | 1320 | 179.63 | 181.72 | 181.1 | 181.84 | 0.003633 |
| studyarea | 29897 | Q2yr | 24800 | 179.63 | 185.73 | 184.3 | 186.17 | 0.002723 |
| studyarea | 29897 | Q100yr | 49990 | 179.63 | 187.48 | 185.7 | 188.23 | 0.002919 |
| | | | | | | | | |
| studyarea | 29727 | Q50% | 1320 | 179.18 | 181.4 | 180.5 | 181.46 | 0.001366 |
| studyarea | 29727 | Q2yr | 24800 | 179.18 | 185.35 | 183.76 | 185.73 | 0.002271 |
| studyarea | 29727 | Q100yr | 49990 | 179.18 | 187.24 | 185.21 | 187.75 | 0.001969 |
| | | | | | | | | |
| studyarea | 29514 | Q50% | 1320 | 178.96 | 181.07 | 180.19 | 181.13 | 0.001734 |

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|---|---|---|---|---|---|
| 4.71 | 5345.89 | 2379.76 | 0.5 | 0.55 | 0.51 |
| 5.71 | 9441.93 | 3167.74 | 0.47 | 0.68 | 0.52 |
| | | | | | |
| 5.12 | 257.73 | 314.07 | 1 | 1.01 | 1.01 |
| 4.96 | 5319.23 | 2576.21 | 0.48 | 0.58 | 0.44 |
| 5.69 | 10064.97 | 3354.94 | 0.44 | 0.65 | 0.47 |
| | | | | | |
| 1.06 | 1245.52 | 1121.2 | 0.18 | 0.04 | 0.04 |
| 2.13 | 11618.49 | 2231.74 | 0.16 | 0.09 | 0.09 |
| 3.16 | 15904.38 | 2565.3 | 0.21 | 0.18 | 0.16 |
| | | | | | |
| 2.9 | 455.44 | 321.17 | 0.43 | 0.26 | 0.26 |
| 3.94 | 6332.51 | 1807.42 | 0.36 | 0.35 | 0.34 |
| 5.25 | 9684.78 | 2200.55 | 0.4 | 0.55 | 0.5 |
| | | | | | |
| 3.41 | 387.65 | 272.17 | 0.5 | 0.36 | 0.36 |
| 4.78 | 5199.06 | 1748.47 | 0.47 | 0.54 | 0.53 |
| 6.18 | 8300.46 | 2325.83 | 0.49 | 0.78 | 0.68 |
| | | | | | |
| 2.39 | 552 | 354.6 | 0.33 | 0.18 | 0.18 |
| 4.87 | 5155.96 | 1827.45 | 0.46 | 0.55 | 0.5 |
| 6.47 | 8023.75 | 2289.35 | 0.5 | 0.85 | 0.75 |
| | | | | | |
| 2.96 | 446.03 | 252.33 | 0.39 | 0.25 | 0.25 |
| 5.44 | 4684.95 | 1816.68 | 0.51 | 0.68 | 0.57 |
| 7.01 | 7595.27 | 2343.41 | 0.54 | 0.99 | 0.78 |
| | | | | | |
| 2.72 | 485.18 | 235.57 | 0.33 | 0.2 | 0.2 |
| 5.4 | 4593.01 | 1830.92 | 0.54 | 0.69 | 0.69 |
| 6.88 | 7579.15 | 2823.33 | 0.55 | 0.97 | 0.74 |
| | | | | | |
| 2.65 | 498.31 | 280.68 | 0.35 | 0.2 | 0.2 |
| 5.52 | 4617.15 | 1865.44 | 0.51 | 0.68 | 0.55 |
| 6.9 | 7992.15 | 3357.37 | 0.51 | 0.93 | 0.66 |
| | | | | | |
| 2.44 | 540.98 | 357.37 | 0.35 | 0.18 | 0.18 |
| 5.6 | 4460.22 | 1481.79 | 0.52 | 0.71 | 0.66 |
| 7.31 | 7491.12 | 3461 | 0.55 | 1.05 | 0.67 |
| | | | | | |
| 2.63 | 501.6 | 691.13 | 0.36 | 0.21 | 0.21 |
| 6.3 | 3938.15 | 2078.72 | 0.61 | 0.93 | 0.92 |
| 8.27 | 6271.08 | 3587.36 | 0.65 | 1.4 | 1.16 |
| | | | | | |
| 2.7 | 489.24 | 730.58 | 0.45 | 0.25 | 0.25 |
| 5.29 | 4768.94 | 2273 | 0.48 | 0.64 | 0.59 |
| 7.07 | 7596.61 | 3868.41 | 0.53 | 1 | 0.8 |
| | | | | | |
| 1.89 | 697.6 | 533.49 | 0.29 | 0.11 | 0.11 |
| 5 | 5179.07 | 2265.63 | 0.45 | 0.55 | 0.4 |
| 6.06 | 9631.67 | 3631.7 | 0.44 | 0.71 | 0.48 |
| | | | | | |
| 2.02 | 659.29 | 533.28 | 0.32 | 0.13 | 0.13 |

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|---|---|---|---|---|---|---|---|---|
| studyarea | 32242 | Q2yr | 24800 | 188 | 192.33 | 191.2 | 192.7 | 0.003591 |
| studyarea | 32242 | Q100yr | 49900 | 188 | 194.05 | 192.52 | 194.52 | 0.002526 |
| studyarea | 32000 | Q50% | 1320 | 184 | 187.06 | 187.06 | 187.53 | 0.019368 |
| studyarea | 32000 | Q2yr | 24800 | 184 | 191.64 | 190.2 | 191.96 | 0.002572 |
| studyarea | 32000 | Q100yr | 49900 | 184 | 193.58 | 191.54 | 193.99 | 0.001817 |
| studyarea | 31833 | Q50% | 1320 | 184 | 186.43 | 184.92 | 186.44 | 0.000668 |
| studyarea | 31833 | Q2yr | 24800 | 184 | 191.69 | 187.7 | 191.77 | 0.000319 |
| studyarea | 31833 | Q100yr | 49900 | 184 | 193.62 | 188.98 | 193.78 | 0.000454 |
| studyarea | 31686 | Q50% | 1320 | 184 | 186.19 | 185.21 | 186.28 | 0.002011 |
| studyarea | 31686 | Q2yr | 24800 | 184 | 191.45 | 189.03 | 191.67 | 0.001377 |
| studyarea | 31686 | Q100yr | 49900 | 184 | 193.25 | 190.63 | 193.65 | 0.001484 |
| studyarea | 31524 | Q50% | 1320 | 184 | 185.71 | 185.05 | 185.86 | 0.003407 |
| studyarea | 31524 | Q2yr | 24800 | 184 | 191.04 | 189.07 | 191.36 | 0.002504 |
| studyarea | 31524 | Q100yr | 49900 | 184 | 192.81 | 190.84 | 193.34 | 0.002292 |
| studyarea | 31287 | Q50% | 1320 | 182 | 185.09 | 184.36 | 185.19 | 0.002257 |
| studyarea | 31287 | Q2yr | 24800 | 182 | 190.37 | 188.83 | 190.75 | 0.002662 |
| studyarea | 31287 | Q100yr | 49900 | 182 | 192.12 | 190.31 | 192.75 | 0.00263 |
| studyarea | 31042 | Q50% | 1320 | 182 | 184.81 | 183.2 | 184.87 | 0.000811 |
| studyarea | 31042 | Q2yr | 24800 | 182 | 189.65 | 188.25 | 190.07 | 0.002814 |
| studyarea | 31042 | Q100yr | 49900 | 182 | 191.37 | 189.69 | 192.07 | 0.002855 |
| studyarea | 30805 | Q50% | 1320 | 182 | 184.56 | 183.09 | 184.63 | 0.001333 |
| studyarea | 30805 | Q2yr | 24800 | 182 | 188.92 | 187.51 | 189.35 | 0.003283 |
| studyarea | 30805 | Q100yr | 49900 | 182 | 190.69 | 189.02 | 191.38 | 0.002969 |
| studyarea | 30599 | Q50% | 1320 | 182 | 184.16 | 183.02 | 184.24 | 0.002852 |
| studyarea | 30599 | Q2yr | 24800 | 182 | 188.35 | 186.78 | 188.76 | 0.002492 |
| studyarea | 30599 | Q100yr | 49900 | 182 | 190.14 | 188.29 | 190.8 | 0.002545 |
| studyarea | 30327 | Q50% | 1320 | 182 | 183.3 | 182.76 | 183.42 | 0.003221 |
| studyarea | 30327 | Q2yr | 24800 | 182 | 187.45 | 186.23 | 187.97 | 0.00336 |
| studyarea | 30327 | Q100yr | 49900 | 182 | 189.24 | 187.64 | 190.02 | 0.003164 |
| studyarea | 30112 | Q50% | 1320 | 180 | 182.69 | 181.8 | 182.8 | 0.002516 |
| studyarea | 30112 | Q2yr | 24800 | 180 | 186.28 | 185.55 | 187.02 | 0.005734 |
| studyarea | 30112 | Q100yr | 49900 | 180 | 187.87 | 187.18 | 189.09 | 0.005643 |
| studyarea | 29897 | Q50% | 1320 | 180 | 181.94 | 181.35 | 182.09 | 0.004457 |
| studyarea | 29897 | Q2yr | 24800 | 180 | 185.78 | 184.16 | 186.17 | 0.002314 |
| studyarea | 29897 | Q100yr | 49900 | 180 | 187.4 | 185.55 | 188.11 | 0.002756 |
| studyarea | 29727 | Q50% | 1320 | 180 | 181.7 | 180.73 | 181.75 | 0.000989 |
| studyarea | 29727 | Q2yr | 24800 | 180 | 185.5 | 183.55 | 185.8 | 0.001743 |
| studyarea | 29727 | Q100yr | 49900 | 180 | 187.16 | 185 | 187.66 | 0.001901 |
| studyarea | 29514 | Q50% | 1320 | 180 | 181.38 | 180.69 | 181.45 | 0.002058 |

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|---|---|---|---|---|---|
| 4.9 | 5189.07 | 2636.54 | 0.52 | 0.62 | 0.52 |
| 5.69 | 9312.83 | 3573.07 | 0.47 | 0.7 | 0.46 |
| | | | | | |
| 5.45 | 241.99 | 262.59 | 1 | 1.11 | 1.11 |
| 4.54 | 5601.89 | 2403.99 | 0.45 | 0.5 | 0.44 |
| 5.26 | 10186.93 | 3132.39 | 0.41 | 0.57 | 0.46 |
| | | | | | |
| 1.05 | 1258.43 | 1309.09 | 0.19 | 0.04 | 0.04 |
| 2.24 | 11079.2 | 2225.45 | 0.17 | 0.1 | 0.1 |
| 3.25 | 15425.07 | 2475.97 | 0.22 | 0.2 | 0.18 |
| | | | | | |
| 2.4 | 551.07 | 389.35 | 0.35 | 0.18 | 0.18 |
| 3.76 | 6595.75 | 1777.29 | 0.34 | 0.32 | 0.32 |
| 5.07 | 9912.7 | 2048.83 | 0.38 | 0.51 | 0.48 |
| | | | | | |
| 3.04 | 433.72 | 317.07 | 0.46 | 0.29 | 0.29 |
| 4.57 | 5426.29 | 1803.72 | 0.45 | 0.5 | 0.49 |
| 5.87 | 8638.82 | 2538.21 | 0.47 | 0.71 | 0.63 |
| | | | | | |
| 2.53 | 522.38 | 355.45 | 0.37 | 0.21 | 0.21 |
| 4.93 | 5093.53 | 1873.54 | 0.47 | 0.57 | 0.51 |
| 6.44 | 8066.38 | 2892.65 | 0.5 | 0.85 | 0.68 |
| | | | | | |
| 2.02 | 653.47 | 297.95 | 0.24 | 0.11 | 0.11 |
| 5.26 | 4816.84 | 1702.49 | 0.49 | 0.63 | 0.56 |
| 6.85 | 7717.67 | 2172.89 | 0.52 | 0.94 | 0.77 |
| | | | | | |
| 2.02 | 653.46 | 438.52 | 0.29 | 0.12 | 0.12 |
| 5.28 | 4696.83 | 1756.31 | 0.52 | 0.66 | 0.65 |
| 6.72 | 7793.06 | 3090.45 | 0.53 | 0.92 | 0.65 |
| | | | | | |
| 2.19 | 603.82 | 636.74 | 0.4 | 0.17 | 0.17 |
| 5.16 | 4913.05 | 2080.21 | 0.47 | 0.59 | 0.46 |
| 6.65 | 8107.25 | 4149.42 | 0.5 | 0.87 | 0.64 |
| | | | | | |
| 2.75 | 480.21 | 393.77 | 0.44 | 0.25 | 0.25 |
| 5.74 | 4323.11 | 1274.58 | 0.54 | 0.75 | 0.75 |
| 7.28 | 7623.88 | 3626.48 | 0.56 | 1.05 | 0.65 |
| | | | | | |
| 2.62 | 503.2 | 776.06 | 0.39 | 0.22 | 0.22 |
| 6.91 | 3612.23 | 2138.64 | 0.68 | 1.14 | 1.05 |
| 8.98 | 5842.61 | 2807.62 | 0.72 | 1.68 | 1.36 |
| | | | | | |
| 3.13 | 421.17 | 607.29 | 0.5 | 0.34 | 0.34 |
| 5 | 5015.88 | 2135.41 | 0.45 | 0.56 | 0.53 |
| 6.88 | 7606.58 | 3759.99 | 0.52 | 0.95 | 0.79 |
| | | | | | |
| 1.67 | 791.96 | 567.04 | 0.25 | 0.09 | 0.09 |
| 4.45 | 5719.97 | 2066.26 | 0.39 | 0.43 | 0.36 |
| 5.87 | 9435.57 | 3604.67 | 0.43 | 0.67 | 0.47 |
| | | | | | |
| 2.16 | 610.45 | 556.78 | 0.35 | 0.15 | 0.15 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| studyarea | 29514 | Q2yr | 24800 | 178.96 | 184.77 | 183.28 | 185.2 | 0.00265 |
| studyarea | 29514 | Q100yr | 49990 | 178.96 | 186.37 | 184.7 | 187.19 | 0.003251 |
| | | | | | | | | |
| studyarea | 29313 | Q50% | 1320 | 177.83 | 180.78 | 179.83 | 180.83 | 0.00129 |
| studyarea | 29313 | Q2yr | 24800 | 177.83 | 184.21 | 182.8 | 184.65 | 0.0028 |
| studyarea | 29313 | Q100yr | 49990 | 177.83 | 185.46 | 184.2 | 186.43 | 0.00424 |
| | | | | | | | | |
| studyarea | 29145 | Q50% | 1320 | 177.79 | 180.49 | 179.65 | 180.55 | 0.002152 |
| studyarea | 29145 | Q2yr | 24800 | 177.79 | 183.82 | 182.49 | 184.13 | 0.002998 |
| studyarea | 29145 | Q100yr | 49990 | 177.79 | 185.18 | 183.78 | 185.7 | 0.003014 |
| | | | | | | | | |
| studyarea | 28870 | Q50% | 1320 | 176.8 | 179.92 | 179.06 | 179.97 | 0.002053 |
| studyarea | 28870 | Q2yr | 24800 | 176.8 | 182.75 | 181.96 | 183.16 | 0.004071 |
| studyarea | 28870 | Q100yr | 49990 | 176.8 | 183.87 | 183.02 | 184.63 | 0.004976 |
| | | | | | | | | |
| studyarea | 28552 | Q50% | 1320 | 176.42 | 178.91 | 178.52 | 179.01 | 0.004903 |
| studyarea | 28552 | Q2yr | 24800 | 176.42 | 181.32 | 180.79 | 181.72 | 0.005087 |
| studyarea | 28552 | Q100yr | 49990 | 176.42 | 182.46 | 181.72 | 183.05 | 0.004645 |
| | | | | | | | | |
| studyarea | 28294 | Q50% | 1320 | 174.8 | 177.65 | 177.23 | 177.74 | 0.004915 |
| studyarea | 28294 | Q2yr | 24800 | 174.8 | 180.39 | 179.51 | 180.63 | 0.003258 |
| studyarea | 28294 | Q100yr | 49990 | 174.8 | 181.66 | 180.34 | 182.04 | 0.002989 |
| | | | | | | | | |
| studyarea | 28027 | Q50% | 1320 | 173.63 | 176.62 | 175.91 | 176.72 | 0.003105 |
| studyarea | 28027 | Q2yr | 24800 | 173.63 | 179.42 | 178.57 | 179.72 | 0.003559 |
| studyarea | 28027 | Q100yr | 49990 | 173.63 | 180.61 | 179.49 | 181.14 | 0.003714 |
| | | | | | | | | |
| studyarea | 27774 | Q50% | 1320 | 173.33 | 175.79 | 175.2 | 175.87 | 0.003628 |
| studyarea | 27774 | Q2yr | 24800 | 173.33 | 178.74 | 177.69 | 178.95 | 0.002478 |
| studyarea | 27774 | Q100yr | 49990 | 173.33 | 179.96 | 178.55 | 180.31 | 0.002547 |
| | | | | | | | | |
| studyarea | 27523 | Q50% | 1320 | 172.51 | 174.8 | 174.24 | 174.89 | 0.004151 |
| studyarea | 27523 | Q2yr | 24800 | 172.51 | 177.79 | 176.95 | 178.11 | 0.004635 |
| studyarea | 27523 | Q100yr | 49990 | 172.51 | 178.94 | 177.94 | 179.46 | 0.004481 |
| | | | | | | | | |
| studyarea | 27350 | Q50% | 1320 | 171.89 | 174.13 | 173.69 | 174.2 | 0.003748 |
| studyarea | 27350 | Q2yr | 24800 | 171.89 | 176.98 | 176.21 | 177.33 | 0.004347 |
| studyarea | 27350 | Q100yr | 49990 | 171.89 | 178.12 | 177.24 | 178.68 | 0.004531 |
| | | | | | | | | |
| studyarea | 27173 | Q50% | 1320 | 170.01 | 172.64 | 172.55 | 172.94 | 0.017293 |
| studyarea | 27173 | Q2yr | 24800 | 170.01 | 176.09 | 175.33 | 176.42 | 0.005952 |
| studyarea | 27173 | Q100yr | 49990 | 170.01 | 177.33 | 176.33 | 177.82 | 0.00494 |
| | | | | | | | | |
| studyarea | 26976 | Q50% | 1320 | 168.67 | 171.71 | 171.08 | 171.82 | 0.002582 |
| studyarea | 26976 | Q2yr | 24800 | 168.67 | 175.39 | 174.3 | 175.66 | 0.002637 |
| studyarea | 26976 | Q100yr | 49990 | 168.67 | 176.65 | 175.42 | 177.07 | 0.002865 |
| | | | | | | | | |
| studyarea | 26621 | Q50% | 1320 | 167.46 | 170.79 | 170.13 | 170.87 | 0.002733 |
| studyarea | 26621 | Q2yr | 24800 | 167.46 | 174.29 | 173.14 | 174.53 | 0.003857 |
| studyarea | 26621 | Q100yr | 49990 | 167.46 | 175.49 | 174.17 | 175.89 | 0.003847 |
| | | | | | | | | |
| studyarea | 26377 | Q50% | 1320 | 167.58 | 170.19 | 169.59 | 170.25 | 0.002325 |

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|---|---|---|---|---|---|
| 5.3 | 4781.2 | 2404.07 | 0.48 | 0.62 | 0.57 |
| 7.41 | 7072.04 | 3798.18 | 0.56 | 1.09 | 0.96 |
| | | | | | |
| 1.74 | 758.98 | 618.6 | 0.28 | 0.1 | 0.1 |
| 5.32 | 4689.01 | 2798.4 | 0.49 | 0.64 | 0.62 |
| 7.94 | 6377.5 | 3737.32 | 0.63 | 1.3 | 1.22 |
| | | | | | |
| 1.96 | 674.17 | 673.79 | 0.34 | 0.13 | 0.13 |
| 4.43 | 5622.12 | 3148.21 | 0.48 | 0.5 | 0.49 |
| 5.83 | 8712.22 | 3997.8 | 0.51 | 0.75 | 0.7 |
| | | | | | |
| 1.88 | 702.96 | 840.34 | 0.35 | 0.12 | 0.12 |
| 5.12 | 4859.39 | 2961.59 | 0.58 | 0.62 | 0.61 |
| 7.04 | 7180.23 | 3739.29 | 0.66 | 1.09 | 1.04 |
| | | | | | |
| 2.48 | 533.4 | 904.64 | 0.5 | 0.23 | 0.23 |
| 5.25 | 5269.43 | 3797.04 | 0.61 | 0.72 | 0.58 |
| 6.55 | 8585.6 | 4137.95 | 0.62 | 0.99 | 0.85 |
| | | | | | |
| 2.49 | 530.98 | 804.08 | 0.51 | 0.22 | 0.22 |
| 3.94 | 6316 | 3990.22 | 0.48 | 0.43 | 0.43 |
| 4.95 | 10146.94 | 4464.36 | 0.48 | 0.63 | 0.62 |
| | | | | | |
| 2.46 | 536.83 | 653.22 | 0.44 | 0.19 | 0.19 |
| 4.41 | 5634.88 | 4009.58 | 0.52 | 0.5 | 0.5 |
| 5.81 | 8622.76 | 4472.02 | 0.55 | 0.8 | 0.8 |
| | | | | | |
| 2.22 | 595.58 | 885.77 | 0.44 | 0.17 | 0.17 |
| 3.67 | 6765.44 | 3965.81 | 0.44 | 0.34 | 0.34 |
| 4.73 | 10609.99 | 4630.02 | 0.45 | 0.54 | 0.53 |
| | | | | | |
| 2.49 | 530.45 | 826.84 | 0.47 | 0.23 | 0.23 |
| 4.51 | 5530.21 | 4327.48 | 0.55 | 0.6 | 0.6 |
| 5.83 | 8638.21 | 5116.61 | 0.58 | 0.89 | 0.88 |
| | | | | | |
| 2.18 | 607.17 | 995.68 | 0.44 | 0.18 | 0.18 |
| 4.74 | 5250.97 | 4396.25 | 0.59 | 0.54 | 0.54 |
| 6.02 | 8350.15 | 5194.82 | 0.61 | 0.87 | 0.86 |
| | | | | | |
| 4.36 | 303.75 | 765.36 | 0.89 | 0.8 | 0.84 |
| 4.57 | 5449.92 | 4032.45 | 0.57 | 0.74 | 0.72 |
| 5.61 | 9058.35 | 4963.59 | 0.56 | 0.96 | 0.93 |
| | | | | | |
| 2.12 | 533.8 | 1025.14 | 0.4 | 0.14 | 0.17 |
| 4.06 | 6028.68 | 4255.48 | 0.49 | 0.35 | 0.35 |
| 5.16 | 9722.43 | 5257.06 | 0.5 | 0.59 | 0.58 |
| | | | | | |
| 2.25 | 592.86 | 797.5 | 0.39 | 0.18 | 0.18 |
| 3.91 | 6340.51 | 3926.1 | 0.46 | 0.54 | 0.54 |
| 5.11 | 9790.28 | 4555.38 | 0.49 | 0.81 | 0.81 |
| | | | | | |
| 2.06 | 641.75 | 1049.07 | 0.36 | 0.15 | 0.15 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| studyarea | 29514 | Q2yr | 24800 | 180 | 184.83 | 183.59 | 185.3 | 0.00315 |
| studyarea | 29514 | Q100yr | 49900 | 180 | 186.61 | 185.26 | 187.19 | 0.00251 |
| | | | | | | | | |
| studyarea | 29313 | Q50% | 1320 | 178 | 180.95 | 180.41 | 181.01 | 0.002275 |
| studyarea | 29313 | Q2yr | 24800 | 178 | 184.1 | 182.95 | 184.62 | 0.003535 |
| studyarea | 29313 | Q100yr | 49900 | 178 | 185.3 | 184.37 | 186.43 | 0.005253 |
| | | | | | | | | |
| studyarea | 29145 | Q50% | 1320 | 178 | 180.56 | 180.17 | 180.61 | 0.002515 |
| studyarea | 29145 | Q2yr | 24800 | 178 | 183.8 | 182.37 | 184.06 | 0.002388 |
| studyarea | 29145 | Q100yr | 49900 | 178 | 185.17 | 183.53 | 185.63 | 0.002562 |
| | | | | | | | | |
| studyarea | 28870 | Q50% | 1320 | 178 | 179.9 | 179.06 | 179.98 | 0.002037 |
| studyarea | 28870 | Q2yr | 24800 | 178 | 182.9 | 181.88 | 183.25 | 0.003667 |
| studyarea | 28870 | Q100yr | 49900 | 178 | 184.09 | 183.01 | 184.74 | 0.004054 |
| | | | | | | | | |
| studyarea | 28552 | Q50% | 1320 | 178 | 179.19 | 178.71 | 179.25 | 0.002619 |
| studyarea | 28552 | Q2yr | 24800 | 178 | 181.49 | 180.89 | 181.89 | 0.005031 |
| studyarea | 28552 | Q100yr | 49900 | 178 | 182.62 | 181.8 | 183.31 | 0.004975 |
| | | | | | | | | |
| studyarea | 28294 | Q50% | 1320 | 176 | 178.23 | 177.68 | 178.28 | 0.005872 |
| studyarea | 28294 | Q2yr | 24800 | 176 | 180.39 | 179.61 | 180.73 | 0.003895 |
| studyarea | 28294 | Q100yr | 49900 | 176 | 181.45 | 180.55 | 182.08 | 0.004449 |
| | | | | | | | | |
| studyarea | 28027 | Q50% | 1320 | 174 | 176.75 | 176.43 | 176.84 | 0.004889 |
| studyarea | 28027 | Q2yr | 24800 | 174 | 179.49 | 178.7 | 179.73 | 0.003423 |
| studyarea | 28027 | Q100yr | 49900 | 174 | 180.59 | 179.46 | 181 | 0.003293 |
| | | | | | | | | |
| studyarea | 27774 | Q50% | 1320 | 174 | 175.79 | 175.11 | 175.89 | 0.002919 |
| studyarea | 27774 | Q2yr | 24800 | 174 | 178.67 | 177.63 | 178.9 | 0.00308 |
| studyarea | 27774 | Q100yr | 49900 | 174 | 179.8 | 178.63 | 180.19 | 0.003021 |
| | | | | | | | | |
| studyarea | 27523 | Q50% | 1320 | 174 | 175.06 | 174.61 | 175.13 | 0.003138 |
| studyarea | 27523 | Q2yr | 24800 | 174 | 177.75 | 176.9 | 178.03 | 0.003932 |
| studyarea | 27523 | Q100yr | 49900 | 174 | 178.81 | 177.81 | 179.3 | 0.004149 |
| | | | | | | | | |
| studyarea | 27350 | Q50% | 1320 | 172 | 174.39 | 174.14 | 174.45 | 0.005025 |
| studyarea | 27350 | Q2yr | 24800 | 172 | 177.08 | 176.36 | 177.35 | 0.00388 |
| studyarea | 27350 | Q100yr | 49900 | 172 | 178.08 | 177.15 | 178.58 | 0.004203 |
| | | | | | | | | |
| studyarea | 27173 | Q50% | 1320 | 171.27 | 173.13 | 172.86 | 173.32 | 0.008286 |
| studyarea | 27173 | Q2yr | 24800 | 171.27 | 176.17 | 175.38 | 176.52 | 0.005764 |
| studyarea | 27173 | Q100yr | 49900 | 171.27 | 177.26 | 176.48 | 177.78 | 0.004783 |
| | | | | | | | | |
| studyarea | 26976 | Q50% | 1320 | 170 | 172.2 | 171.32 | 172.27 | 0.003524 |
| studyarea | 26976 | Q2yr | 24800 | 170 | 175.46 | 174.46 | 175.69 | 0.002965 |
| studyarea | 26976 | Q100yr | 49900 | 170 | 176.59 | 175.34 | 177 | 0.003076 |
| | | | | | | | | |
| studyarea | 26621 | Q50% | 1320 | 168 | 171.12 | 170.51 | 171.2 | 0.00262 |
| studyarea | 26621 | Q2yr | 24800 | 168 | 174.27 | 173.18 | 174.53 | 0.003584 |
| studyarea | 26621 | Q100yr | 49900 | 168 | 175.39 | 174.28 | 175.84 | 0.003496 |
| | | | | | | | | |
| studyarea | 26377 | Q50% | 1320 | 168 | 170.4 | 169.75 | 170.47 | 0.003395 |

| | | | | | |
|---|---|---|---|---|---|
| 5.57 | 4821.78 | 2918.81 | 0.52 | 0.7 | 0.46 |
| 6.5 | 8669.98 | 3879.84 | 0.5 | 0.84 | 0.61 |
| | | | | | |
| 1.91 | 690.25 | 776.03 | 0.35 | 0.13 | 0.13 |
| 5.78 | 4307.28 | 3154.98 | 0.55 | 0.76 | 0.72 |
| 8.58 | 5898.39 | 3672.05 | 0.7 | 1.53 | 1.43 |
| | | | | | |
| 1.67 | 788.47 | 1124.21 | 0.35 | 0.11 | 0.11 |
| 4.12 | 6026.36 | 2725.26 | 0.43 | 0.42 | 0.42 |
| 5.49 | 9209.74 | 4034.55 | 0.48 | 0.66 | 0.61 |
| | | | | | |
| 2.27 | 581.48 | 490.13 | 0.35 | 0.16 | 0.16 |
| 4.77 | 5210.33 | 3012.71 | 0.53 | 0.58 | 0.57 |
| 6.47 | 7761.43 | 4605.82 | 0.59 | 0.94 | 0.91 |
| | | | | | |
| 1.83 | 720.58 | 1120.53 | 0.37 | 0.13 | 0.13 |
| 5.1 | 4921.04 | 3760.15 | 0.61 | 0.69 | 0.67 |
| 6.69 | 7547.05 | 4606.8 | 0.65 | 1.04 | 1.01 |
| | | | | | |
| 1.79 | 738.68 | 2176.42 | 0.49 | 0.15 | 0.15 |
| 4.75 | 5351.02 | 4015.28 | 0.54 | 0.58 | 0.55 |
| 6.48 | 7866.42 | 4079.23 | 0.61 | 0.96 | 0.92 |
| | | | | | |
| 2.42 | 544.85 | 831.28 | 0.5 | 0.23 | 0.23 |
| 3.96 | 6288.87 | 3959.96 | 0.49 | 0.44 | 0.43 |
| 5.13 | 10065.33 | 4685.77 | 0.51 | 0.65 | 0.55 |
| | | | | | |
| 2.56 | 515.57 | 500.04 | 0.42 | 0.21 | 0.21 |
| 3.91 | 6356.29 | 4031.59 | 0.48 | 0.39 | 0.39 |
| 5.05 | 9942.47 | 4224.01 | 0.5 | 0.6 | 0.59 |
| | | | | | |
| 2.09 | 632.46 | 1050.5 | 0.41 | 0.16 | 0.16 |
| 4.26 | 5822.68 | 4061.89 | 0.52 | 0.52 | 0.52 |
| 5.61 | 8889.68 | 5343.18 | 0.57 | 0.79 | 0.79 |
| | | | | | |
| 2.11 | 624.82 | 1446.05 | 0.48 | 0.18 | 0.18 |
| 4.22 | 5873.08 | 4448.36 | 0.52 | 0.49 | 0.49 |
| 5.66 | 8815.68 | 5534.86 | 0.58 | 0.79 | 0.79 |
| | | | | | |
| 3.48 | 379.1 | 919.08 | 0.64 | 0.47 | 0.47 |
| 4.72 | 5298.06 | 4491.52 | 0.61 | 0.66 | 0.61 |
| 5.86 | 8840.54 | 4888.27 | 0.6 | 0.88 | 0.79 |
| | | | | | |
| 2.1 | 630.01 | 1668.79 | 0.43 | 0.16 | 0.16 |
| 3.88 | 6410.19 | 4347.56 | 0.46 | 0.42 | 0.41 |
| 5.19 | 9678.05 | 5502.15 | 0.5 | 0.65 | 0.64 |
| | | | | | |
| 2.18 | 604.56 | 907.5 | 0.38 | 0.17 | 0.17 |
| 4.09 | 6068.7 | 4180.53 | 0.5 | 0.47 | 0.47 |
| 5.37 | 9314.72 | 4429.37 | 0.53 | 0.7 | 0.7 |
| | | | | | |
| 2.1 | 627.26 | 1303.91 | 0.41 | 0.17 | 0.17 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| studyarea | 26377 | Q2yr | 24800 | 167.58 | 173.27 | 172.35 | 173.56 | 0.00407 |
| studyarea | 26377 | Q100yr | 49990 | 167.58 | 174.48 | 173.34 | 174.93 | 0.003984 |
| | | | | | | | | |
| studyarea | 26215 | Q50% | 1320 | 167.51 | 169.75 | 169.17 | 169.83 | 0.002972 |
| studyarea | 26215 | Q2yr | 24800 | 167.51 | 172.72 | 171.68 | 173 | 0.002889 |
| studyarea | 26215 | Q100yr | 49990 | 167.51 | 173.85 | 172.74 | 174.34 | 0.003398 |
| | | | | | | | | |
| studyarea | 25965 | Q50% | 1320 | 166.48 | 168.97 | 168.49 | 169.06 | 0.00323 |
| studyarea | 25965 | Q2yr | 24800 | 166.48 | 171.86 | 171.1 | 172.17 | 0.003898 |
| studyarea | 25965 | Q100yr | 49990 | 166.48 | 172.88 | 172.06 | 173.39 | 0.004226 |
| | | | | | | | | |
| studyarea | 25745 | Q50% | 1320 | 165.18 | 168.02 | 167.59 | 168.15 | 0.005478 |
| studyarea | 25745 | Q2yr | 24800 | 165.18 | 170.72 | 170.26 | 171.11 | 0.006052 |
| studyarea | 25745 | Q100yr | 49990 | 165.18 | 171.83 | 171.14 | 172.35 | 0.005268 |
| | | | | | | | | |
| studyarea | 25598 | Q50% | 1320 | 165.2 | 167.57 | 167.03 | 167.63 | 0.002257 |
| studyarea | 25598 | Q2yr | 24800 | 165.2 | 170.21 | 169.32 | 170.45 | 0.00302 |
| studyarea | 25598 | Q100yr | 49990 | 165.2 | 171.35 | 170.22 | 171.73 | 0.003017 |
| | | | | | | | | |
| studyarea | 25359 | Q50% | 1320 | 163.95 | 166.32 | 166.21 | 166.51 | 0.014046 |
| studyarea | 25359 | Q2yr | 24800 | 163.95 | 169.4 | 168.53 | 169.64 | 0.003831 |
| studyarea | 25359 | Q100yr | 49990 | 163.95 | 170.64 | 169.41 | 171 | 0.003074 |
| | | | | | | | | |
| studyarea | 25206 | Q50% | 1320 | 163.37 | 165.68 | 165.17 | 165.74 | 0.002402 |
| studyarea | 25206 | Q2yr | 24800 | 163.37 | 169.06 | 167.63 | 169.24 | 0.001796 |
| studyarea | 25206 | Q100yr | 49990 | 163.37 | 170.31 | 168.67 | 170.61 | 0.001971 |
| | | | | | | | | |
| studyarea | 24915 | Q50% | 1320 | 162.31 | 165.09 | 164.24 | 165.15 | 0.001762 |
| studyarea | 24915 | Q2yr | 24800 | 162.31 | 168.33 | 167.27 | 168.58 | 0.00278 |
| studyarea | 24915 | Q100yr | 49990 | 162.31 | 169.5 | 168.36 | 169.9 | 0.00303 |
| | | | | | | | | |
| studyarea | 24671 | Q50% | 1320 | 162.12 | 164.45 | 163.93 | 164.54 | 0.003792 |
| studyarea | 24671 | Q2yr | 24800 | 162.12 | 167.56 | 166.62 | 167.82 | 0.00355 |
| studyarea | 24671 | Q100yr | 49990 | 162.12 | 168.66 | 167.59 | 169.09 | 0.003612 |
| | | | | | | | | |
| studyarea | 24505 | Q50% | 1320 | 161.44 | 163.61 | 163.32 | 163.73 | 0.006324 |
| studyarea | 24505 | Q2yr | 24800 | 161.44 | 166.94 | 165.98 | 167.2 | 0.003956 |
| studyarea | 24505 | Q100yr | 49990 | 161.44 | 168.08 | 166.99 | 168.47 | 0.003716 |
| | | | | | | | | |
| studyarea | 24348 | Q50% | 1320 | 160.95 | 163.22 | 162.42 | 163.27 | 0.001562 |
| studyarea | 24348 | Q2yr | 24800 | 160.95 | 166.42 | 165.45 | 166.65 | 0.002966 |
| studyarea | 24348 | Q100yr | 49990 | 160.95 | 167.58 | 166.38 | 167.96 | 0.002847 |
| | | | | | | | | |
| studyarea | 24224 | Q50% | 1320 | 160.73 | 163.02 | 162.07 | 163.07 | 0.00165 |
| studyarea | 24224 | Q2yr | 24800 | 160.73 | 166.1 | 164.92 | 166.3 | 0.002601 |
| studyarea | 24224 | Q100yr | 49990 | 160.73 | 167.27 | 165.88 | 167.6 | 0.002693 |
| | | | | | | | | |
| studyarea | 24040 | Q50% | 1320 | 159.59 | 162.59 | 161.82 | 162.67 | 0.002868 |
| studyarea | 24040 | Q2yr | 24800 | 159.59 | 165.52 | 164.58 | 165.76 | 0.003209 |
| studyarea | 24040 | Q100yr | 49990 | 159.59 | 166.7 | 165.51 | 167.08 | 0.002987 |
| | | | | | | | | |
| studyarea | 23879 | Q50% | 1320 | 159.34 | 162.12 | 161.56 | 162.19 | 0.003118 |

| | | | | | |
|---|---|---|---|---|---|
| 4.18 | 5844.76 | 3948.85 | 0.51 | 0.54 | 0.54 |
| 5.32 | 9301.89 | 4626.67 | 0.53 | 0.78 | 0.79 |
| | | | | | |
| 2.17 | 608.14 | 977.98 | 0.4 | 0.17 | 0.17 |
| 4.24 | 5853.59 | 3781.99 | 0.5 | 0.4 | 0.4 |
| 5.58 | 8978.37 | 4369.21 | 0.55 | 0.67 | 0.67 |
| | | | | | |
| 2.38 | 557.07 | 1001.28 | 0.45 | 0.17 | 0.17 |
| 4.46 | 5598.66 | 4033.33 | 0.57 | 0.46 | 0.45 |
| 5.75 | 8841.35 | 4558.41 | 0.6 | 0.75 | 0.71 |
| | | | | | |
| 2.84 | 465.2 | 919.35 | 0.56 | 0.27 | 0.27 |
| 4.99 | 4993.32 | 3617.81 | 0.68 | 0.63 | 0.63 |
| 5.84 | 8659.24 | 4318.08 | 0.65 | 0.82 | 0.8 |
| | | | | | |
| 1.73 | 732.16 | 1372.83 | 0.35 | 0.11 | 0.11 |
| 3.98 | 6229.02 | 3942.25 | 0.5 | 0.37 | 0.37 |
| 4.98 | 10136.63 | 4835.86 | 0.52 | 0.54 | 0.53 |
| | | | | | |
| 3.54 | 373.28 | 801.38 | 0.81 | 0.52 | 0.52 |
| 3.95 | 6343.56 | 4072.49 | 0.49 | 0.47 | 0.46 |
| 4.82 | 10586.19 | 4824.67 | 0.48 | 0.61 | 0.57 |
| | | | | | |
| 1.9 | 699.78 | 970.25 | 0.36 | 0.13 | 0.12 |
| 3.43 | 7397.88 | 4307.09 | 0.39 | 0.27 | 0.26 |
| 4.47 | 11585.87 | 4865.01 | 0.41 | 0.44 | 0.41 |
| | | | | | |
| 1.87 | 706.15 | 846.81 | 0.32 | 0.12 | 0.12 |
| 4.13 | 6311.26 | 4436.28 | 0.49 | 0.39 | 0.33 |
| 5.23 | 10341.57 | 4888.44 | 0.5 | 0.64 | 0.55 |
| | | | | | |
| 2.35 | 562.23 | 793.32 | 0.44 | 0.21 | 0.21 |
| 4.18 | 6171.09 | 4125.09 | 0.49 | 0.5 | 0.44 |
| 5.42 | 9884.84 | 5018.83 | 0.53 | 0.74 | 0.63 |
| | | | | | |
| 2.77 | 477.35 | 868.74 | 0.57 | 0.29 | 0.29 |
| 4.08 | 6182.46 | 4183.78 | 0.51 | 0.49 | 0.48 |
| 5.09 | 10094.64 | 5128.25 | 0.52 | 0.68 | 0.63 |
| | | | | | |
| 1.88 | 707.09 | 830.71 | 0.31 | 0.11 | 0.11 |
| 4.05 | 6442.81 | 4062.31 | 0.47 | 0.43 | 0.37 |
| 5.14 | 10431.94 | 4882.96 | 0.5 | 0.58 | 0.51 |
| | | | | | |
| 1.74 | 763.33 | 761.48 | 0.3 | 0.11 | 0.1 |
| 3.59 | 6936.15 | 3921.9 | 0.43 | 0.36 | 0.35 |
| 4.67 | 10912 | 4653.27 | 0.46 | 0.54 | 0.51 |
| | | | | | |
| 2.36 | 558.88 | 575.21 | 0.42 | 0.17 | 0.17 |
| 3.98 | 6237.31 | 3811.82 | 0.49 | 0.4 | 0.4 |
| 4.91 | 10210.52 | 5083.47 | 0.51 | 0.53 | 0.53 |
| | | | | | |
| 2.11 | 625.33 | 742.93 | 0.41 | 0.16 | 0.16 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| studyarea | 26377 | Q2yr | 24800 | 168 | 173.36 | 172.56 | 173.64 | 0.003766 |
| studyarea | 26377 | Q100yr | 49900 | 168 | 174.49 | 173.41 | 174.96 | 0.003744 |
| | | | | | | | | |
| studyarea | 26215 | Q50% | 1320 | 168 | 169.85 | 169.13 | 169.94 | 0.003104 |
| studyarea | 26215 | Q2yr | 24800 | 168 | 172.8 | 171.69 | 173.06 | 0.003353 |
| studyarea | 26215 | Q100yr | 49900 | 168 | 173.9 | 172.76 | 174.36 | 0.003612 |
| | | | | | | | | |
| studyarea | 25965 | Q50% | 1320 | 168 | 169.09 | 168.62 | 169.17 | 0.003075 |
| studyarea | 25965 | Q2yr | 24800 | 168 | 171.97 | 171.05 | 172.22 | 0.003305 |
| studyarea | 25965 | Q100yr | 49900 | 168 | 172.95 | 171.91 | 173.42 | 0.003956 |
| | | | | | | | | |
| studyarea | 25745 | Q50% | 1320 | 166 | 168.39 | 167.65 | 168.46 | 0.003392 |
| studyarea | 25745 | Q2yr | 24800 | 166 | 170.93 | 170.46 | 171.25 | 0.005985 |
| studyarea | 25745 | Q100yr | 49900 | 166 | 171.82 | 171.23 | 172.36 | 0.005843 |
| | | | | | | | | |
| studyarea | 25598 | Q50% | 1320 | 166 | 167.67 | 167.19 | 167.79 | 0.00601 |
| studyarea | 25598 | Q2yr | 24800 | 166 | 170.27 | 169.38 | 170.51 | 0.004025 |
| studyarea | 25598 | Q100yr | 49900 | 166 | 171.15 | 170.33 | 171.59 | 0.00429 |
| | | | | | | | | |
| studyarea | 25359 | Q50% | 1320 | 165.07 | 166.86 | 166.42 | 166.91 | 0.002398 |
| studyarea | 25359 | Q2yr | 24800 | 165.07 | 169.47 | 168.61 | 169.68 | 0.002982 |
| studyarea | 25359 | Q100yr | 49900 | 165.07 | 170.63 | 169.37 | 170.86 | 0.00196 |
| | | | | | | | | |
| studyarea | 25206 | Q50% | 1320 | 164 | 166.37 | 166.16 | 166.42 | 0.004564 |
| studyarea | 25206 | Q2yr | 24800 | 164 | 169.23 | 168.12 | 169.34 | 0.001475 |
| studyarea | 25206 | Q100yr | 49900 | 164 | 170.4 | 168.89 | 170.59 | 0.001478 |
| | | | | | | | | |
| studyarea | 24915 | Q50% | 1320 | 164 | 165.42 | 164.81 | 165.48 | 0.0024 |
| studyarea | 24915 | Q2yr | 24800 | 164 | 168.4 | 167.4 | 168.68 | 0.003659 |
| studyarea | 24915 | Q100yr | 49900 | 164 | 169.5 | 168.53 | 169.94 | 0.003407 |
| | | | | | | | | |
| studyarea | 24671 | Q50% | 1320 | 164 | 164.81 | 164.42 | 164.86 | 0.002713 |
| studyarea | 24671 | Q2yr | 24800 | 164 | 167.55 | 166.71 | 167.82 | 0.00339 |
| studyarea | 24671 | Q100yr | 49900 | 164 | 168.64 | 167.57 | 169.09 | 0.003516 |
| | | | | | | | | |
| studyarea | 24505 | Q50% | 1320 | 162 | 164.12 | 163.48 | 164.21 | 0.006218 |
| studyarea | 24505 | Q2yr | 24800 | 162 | 166.98 | 166.24 | 167.23 | 0.003591 |
| studyarea | 24505 | Q100yr | 49900 | 162 | 168.09 | 167 | 168.51 | 0.003452 |
| | | | | | | | | |
| studyarea | 24348 | Q50% | 1320 | 162 | 163.72 | 162.9 | 163.78 | 0.001458 |
| studyarea | 24348 | Q2yr | 24800 | 162 | 166.55 | 165.36 | 166.76 | 0.002488 |
| studyarea | 24348 | Q100yr | 49900 | 162 | 167.68 | 166.39 | 168.02 | 0.002563 |
| | | | | | | | | |
| studyarea | 24224 | Q50% | 1320 | 162 | 163.55 | 162.71 | 163.6 | 0.001449 |
| studyarea | 24224 | Q2yr | 24800 | 162 | 166.19 | 165.15 | 166.41 | 0.003151 |
| studyarea | 24224 | Q100yr | 49900 | 162 | 167.35 | 166.12 | 167.69 | 0.002799 |
| | | | | | | | | |
| studyarea | 24040 | Q50% | 1320 | 160 | 163.1 | 162.5 | 163.17 | 0.004331 |
| studyarea | 24040 | Q2yr | 24800 | 160 | 165.55 | 164.75 | 165.79 | 0.003523 |
| studyarea | 24040 | Q100yr | 49900 | 160 | 166.77 | 165.54 | 167.13 | 0.003202 |
| | | | | | | | | |
| studyarea | 23879 | Q50% | 1320 | 160 | 162.48 | 162.23 | 162.53 | 0.003618 |

| | | | | | |
|---|---|---|---|---|---|
| 4.22 | 5890.32 | 3967.72 | 0.51 | 0.5 | 0.5 |
| 5.5 | 9114.27 | 5075.21 | 0.54 | 0.74 | 0.73 |
| | | | | | |
| 2.45 | 539.43 | 744.5 | 0.41 | 0.21 | 0.21 |
| 4.07 | 6089.15 | 3944.33 | 0.48 | 0.46 | 0.46 |
| 5.46 | 9152.27 | 4119.05 | 0.53 | 0.73 | 0.73 |
| | | | | | |
| 2.26 | 584.76 | 982.78 | 0.41 | 0.18 | 0.18 |
| 4.04 | 6135.96 | 3806.25 | 0.48 | 0.45 | 0.45 |
| 5.46 | 9193.16 | 4545.04 | 0.55 | 0.74 | 0.73 |
| | | | | | |
| 2.07 | 638 | 1295.73 | 0.42 | 0.16 | 0.16 |
| 4.58 | 5441.56 | 3988.03 | 0.63 | 0.61 | 0.61 |
| 5.92 | 8478.82 | 4170.4 | 0.66 | 0.9 | 0.89 |
| | | | | | |
| 2.84 | 466.17 | 844.73 | 0.56 | 0.3 | 0.31 |
| 3.99 | 6252.51 | 4353.83 | 0.52 | 0.45 | 0.45 |
| 5.37 | 9359.1 | 4663.42 | 0.58 | 0.72 | 0.71 |
| | | | | | |
| 1.78 | 740.22 | 1163.86 | 0.35 | 0.12 | 0.12 |
| 3.73 | 6683.46 | 4026.5 | 0.46 | 0.38 | 0.37 |
| 4.09 | 13457.77 | 4937.4 | 0.4 | 0.39 | 0.33 |
| | | | | | |
| 1.78 | 740.02 | 1817.56 | 0.45 | 0.14 | 0.14 |
| 2.8 | 9471.44 | 4496.49 | 0.33 | 0.21 | 0.19 |
| 3.7 | 14959.56 | 4984.31 | 0.35 | 0.32 | 0.28 |
| | | | | | |
| 1.95 | 675.58 | 918.04 | 0.36 | 0.14 | 0.14 |
| 4.3 | 5976.46 | 4644.96 | 0.51 | 0.5 | 0.41 |
| 5.46 | 9694.82 | 4810.83 | 0.53 | 0.7 | 0.6 |
| | | | | | |
| 1.85 | 715.01 | 1099.68 | 0.37 | 0.13 | 0.13 |
| 4.24 | 6003.91 | 3862.18 | 0.5 | 0.48 | 0.44 |
| 5.53 | 9483.5 | 5157.42 | 0.54 | 0.72 | 0.61 |
| | | | | | |
| 2.28 | 578.45 | 1525.65 | 0.54 | 0.22 | 0.22 |
| 4.04 | 6167.27 | 4159.16 | 0.5 | 0.45 | 0.44 |
| 5.19 | 9755.49 | 5345.48 | 0.53 | 0.65 | 0.59 |
| | | | | | |
| 1.91 | 689.7 | 863.33 | 0.3 | 0.12 | 0.12 |
| 3.67 | 6896.13 | 4525.71 | 0.43 | 0.35 | 0.32 |
| 4.76 | 10770.93 | 4788.52 | 0.46 | 0.53 | 0.49 |
| | | | | | |
| 1.9 | 693.62 | 542.35 | 0.3 | 0.12 | 0.12 |
| 3.72 | 6669.67 | 4450.25 | 0.47 | 0.38 | 0.38 |
| 4.66 | 10705.92 | 4663.15 | 0.47 | 0.52 | 0.52 |
| | | | | | |
| 2.11 | 626.16 | 925.85 | 0.45 | 0.18 | 0.18 |
| 3.98 | 6227.42 | 3805.57 | 0.49 | 0.44 | 0.44 |
| 4.82 | 10354.86 | 5063 | 0.5 | 0.58 | 0.58 |
| | | | | | |
| 1.66 | 797.15 | 1525.96 | 0.4 | 0.12 | 0.12 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| studyarea | 23879 | Q2yr | 24800 | 159.34 | 164.98 | 163.98 | 165.24 | 0.003303 |
| studyarea | 23879 | Q100yr | 49990 | 159.34 | 166.16 | 164.98 | 166.57 | 0.003238 |
| | | | | | | | | |
| studyarea | 23694 | Q50% | 1320 | 159 | 161.5 | 160.99 | 161.57 | 0.003594 |
| studyarea | 23694 | Q2yr | 24800 | 159 | 164.2 | 163.37 | 164.53 | 0.004401 |
| studyarea | 23694 | Q100yr | 49990 | 159 | 165.35 | 164.41 | 165.87 | 0.004352 |
| | | | | | | | | |
| studyarea | 23523 | Q50% | 1320 | 158.5 | 160.7 | 160.32 | 160.8 | 0.005693 |
| studyarea | 23523 | Q2yr | 24800 | 158.5 | 163.49 | 162.65 | 163.81 | 0.004081 |
| studyarea | 23523 | Q100yr | 49990 | 158.5 | 164.67 | 163.68 | 165.15 | 0.00392 |
| | | | | | | | | |
| studyarea | 23357 | Q50% | 1320 | 156.29 | 159.56 | 159.17 | 159.74 | 0.007165 |
| studyarea | 23357 | Q2yr | 24800 | 156.29 | 162.71 | 161.98 | 163.05 | 0.004989 |
| studyarea | 23357 | Q100yr | 49990 | 156.29 | 164.03 | 162.99 | 164.49 | 0.00398 |
| | | | | | | | | |
| studyarea | 23206 | Q50% | 1320 | 155.13 | 158.52 | | 158.72 | 0.006331 |
| studyarea | 23206 | Q2yr | 24800 | 155.13 | 162.35 | | 162.55 | 0.002071 |
| studyarea | 23206 | Q100yr | 49990 | 155.13 | 163.74 | | 164.04 | 0.001897 |
| | | | | | | | | |
| studyarea | 22998 | Q50% | 1320 | 155.05 | 157.98 | | 158.05 | 0.001778 |
| studyarea | 22998 | Q2yr | 24800 | 155.05 | 161.75 | | 162.03 | 0.00286 |
| studyarea | 22998 | Q100yr | 49990 | 155.05 | 163.09 | | 163.54 | 0.002915 |
| | | | | | | | | |
| studyarea | 22793 | Q50% | 1320 | 154.95 | 157.66 | | 157.71 | 0.001547 |
| studyarea | 22793 | Q2yr | 24800 | 154.95 | 161.39 | | 161.56 | 0.001686 |
| studyarea | 22793 | Q100yr | 49990 | 154.95 | 162.73 | | 163.03 | 0.00179 |
| | | | | | | | | |
| studyarea | 22580 | Q50% | 1320 | 154.63 | 157.13 | | 157.23 | 0.003442 |
| studyarea | 22580 | Q2yr | 24800 | 154.63 | 160.79 | | 161.07 | 0.003032 |
| studyarea | 22580 | Q100yr | 49990 | 154.63 | 162.03 | | 162.51 | 0.003208 |
| | | | | | | | | |
| studyarea | 22396 | Q50% | 1320 | 153.92 | 156.53 | | 156.64 | 0.002966 |
| studyarea | 22396 | Q2yr | 24800 | 153.92 | 159.58 | | 160.2 | 0.007561 |
| studyarea | 22396 | Q100yr | 49990 | 153.92 | 160.7 | | 161.61 | 0.007538 |
| | | | | | | | | |
| studyarea | 22136 | Q50% | 1320 | 152.79 | 154.78 | 154.77 | 155.08 | 0.017359 |
| studyarea | 22136 | Q2yr | 24800 | 152.79 | 158.38 | | 158.72 | 0.004009 |
| studyarea | 22136 | Q100yr | 49990 | 152.79 | 159.59 | | 160.09 | 0.004029 |
| | | | | | | | | |
| studyarea | 21905 | Q50% | 1320 | 150.8 | 154.02 | | 154.08 | 0.001741 |
| studyarea | 21905 | Q2yr | 24800 | 150.8 | 157.33 | | 157.73 | 0.004543 |
| studyarea | 21905 | Q100yr | 49990 | 150.8 | 158.55 | | 159.1 | 0.004524 |
| | | | | | | | | |
| studyarea | 21774 | Q50% | 1320 | 151.05 | 153.81 | | 153.87 | 0.001501 |
| studyarea | 21774 | Q2yr | 24800 | 151.05 | 157.02 | | 157.25 | 0.002488 |
| studyarea | 21774 | Q100yr | 49990 | 151.05 | 158.26 | | 158.61 | 0.002503 |
| | | | | | | | | |
| studyarea | 21415 | Q50% | 1320 | 150.15 | 152.11 | 152.11 | 152.51 | 0.019672 |
| studyarea | 21415 | Q2yr | 24800 | 150.15 | 155.67 | | 156.05 | 0.004605 |
| studyarea | 21415 | Q100yr | 49990 | 150.15 | 156.87 | | 157.44 | 0.004286 |
| | | | | | | | | |
| studyarea | 21091 | Q50% | 1320 | 147.62 | 151 | 149.71 | 151.08 | 0.001151 |

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|---|---|---|---|---|---|
| 4.08 | 6104.48 | 3011.25 | 0.49 | 0.44 | 0.43 |
| 5.17 | 9733.24 | 4212.62 | 0.53 | 0.59 | 0.58 |
| | | | | | |
| 2.14 | 616.44 | 791.94 | 0.43 | 0.18 | 0.18 |
| 4.59 | 5405.01 | 2677.72 | 0.57 | 0.56 | 0.56 |
| 5.77 | 8684.64 | 3172.69 | 0.61 | 0.76 | 0.76 |
| | | | | | |
| 2.57 | 513.67 | 714.14 | 0.53 | 0.26 | 0.26 |
| 4.54 | 5486.14 | 2704.82 | 0.55 | 0.53 | 0.52 |
| 5.58 | 9006.68 | 3399.72 | 0.6 | 0.66 | 0.65 |
| | | | | | |
| 3.37 | 391.97 | 433.27 | 0.62 | 0.4 | 0.4 |
| 4.74 | 5233.15 | 2624.89 | 0.59 | 0.62 | 0.62 |
| 5.46 | 9170.16 | 3317.2 | 0.58 | 0.69 | 0.69 |
| | | | | | |
| 3.55 | 372.22 | 360.12 | 0.61 | 0.41 | 0.41 |
| 3.51 | 7070.48 | 2947.69 | 0.4 | 0.31 | 0.31 |
| 4.37 | 11481.35 | 3361.67 | 0.41 | 0.41 | 0.4 |
| | | | | | |
| 2.19 | 602.55 | 448.66 | 0.33 | 0.15 | 0.15 |
| 4.31 | 5771.36 | 2404.01 | 0.49 | 0.43 | 0.43 |
| 5.4 | 9393.31 | 3018.18 | 0.52 | 0.62 | 0.56 |
| | | | | | |
| 1.71 | 772.3 | 737.62 | 0.29 | 0.1 | 0.1 |
| 3.34 | 7548.64 | 2893.67 | 0.35 | 0.29 | 0.27 |
| 4.45 | 11749.3 | 3198.87 | 0.39 | 0.46 | 0.41 |
| | | | | | |
| 2.51 | 526.65 | 484.57 | 0.42 | 0.23 | 0.23 |
| 4.32 | 5944.72 | 2577.25 | 0.47 | 0.49 | 0.43 |
| 5.68 | 9396.64 | 2853.77 | 0.52 | 0.75 | 0.66 |
| | | | | | |
| 2.69 | 493.59 | 402.74 | 0.43 | 0.23 | 0.23 |
| 6.43 | 4052.77 | 2234.3 | 0.79 | 0.96 | 0.85 |
| 7.83 | 6934.28 | 2814.8 | 0.82 | 1.33 | 1.16 |
| | | | | | |
| 4.34 | 304.34 | 525.49 | 1 | 0.63 | 0.63 |
| 4.71 | 5350.2 | 2696.83 | 0.57 | 0.52 | 0.5 |
| 5.77 | 8965.61 | 3194.43 | 0.58 | 0.76 | 0.7 |
| | | | | | |
| 2.02 | 652.91 | 519.68 | 0.32 | 0.14 | 0.14 |
| 5.05 | 4971.38 | 2453.43 | 0.61 | 0.6 | 0.57 |
| 5.98 | 8577.65 | 3259.03 | 0.63 | 0.79 | 0.74 |
| | | | | | |
| 1.89 | 697.45 | 572.34 | 0.3 | 0.11 | 0.11 |
| 3.81 | 6526.03 | 3052.89 | 0.46 | 0.33 | 0.33 |
| 4.77 | 10528.53 | 3350.56 | 0.47 | 0.5 | 0.49 |
| | | | | | |
| 5.06 | 260.73 | 337.18 | 1.01 | 0.95 | 0.95 |
| 4.92 | 5073 | 2502.27 | 0.6 | 0.59 | 0.58 |
| 6.04 | 8341.65 | 2871.78 | 0.62 | 0.78 | 0.78 |
| | | | | | |
| 2.22 | 593.61 | 311.93 | 0.28 | 0.14 | 0.14 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| studyarea | 23879 | Q2yr | 24800 | 160 | 165.04 | 164.13 | 165.27 | 0.002949 |
| studyarea | 23879 | Q100yr | 49900 | 160 | 166.21 | 164.93 | 166.6 | 0.003376 |
| studyarea | 23694 | Q50% | 1320 | 160 | 161.6 | 161.14 | 161.73 | 0.005221 |
| studyarea | 23694 | Q2yr | 24800 | 160 | 164.29 | 163.45 | 164.59 | 0.004605 |
| studyarea | 23694 | Q100yr | 49900 | 160 | 165.45 | 164.47 | 165.91 | 0.004041 |
| studyarea | 23523 | Q50% | 1320 | 160 | 160.96 | 160.56 | 161.02 | 0.003182 |
| studyarea | 23523 | Q2yr | 24800 | 160 | 163.49 | 162.75 | 163.82 | 0.004341 |
| studyarea | 23523 | Q100yr | 49900 | 160 | 164.65 | 163.67 | 165.15 | 0.004913 |
| studyarea | 23357 | Q50% | 1320 | 158 | 159.86 | 159.57 | 160.18 | 0.008541 |
| studyarea | 23357 | Q2yr | 24800 | 158 | 162.77 | 162.16 | 163.07 | 0.004629 |
| studyarea | 23357 | Q100yr | 49900 | 158 | 163.99 | 162.94 | 164.43 | 0.003646 |
| studyarea | 23206 | Q50% | 1320 | 156 | 159.16 | | 159.26 | 0.004031 |
| studyarea | 23206 | Q2yr | 24800 | 156 | 162.41 | | 162.58 | 0.002049 |
| studyarea | 23206 | Q100yr | 49900 | 156 | 163.72 | | 164 | 0.001821 |
| studyarea | 22998 | Q50% | 1320 | 156 | 158.66 | | 158.71 | 0.00175 |
| studyarea | 22998 | Q2yr | 24800 | 156 | 161.79 | | 162.07 | 0.002939 |
| studyarea | 22998 | Q100yr | 49900 | 156 | 163.07 | | 163.5 | 0.00311 |
| studyarea | 22793 | Q50% | 1320 | 156 | 158.19 | | 158.24 | 0.003264 |
| studyarea | 22793 | Q2yr | 24800 | 156 | 161.42 | | 161.59 | 0.001665 |
| studyarea | 22793 | Q100yr | 49900 | 156 | 162.66 | | 162.98 | 0.001866 |
| studyarea | 22580 | Q50% | 1320 | 156 | 157.58 | | 157.65 | 0.002324 |
| studyarea | 22580 | Q2yr | 24800 | 156 | 160.82 | | 161.1 | 0.003253 |
| studyarea | 22580 | Q100yr | 49900 | 156 | 161.95 | | 162.44 | 0.003441 |
| studyarea | 22396 | Q50% | 1320 | 154 | 156.75 | 156.51 | 156.93 | 0.007724 |
| studyarea | 22396 | Q2yr | 24800 | 154 | 159.68 | | 160.2 | 0.007473 |
| studyarea | 22396 | Q100yr | 49900 | 154 | 160.66 | | 161.49 | 0.007763 |
| studyarea | 22136 | Q50% | 1320 | 154 | 155.08 | | 155.2 | 0.005646 |
| studyarea | 22136 | Q2yr | 24800 | 154 | 158.49 | | 158.76 | 0.003897 |
| studyarea | 22136 | Q100yr | 49900 | 154 | 159.6 | | 160.03 | 0.003658 |
| studyarea | 21905 | Q50% | 1320 | 152 | 154.49 | | 154.54 | 0.001609 |
| studyarea | 21905 | Q2yr | 24800 | 152 | 157.38 | | 157.75 | 0.004845 |
| studyarea | 21905 | Q100yr | 49900 | 152 | 158.53 | | 159.07 | 0.004714 |
| studyarea | 21774 | Q50% | 1320 | 152 | 154.28 | | 154.31 | 0.001864 |
| studyarea | 21774 | Q2yr | 24800 | 152 | 157.04 | | 157.25 | 0.002611 |
| studyarea | 21774 | Q100yr | 49900 | 152 | 158.23 | | 158.58 | 0.002473 |
| studyarea | 21415 | Q50% | 1320 | 150.41 | 152.36 | 152.36 | 152.72 | 0.019699 |
| studyarea | 21415 | Q2yr | 24800 | 150.41 | 155.7 | | 156.06 | 0.004197 |
| studyarea | 21415 | Q100yr | 49900 | 150.41 | 156.87 | | 157.42 | 0.004191 |
| studyarea | 21091 | Q50% | 1320 | 148 | 151.34 | | 151.41 | 0.001326 |

| | | | | | |
|---|---|---|---|---|---|
| 3.9 | 6374.11 | 3151.75 | 0.46 | 0.41 | 0.4 |
| 5.03 | 9946.96 | 4503.42 | 0.52 | 0.61 | 0.61 |
| | | | | | |
| 2.89 | 456.43 | 480.78 | 0.52 | 0.31 | 0.31 |
| 4.42 | 5610.92 | 2995.39 | 0.56 | 0.55 | 0.55 |
| 5.46 | 9149.47 | 3282.26 | 0.57 | 0.73 | 0.73 |
| | | | | | |
| 1.94 | 679 | 920.37 | 0.4 | 0.15 | 0.15 |
| 4.65 | 5333.63 | 2474.89 | 0.56 | 0.58 | 0.58 |
| 5.67 | 8833.38 | 3449.99 | 0.61 | 0.81 | 0.8 |
| | | | | | |
| 4.49 | 294.04 | 240.07 | 0.71 | 0.65 | 0.65 |
| 4.4 | 5633.44 | 2993.01 | 0.57 | 0.54 | 0.54 |
| 5.32 | 9382.98 | 3142.85 | 0.54 | 0.68 | 0.68 |
| | | | | | |
| 2.6 | 506.93 | 532.95 | 0.47 | 0.24 | 0.24 |
| 3.32 | 7462.5 | 3276.64 | 0.39 | 0.29 | 0.29 |
| 4.24 | 11773.69 | 3330.22 | 0.39 | 0.41 | 0.4 |
| | | | | | |
| 1.77 | 744.27 | 740.16 | 0.31 | 0.11 | 0.11 |
| 4.25 | 5834.32 | 2310.01 | 0.47 | 0.46 | 0.46 |
| 5.34 | 9622.78 | 3100.72 | 0.51 | 0.66 | 0.6 |
| | | | | | |
| 1.73 | 761.74 | 1256.42 | 0.39 | 0.12 | 0.12 |
| 3.38 | 7504.62 | 2955.75 | 0.36 | 0.28 | 0.26 |
| 4.59 | 11376.66 | 3197.61 | 0.41 | 0.46 | 0.41 |
| | | | | | |
| 2.14 | 617.83 | 563.93 | 0.36 | 0.16 | 0.16 |
| 4.32 | 6031.07 | 2817.19 | 0.49 | 0.49 | 0.43 |
| 5.72 | 9266.92 | 2852.8 | 0.54 | 0.76 | 0.7 |
| | | | | | |
| 3.33 | 396.49 | 488.53 | 0.65 | 0.39 | 0.39 |
| 5.81 | 4269.53 | 2195.89 | 0.73 | 0.91 | 0.91 |
| 7.33 | 6885.17 | 2890.55 | 0.82 | 1.2 | 1.15 |
| | | | | | |
| 2.83 | 467.12 | 524.74 | 0.53 | 0.31 | 0.31 |
| 4.21 | 5926.13 | 3185.55 | 0.54 | 0.46 | 0.45 |
| 5.31 | 9479.15 | 3194.73 | 0.54 | 0.69 | 0.68 |
| | | | | | |
| 1.78 | 740.18 | 700.74 | 0.31 | 0.11 | 0.11 |
| 4.86 | 5150.19 | 2564.29 | 0.6 | 0.62 | 0.61 |
| 5.91 | 8596.66 | 3342.39 | 0.63 | 0.8 | 0.76 |
| | | | | | |
| 1.59 | 832.74 | 1111.11 | 0.32 | 0.09 | 0.09 |
| 3.68 | 6742.85 | 3164.25 | 0.44 | 0.35 | 0.35 |
| 4.7 | 10610.61 | 3342.71 | 0.46 | 0.49 | 0.49 |
| | | | | | |
| 4.8 | 274.92 | 386.15 | 1 | 0.88 | 0.88 |
| 4.8 | 5165.17 | 2351.15 | 0.57 | 0.58 | 0.58 |
| 5.98 | 8341.72 | 2891.23 | 0.62 | 0.76 | 0.75 |
| | | | | | |
| 2.13 | 618.28 | 381.91 | 0.3 | 0.13 | 0.13 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| studyarea | 21091 | Q2yr | 24800 | 147.62 | 154.42 | | 154.75 | 0.003418 |
| studyarea | 21091 | Q100yr | 49990 | 147.62 | 155.54 | | 156.09 | 0.004028 |
| | | | | | | | | |
| studyarea | 20822 | Q50% | 1320 | 147.38 | 149.98 | 149.79 | 150.34 | 0.010992 |
| studyarea | 20822 | Q2yr | 24800 | 147.38 | 152.69 | 152.5 | 153.23 | 0.010709 |
| studyarea | 20822 | Q100yr | 49990 | 147.38 | 153.55 | 153.37 | 154.4 | 0.010701 |
| | | | | | | | | |
| studyarea | 20629 | Q50% | 1320 | 145.98 | 148.88 | 148.38 | 148.99 | 0.004379 |
| studyarea | 20629 | Q2yr | 24800 | 145.98 | 151.68 | 151.02 | 151.94 | 0.004097 |
| studyarea | 20629 | Q100yr | 49990 | 145.98 | 152.74 | 151.82 | 153.13 | 0.003664 |
| | | | | | | | | |
| studyarea | 20353 | Q50% | 1320 | 145.52 | 147.93 | 147.34 | 147.99 | 0.002915 |
| studyarea | 20353 | Q2yr | 24800 | 145.52 | 150.7 | 149.76 | 150.92 | 0.003299 |
| studyarea | 20353 | Q100yr | 49990 | 145.52 | 151.84 | 150.62 | 152.16 | 0.003252 |
| | | | | | | | | |
| studyarea | 20162 | Q50% | 1320 | 144.82 | 147.28 | 146.78 | 147.34 | 0.004052 |
| studyarea | 20162 | Q2yr | 24800 | 144.82 | 150.05 | 148.92 | 150.25 | 0.003667 |
| studyarea | 20162 | Q100yr | 49990 | 144.82 | 151.22 | 149.91 | 151.51 | 0.00348 |
| | | | | | | | | |
| studyarea | 19962 | Q50% | 1320 | 144.29 | 146.67 | 146.12 | 146.71 | 0.002469 |
| studyarea | 19962 | Q2yr | 24800 | 144.29 | 149.38 | 148.24 | 149.56 | 0.003182 |
| studyarea | 19962 | Q100yr | 49990 | 144.29 | 150.56 | 149.12 | 150.82 | 0.003311 |
| | | | | | | | | |
| studyarea | 19632 | Q50% | 1320 | 142.8 | 145.78 | 145.15 | 145.83 | 0.002875 |
| studyarea | 19632 | Q2yr | 24800 | 142.8 | 148.55 | 147.39 | 148.72 | 0.00207 |
| studyarea | 19632 | Q100yr | 49990 | 142.8 | 149.67 | 148.23 | 149.96 | 0.00212 |
| | | | | | | | | |
| studyarea | 19295 | Q50% | 1320 | 142 | 144.86 | 144.37 | 144.91 | 0.00255 |
| studyarea | 19295 | Q2yr | 24800 | 142 | 147.64 | 146.53 | 147.86 | 0.003194 |
| studyarea | 19295 | Q100yr | 49990 | 142 | 148.76 | 147.57 | 149.1 | 0.003101 |
| | | | | | | | | |
| studyarea | 19070 | Q50% | 1320 | 141.84 | 144.19 | 143.76 | 144.25 | 0.00339 |
| studyarea | 19070 | Q2yr | 24800 | 141.84 | 146.76 | 145.93 | 147.08 | 0.00375 |
| studyarea | 19070 | Q100yr | 49990 | 141.84 | 147.83 | 147 | 148.3 | 0.003899 |
| | | | | | | | | |
| studyarea | 18899 | Q50% | 1320 | 141.34 | 143.54 | 143.21 | 143.61 | 0.004212 |
| studyarea | 18899 | Q2yr | 24800 | 141.34 | 146.2 | 145.26 | 146.46 | 0.00324 |
| studyarea | 18899 | Q100yr | 49990 | 141.34 | 147.24 | 146.24 | 147.66 | 0.003441 |
| | | | | | | | | |
| studyarea | 18750 | Q50% | 1320 | 139.37 | 142.89 | 142.42 | 142.99 | 0.004092 |
| studyarea | 18750 | Q2yr | 24800 | 139.37 | 145.6 | 144.86 | 145.92 | 0.003991 |
| studyarea | 18750 | Q100yr | 49990 | 139.37 | 146.59 | 145.87 | 147.08 | 0.004364 |
| | | | | | | | | |
| studyarea | 18647 | Q50% | 1320 | 139.5 | 142.48 | 142 | 142.56 | 0.004129 |
| studyarea | 18647 | Q2yr | 24800 | 139.5 | 145.35 | 144.27 | 145.56 | 0.002594 |
| studyarea | 18647 | Q100yr | 49990 | 139.5 | 146.34 | 145.32 | 146.65 | 0.003046 |
| | | | | | | | | |
| studyarea | 18512 | Q50% | 1320 | 139.38 | 141.95 | 141.57 | 142.01 | 0.003927 |
| studyarea | 18512 | Q2yr | 24800 | 139.38 | 144.9 | 143.89 | 145.09 | 0.004832 |
| studyarea | 18512 | Q100yr | 49990 | 139.38 | 145.84 | 144.85 | 146.14 | 0.004718 |
| | | | | | | | | |
| studyarea | 18408 | Q50% | 1320 | 139.02 | 141.69 | 141.12 | 141.73 | 0.001885 |

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|---|---|---|---|---|---|
| 4.61 | 5384.47 | 2556.2 | 0.56 | 0.45 | 0.45 |
| 5.96 | 8411.05 | 2851.64 | 0.61 | 0.75 | 0.74 |
| | | | | | |
| 4.83 | 273.12 | 255.82 | 0.82 | 0.73 | 0.73 |
| 5.93 | 4184.18 | 2903.82 | 0.85 | 1.01 | 1.01 |
| 7.4 | 6757.33 | 3334.12 | 0.89 | 1.43 | 1.43 |
| | | | | | |
| 2.58 | 511.69 | 650.44 | 0.5 | 0.22 | 0.22 |
| 4.11 | 6027.53 | 3619.76 | 0.55 | 0.44 | 0.44 |
| 5 | 9995.42 | 4108.29 | 0.55 | 0.58 | 0.58 |
| | | | | | |
| 1.94 | 681.46 | 876.07 | 0.39 | 0.14 | 0.14 |
| 3.68 | 6742.6 | 3483.43 | 0.47 | 0.4 | 0.4 |
| 4.56 | 10980.97 | 4192.85 | 0.48 | 0.57 | 0.57 |
| | | | | | |
| 1.96 | 674.4 | 1075.63 | 0.44 | 0.16 | 0.16 |
| 3.56 | 6968.88 | 3621.55 | 0.45 | 0.44 | 0.44 |
| 4.33 | 11542.67 | 4386.6 | 0.46 | 0.61 | 0.6 |
| | | | | | |
| 1.68 | 784.48 | 1099.59 | 0.35 | 0.11 | 0.11 |
| 3.38 | 7343.37 | 3654.64 | 0.42 | 0.4 | 0.4 |
| 4.13 | 12096.95 | 4507.03 | 0.43 | 0.59 | 0.58 |
| | | | | | |
| 1.76 | 750.23 | 1080.28 | 0.37 | 0.12 | 0.12 |
| 3.36 | 7665.37 | 3857.3 | 0.39 | 0.29 | 0.26 |
| 4.39 | 12332.42 | 4657.86 | 0.42 | 0.45 | 0.37 |
| | | | | | |
| 1.77 | 747.73 | 990.81 | 0.36 | 0.12 | 0.12 |
| 3.81 | 6681.33 | 3601.6 | 0.46 | 0.43 | 0.38 |
| 4.79 | 11137.06 | 4584.49 | 0.47 | 0.61 | 0.51 |
| | | | | | |
| 1.96 | 673.95 | 999.95 | 0.42 | 0.14 | 0.14 |
| 4.55 | 5588.64 | 3195.19 | 0.56 | 0.47 | 0.42 |
| 5.62 | 9589.17 | 4455.01 | 0.59 | 0.68 | 0.55 |
| | | | | | |
| 2.05 | 642.86 | 1052.24 | 0.46 | 0.16 | 0.16 |
| 4.11 | 6094.38 | 3264.91 | 0.5 | 0.43 | 0.38 |
| 5.27 | 10139.13 | 4492.91 | 0.54 | 0.62 | 0.51 |
| | | | | | |
| 2.47 | 534.71 | 819.7 | 0.54 | 0.17 | 0.17 |
| 4.55 | 5563.88 | 3316.37 | 0.57 | 0.49 | 0.43 |
| 5.73 | 9456.22 | 4510.8 | 0.61 | 0.74 | 0.6 |
| | | | | | |
| 2.21 | 596.25 | 862.61 | 0.47 | 0.18 | 0.18 |
| 3.63 | 6839.3 | 4040.65 | 0.48 | 0.28 | 0.28 |
| 4.5 | 11188.69 | 5006.18 | 0.5 | 0.47 | 0.46 |
| | | | | | |
| 2.02 | 654.01 | 986.38 | 0.44 | 0.16 | 0.16 |
| 3.52 | 7060.5 | 4357.99 | 0.48 | 0.51 | 0.5 |
| 4.44 | 11322.6 | 5120.71 | 0.5 | 0.72 | 0.7 |
| | | | | | |
| 1.58 | 835.54 | 1032.39 | 0.31 | 0.1 | 0.1 |

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|---|---|---|---|---|---|---|---|---|
| studyarea | 21091 | Q2yr | 24800 | 148 | 154.55 | | 154.84 | 0.003306 |
| studyarea | 21091 | Q100yr | 49900 | 148 | 155.55 | | 156.08 | 0.00405 |
| studyarea | 20822 | Q50% | 1320 | 148 | 150.18 | 150.18 | 150.47 | 0.021573 |
| studyarea | 20822 | Q2yr | 24800 | 148 | 152.7 | 152.59 | 153.24 | 0.012964 |
| studyarea | 20822 | Q100yr | 49900 | 148 | 153.57 | 153.38 | 154.37 | 0.011123 |
| studyarea | 20629 | Q50% | 1320 | 146.33 | 149.27 | 148.56 | 149.33 | 0.001852 |
| studyarea | 20629 | Q2yr | 24800 | 146.33 | 151.81 | 150.98 | 152.04 | 0.003222 |
| studyarea | 20629 | Q100yr | 49900 | 146.33 | 152.76 | 151.76 | 153.13 | 0.003496 |
| studyarea | 20353 | Q50% | 1320 | 146 | 148.24 | 148.11 | 148.34 | 0.009431 |
| studyarea | 20353 | Q2yr | 24800 | 146 | 150.69 | 150.29 | 150.95 | 0.004864 |
| studyarea | 20353 | Q100yr | 49900 | 146 | 151.73 | 150.86 | 152.1 | 0.003959 |
| studyarea | 20162 | Q50% | 1320 | 146 | 147.3 | 146.74 | 147.36 | 0.003116 |
| studyarea | 20162 | Q2yr | 24800 | 146 | 149.96 | 148.97 | 150.2 | 0.003196 |
| studyarea | 20162 | Q100yr | 49900 | 146 | 151.12 | 150.09 | 151.43 | 0.003003 |
| studyarea | 19962 | Q50% | 1320 | 145.52 | 146.81 | 146.37 | 146.84 | 0.002176 |
| studyarea | 19962 | Q2yr | 24800 | 145.52 | 149.41 | 148.41 | 149.6 | 0.002671 |
| studyarea | 19962 | Q100yr | 49900 | 145.52 | 150.55 | 149.19 | 150.84 | 0.002826 |
| studyarea | 19632 | Q50% | 1320 | 144 | 145.85 | 145.26 | 145.94 | 0.00339 |
| studyarea | 19632 | Q2yr | 24800 | 144 | 148.6 | 147.24 | 148.76 | 0.002379 |
| studyarea | 19632 | Q100yr | 49900 | 144 | 149.71 | 148.26 | 149.96 | 0.00242 |
| studyarea | 19295 | Q50% | 1320 | 142.09 | 145.1 | 144.44 | 145.13 | 0.001757 |
| studyarea | 19295 | Q2yr | 24800 | 142.09 | 147.7 | 146.62 | 147.9 | 0.002704 |
| studyarea | 19295 | Q100yr | 49900 | 142.09 | 148.73 | 147.48 | 149.06 | 0.00292 |
| studyarea | 19070 | Q50% | 1320 | 142.43 | 144.47 | 144.26 | 144.53 | 0.004621 |
| studyarea | 19070 | Q2yr | 24800 | 142.43 | 146.87 | 146.22 | 147.14 | 0.004199 |
| studyarea | 19070 | Q100yr | 49900 | 142.43 | 147.78 | 147.01 | 148.25 | 0.004353 |
| studyarea | 18899 | Q50% | 1320 | 142 | 143.26 | 143.11 | 143.43 | 0.009257 |
| studyarea | 18899 | Q2yr | 24800 | 142 | 146.15 | 145.18 | 146.43 | 0.004035 |
| studyarea | 18899 | Q100yr | 49900 | 142 | 147.17 | 146.38 | 147.56 | 0.003488 |
| studyarea | 18750 | Q50% | 1320 | 140 | 142.93 | 142.34 | 142.96 | 0.001362 |
| studyarea | 18750 | Q2yr | 24800 | 140 | 145.67 | 144.65 | 145.92 | 0.002872 |
| studyarea | 18750 | Q100yr | 49900 | 140 | 146.59 | 145.58 | 147.01 | 0.003866 |
| studyarea | 18647 | Q50% | 1320 | 140 | 142.79 | 142.26 | 142.82 | 0.001404 |
| studyarea | 18647 | Q2yr | 24800 | 140 | 145.41 | 144.43 | 145.59 | 0.003049 |
| studyarea | 18647 | Q100yr | 49900 | 140 | 146.29 | 145.29 | 146.6 | 0.003442 |
| studyarea | 18512 | Q50% | 1320 | 140 | 142.54 | 142.19 | 142.58 | 0.002334 |
| studyarea | 18512 | Q2yr | 24800 | 140 | 144.94 | 144.32 | 145.14 | 0.003738 |
| studyarea | 18512 | Q100yr | 49900 | 140 | 145.77 | 144.94 | 146.11 | 0.003875 |
| studyarea | 18408 | Q50% | 1320 | 140 | 142.27 | 141.7 | 142.3 | 0.003168 |

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|---|---|---|---|---|---|
| 4.3 | 5761.33 | 2719.34 | 0.52 | 0.44 | 0.44 |
| 5.86 | 8520.03 | 2824.7 | 0.59 | 0.76 | 0.76 |
| 4.34 | 304.37 | 524.29 | 1 | 0.78 | 0.78 |
| 5.93 | 4181.92 | 3224.26 | 0.9 | 1.1 | 1.1 |
| 7.16 | 6969.62 | 3546.01 | 0.88 | 1.44 | 1.44 |
| 1.92 | 686.35 | 657.27 | 0.33 | 0.12 | 0.12 |
| 3.77 | 6576.81 | 3468.58 | 0.48 | 0.39 | 0.39 |
| 4.87 | 10245.25 | 4138.52 | 0.54 | 0.56 | 0.56 |
| 2.5 | 528.47 | 1188.42 | 0.64 | 0.28 | 0.28 |
| 4.13 | 6059.14 | 3788.32 | 0.57 | 0.5 | 0.49 |
| 4.95 | 10191.89 | 4108.18 | 0.55 | 0.63 | 0.61 |
| 1.93 | 683.54 | 904.69 | 0.38 | 0.15 | 0.15 |
| 3.92 | 6332.02 | 3017.82 | 0.47 | 0.42 | 0.42 |
| 4.47 | 11153.02 | 4423.14 | 0.49 | 0.49 | 0.49 |
| 1.48 | 892.66 | 1294.55 | 0.31 | 0.1 | 0.1 |
| 3.48 | 7131.73 | 3487.9 | 0.43 | 0.35 | 0.35 |
| 4.29 | 11632.38 | 4592.53 | 0.46 | 0.48 | 0.48 |
| 2.4 | 549.3 | 522.28 | 0.4 | 0.23 | 0.23 |
| 3.19 | 8051.71 | 4308.52 | 0.37 | 0.33 | 0.29 |
| 4.14 | 12784.61 | 4611.67 | 0.4 | 0.5 | 0.44 |
| 1.41 | 938.03 | 1156.55 | 0.27 | 0.09 | 0.09 |
| 3.58 | 6928.24 | 3336.68 | 0.43 | 0.37 | 0.36 |
| 4.68 | 11124.55 | 4679.14 | 0.47 | 0.56 | 0.47 |
| 1.84 | 715.57 | 1410.72 | 0.46 | 0.15 | 0.15 |
| 4.21 | 5899.7 | 3452.71 | 0.55 | 0.48 | 0.46 |
| 5.52 | 9293.92 | 4155.12 | 0.59 | 0.74 | 0.64 |
| 3.29 | 401.5 | 709.61 | 0.77 | 0.33 | 0.33 |
| 4.25 | 5946.53 | 4202.41 | 0.55 | 0.47 | 0.36 |
| 5.14 | 10324.24 | 4509.24 | 0.54 | 0.62 | 0.52 |
| 1.46 | 901.97 | 1053.65 | 0.28 | 0.07 | 0.07 |
| 4 | 6214.53 | 2879.64 | 0.47 | 0.41 | 0.39 |
| 5.32 | 9909.58 | 4835.32 | 0.57 | 0.66 | 0.52 |
| 1.35 | 981.22 | 1261.76 | 0.27 | 0.07 | 0.07 |
| 3.44 | 7216.22 | 4077.67 | 0.45 | 0.34 | 0.34 |
| 4.53 | 11072.73 | 5298.05 | 0.51 | 0.52 | 0.5 |
| 1.56 | 848.22 | 1281.6 | 0.34 | 0.1 | 0.1 |
| 3.55 | 6982.06 | 4431.33 | 0.49 | 0.37 | 0.37 |
| 4.69 | 10644.04 | 4624.03 | 0.54 | 0.57 | 0.57 |
| 1.49 | 888.31 | 1575.7 | 0.35 | 0.11 | 0.11 |

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|---|---|---|---|---|---|---|---|---|
| studyarea | 18408 | Q2yr | 24800 | 139.02 | 144.47 | 143.49 | 144.65 | 0.003759 |
| studyarea | 18408 | Q100yr | 49990 | 139.02 | 145.39 | 144.37 | 145.68 | 0.004142 |
| | | | | | | | | |
| studyarea | 18268 | Q50% | 1320 | 138.47 | 141.3 | 140.87 | 141.37 | 0.003629 |
| studyarea | 18268 | Q2yr | 24800 | 138.47 | 143.79 | 143.09 | 144 | 0.00579 |
| studyarea | 18268 | Q100yr | 49990 | 138.47 | 144.67 | 143.84 | 145 | 0.005684 |
| | | | | | | | | |
| studyarea | 18170 | Q50% | 1320 | 137.77 | 140.29 | 140.25 | 140.7 | 0.015444 |
| studyarea | 18170 | Q2yr | 24800 | 137.77 | 143 | 142.62 | 143.35 | 0.007407 |
| studyarea | 18170 | Q100yr | 49990 | 137.77 | 143.9 | 143.41 | 144.39 | 0.00678 |
| | | | | | | | | |
| studyarea | 18106 | Q50% | 1320 | 136.64 | 139.79 | 139.51 | 140.03 | 0.006559 |
| studyarea | 18106 | Q2yr | 24800 | 136.64 | 142.66 | 142.05 | 142.92 | 0.005245 |
| studyarea | 18106 | Q100yr | 49990 | 136.64 | 143.62 | 142.89 | 143.98 | 0.004994 |
| | | | | | | | | |
| studyarea | 17966 | Q50% | 1320 | 135.51 | 139.48 | 138.49 | 139.54 | 0.001798 |
| studyarea | 17966 | Q2yr | 24800 | 135.51 | 142.19 | 141.26 | 142.36 | 0.002904 |
| studyarea | 17966 | Q100yr | 49990 | 135.51 | 143.16 | 142.07 | 143.42 | 0.002959 |
| | | | | | | | | |
| studyarea | 17752 | Q50% | 1320 | 135.05 | 138.88 | 137.97 | 138.99 | 0.004039 |
| studyarea | 17752 | Q2yr | 24800 | 135.05 | 141.4 | 140.73 | 141.61 | 0.004357 |
| studyarea | 17752 | Q100yr | 49990 | 135.05 | 142.43 | 141.43 | 142.72 | 0.003557 |
| | | | | | | | | |
| studyarea | 17448 | Q50% | 1320 | 134.64 | 137.78 | 137.34 | 137.84 | 0.003411 |
| studyarea | 17448 | Q2yr | 24800 | 134.64 | 140.43 | 139.4 | 140.62 | 0.002478 |
| studyarea | 17448 | Q100yr | 49990 | 134.64 | 141.46 | 140.21 | 141.78 | 0.002668 |
| | | | | | | | | |
| studyarea | 17112 | Q50% | 1320 | 133.72 | 136.37 | 135.84 | 136.51 | 0.004606 |
| studyarea | 17112 | Q2yr | 24800 | 133.72 | 139.3 | 138.58 | 139.56 | 0.004095 |
| studyarea | 17112 | Q100yr | 49990 | 133.72 | 140.22 | 139.44 | 140.65 | 0.004338 |
| | | | | | | | | |
| studyarea | 16849 | Q50% | 1320 | 131.89 | 135.46 | 134.46 | 135.54 | 0.002926 |
| studyarea | 16849 | Q2yr | 24800 | 131.89 | 138.2 | 137.48 | 138.43 | 0.004458 |
| studyarea | 16849 | Q100yr | 49990 | 131.89 | 139.18 | 138.29 | 139.53 | 0.004009 |
| | | | | | | | | |
| studyarea | 16598 | Q50% | 1320 | 131.62 | 134.24 | 133.78 | 134.39 | 0.007977 |
| studyarea | 16598 | Q2yr | 24800 | 131.62 | 137.04 | 136.29 | 137.28 | 0.0047 |
| studyarea | 16598 | Q100yr | 49990 | 131.62 | 138.06 | 137.12 | 138.41 | 0.004945 |
| | | | | | | | | |
| studyarea | 16373 | Q50% | 1320 | 130.75 | 132.86 | 132.44 | 133 | 0.004987 |
| studyarea | 16373 | Q2yr | 24800 | 130.75 | 135.83 | 135.19 | 136.16 | 0.005243 |
| studyarea | 16373 | Q100yr | 49990 | 130.75 | 136.9 | 136.17 | 137.32 | 0.004671 |
| | | | | | | | | |
| studyarea | 16056 | Q50% | 1320 | 128.55 | 131.58 | 130.87 | 131.67 | 0.00349 |
| studyarea | 16056 | Q2yr | 24800 | 128.55 | 134.49 | 133.61 | 134.77 | 0.003624 |
| studyarea | 16056 | Q100yr | 49990 | 128.55 | 135.61 | 134.64 | 135.99 | 0.003722 |
| | | | | | | | | |
| studyarea | 15826 | Q50% | 1320 | 127.27 | 130.72 | 129.64 | 130.82 | 0.003943 |
| studyarea | 15826 | Q2yr | 24800 | 127.27 | 133.72 | 132.71 | 133.96 | 0.003299 |
| studyarea | 15826 | Q100yr | 49990 | 127.27 | 134.79 | 133.77 | 135.15 | 0.003525 |
| | | | | | | | | |
| studyarea | 15585 | Q50% | 1320 | 126.86 | 130.1 | 128.93 | 130.17 | 0.001932 |

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|---|---|---|---|---|---|
| 3.43 | 7247.96 | 4427 | 0.46 | 0.4 | 0.4 |
| 4.39 | 11408 | 5116.17 | 0.5 | 0.62 | 0.62 |
| | | | | | |
| 2.06 | 641.32 | 886.54 | 0.43 | 0.16 | 0.16 |
| 3.7 | 6743.39 | 4433.45 | 0.52 | 0.57 | 0.56 |
| 4.67 | 10838.23 | 5158.84 | 0.54 | 0.81 | 0.79 |
| | | | | | |
| 5.13 | 257.26 | 285.94 | 0.95 | 0.86 | 0.86 |
| 4.75 | 5278.31 | 3778.93 | 0.69 | 0.67 | 0.66 |
| 5.64 | 9040.08 | 4958.38 | 0.7 | 0.85 | 0.83 |
| | | | | | |
| 3.93 | 338.56 | 373.18 | 0.71 | 0.38 | 0.37 |
| 4.12 | 6093.97 | 4276.53 | 0.59 | 0.5 | 0.49 |
| 4.81 | 10509.79 | 5721 | 0.58 | 0.66 | 0.66 |
| | | | | | |
| 2 | 659.14 | 710.5 | 0.37 | 0.1 | 0.1 |
| 3.27 | 7620.03 | 4923.36 | 0.45 | 0.3 | 0.3 |
| 4.08 | 12319.99 | 6128.26 | 0.46 | 0.44 | 0.44 |
| | | | | | |
| 2.63 | 502.23 | 519.24 | 0.47 | 0.24 | 0.24 |
| 3.66 | 6834.36 | 4904.95 | 0.51 | 0.43 | 0.43 |
| 4.36 | 11585.12 | 6079.68 | 0.49 | 0.55 | 0.54 |
| | | | | | |
| 1.91 | 689.41 | 1137.07 | 0.43 | 0.13 | 0.13 |
| 3.43 | 7235.46 | 4228.43 | 0.42 | 0.32 | 0.32 |
| 4.61 | 10868.42 | 5254.3 | 0.47 | 0.49 | 0.49 |
| | | | | | |
| 2.96 | 445.35 | 483.99 | 0.54 | 0.26 | 0.26 |
| 4.12 | 6023.99 | 3832.25 | 0.55 | 0.44 | 0.44 |
| 5.26 | 9503.63 | 4721 | 0.6 | 0.65 | 0.65 |
| | | | | | |
| 2.29 | 575.4 | 630.13 | 0.42 | 0.17 | 0.17 |
| 3.88 | 6389.76 | 3918.23 | 0.53 | 0.46 | 0.46 |
| 4.76 | 10524.65 | 4643.48 | 0.54 | 0.59 | 0.59 |
| | | | | | |
| 3.07 | 430.17 | 571.63 | 0.62 | 0.37 | 0.37 |
| 3.91 | 6370.86 | 3770.3 | 0.53 | 0.5 | 0.49 |
| 4.75 | 10569.54 | 4595.15 | 0.55 | 0.72 | 0.71 |
| | | | | | |
| 2.91 | 453.04 | 514.21 | 0.55 | 0.27 | 0.27 |
| 4.58 | 5413.81 | 3201.48 | 0.62 | 0.55 | 0.55 |
| 5.24 | 9544.73 | 4339.74 | 0.62 | 0.64 | 0.64 |
| | | | | | |
| 2.39 | 552.89 | 590.19 | 0.43 | 0.2 | 0.2 |
| 4.22 | 5884.86 | 3202.8 | 0.55 | 0.42 | 0.42 |
| 4.97 | 10068.37 | 4580.04 | 0.58 | 0.53 | 0.53 |
| | | | | | |
| 2.44 | 540.43 | 698.53 | 0.49 | 0.19 | 0.19 |
| 3.94 | 6296.46 | 3517.98 | 0.51 | 0.38 | 0.38 |
| 4.81 | 10392.89 | 4624.55 | 0.54 | 0.55 | 0.55 |
| | | | | | |
| 1.98 | 666.13 | 770.28 | 0.38 | 0.1 | 0.1 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| studyarea | 18408 | Q2yr | 24800 | 140 | 144.5 | 143.64 | 144.71 | 0.004714 |
| studyarea | 18408 | Q100yr | 49900 | 140 | 145.37 | 144.56 | 145.69 | 0.004119 |
| studyarea | 18268 | Q50% | 1320 | 140 | 141.62 | 141.21 | 141.7 | 0.00583 |
| studyarea | 18268 | Q2yr | 24800 | 140 | 143.74 | 143.11 | 144 | 0.005265 |
| studyarea | 18268 | Q100yr | 49900 | 140 | 144.65 | 143.88 | 145.03 | 0.005329 |
| studyarea | 18170 | Q50% | 1320 | 138 | 140.86 | 140.64 | 141.03 | 0.008509 |
| studyarea | 18170 | Q2yr | 24800 | 138 | 143.01 | 142.71 | 143.37 | 0.007667 |
| studyarea | 18170 | Q100yr | 49900 | 138 | 143.8 | 143.43 | 144.37 | 0.008283 |
| studyarea | 18106 | Q50% | 1320 | 138 | 140.2 | 139.71 | 140.39 | 0.011474 |
| studyarea | 18106 | Q2yr | 24800 | 138 | 142.73 | 142.21 | 142.95 | 0.00466 |
| studyarea | 18106 | Q100yr | 49900 | 138 | 143.58 | 142.83 | 143.93 | 0.004243 |
| studyarea | 17966 | Q50% | 1320 | 136 | 139.59 | 138.5 | 139.74 | 0.002436 |
| studyarea | 17966 | Q2yr | 24800 | 136 | 142.19 | 141.27 | 142.38 | 0.003566 |
| studyarea | 17966 | Q100yr | 49900 | 136 | 143.11 | 142.17 | 143.4 | 0.00319 |
| studyarea | 17752 | Q50% | 1320 | 136 | 139.1 | 138.4 | 139.17 | 0.00266 |
| studyarea | 17752 | Q2yr | 24800 | 136 | 141.41 | 140.75 | 141.6 | 0.003672 |
| studyarea | 17752 | Q100yr | 49900 | 136 | 142.45 | 141.39 | 142.73 | 0.003064 |
| studyarea | 17448 | Q50% | 1320 | 136 | 138.25 | 137.57 | 138.28 | 0.003155 |
| studyarea | 17448 | Q2yr | 24800 | 136 | 140.52 | 139.45 | 140.7 | 0.002403 |
| studyarea | 17448 | Q100yr | 49900 | 136 | 141.57 | 140.28 | 141.88 | 0.002501 |
| studyarea | 17112 | Q50% | 1320 | 134 | 136.73 | 136.48 | 136.84 | 0.006182 |
| studyarea | 17112 | Q2yr | 24800 | 134 | 139.41 | 138.72 | 139.66 | 0.004022 |
| studyarea | 17112 | Q100yr | 49900 | 134 | 140.3 | 139.48 | 140.74 | 0.00481 |
| studyarea | 16849 | Q50% | 1320 | 132.36 | 135.53 | 134.77 | 135.67 | 0.003303 |
| studyarea | 16849 | Q2yr | 24800 | 132.36 | 138.27 | 137.52 | 138.5 | 0.004865 |
| studyarea | 16849 | Q100yr | 49900 | 132.36 | 139.15 | 138.39 | 139.51 | 0.004351 |
| studyarea | 16598 | Q50% | 1320 | 132 | 134.52 | 133.78 | 134.61 | 0.005438 |
| studyarea | 16598 | Q2yr | 24800 | 132 | 137.06 | 136.42 | 137.3 | 0.00472 |
| studyarea | 16598 | Q100yr | 49900 | 132 | 137.98 | 137.13 | 138.37 | 0.004742 |
| studyarea | 16373 | Q50% | 1320 | 132 | 133.25 | 132.84 | 133.38 | 0.005354 |
| studyarea | 16373 | Q2yr | 24800 | 132 | 135.8 | 135.22 | 136.15 | 0.005432 |
| studyarea | 16373 | Q100yr | 49900 | 132 | 136.82 | 136.29 | 137.25 | 0.005202 |
| studyarea | 16056 | Q50% | 1320 | 130 | 131.75 | 131.14 | 131.93 | 0.00395 |
| studyarea | 16056 | Q2yr | 24800 | 130 | 134.67 | 133.61 | 134.87 | 0.002929 |
| studyarea | 16056 | Q100yr | 49900 | 130 | 135.72 | 134.64 | 136.01 | 0.002863 |
| studyarea | 15826 | Q50% | 1320 | 128 | 131.02 | 130.49 | 131.11 | 0.003039 |
| studyarea | 15826 | Q2yr | 24800 | 128 | 133.84 | 133.01 | 134.11 | 0.003737 |
| studyarea | 15826 | Q100yr | 49900 | 128 | 134.9 | 134.12 | 135.24 | 0.003964 |
| studyarea | 15585 | Q50% | 1320 | 128 | 130.49 | 129.52 | 130.52 | 0.001922 |

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|---|---|---|---|---|---|
| 3.61 | 6881.35 | 4963.43 | 0.52 | 0.43 | 0.43 |
| 4.56 | 10976.34 | 5125.33 | 0.53 | 0.6 | 0.59 |
| | | | | | |
| 2.38 | 555.29 | 743.23 | 0.48 | 0.27 | 0.27 |
| 4.09 | 6080.79 | 3685.62 | 0.56 | 0.55 | 0.55 |
| 4.94 | 10184.99 | 5523.27 | 0.59 | 0.72 | 0.71 |
| | | | | | |
| 3.26 | 404.6 | 666.21 | 0.74 | 0.32 | 0.32 |
| 4.85 | 5183.72 | 3701.33 | 0.7 | 0.71 | 0.68 |
| 6.12 | 8217.97 | 4284.13 | 0.77 | 1.03 | 1.01 |
| | | | | | |
| 3.53 | 378.86 | 723.48 | 0.83 | 0.4 | 0.38 |
| 3.8 | 6642.24 | 5064.72 | 0.54 | 0.44 | 0.42 |
| 4.8 | 10534.22 | 5372.37 | 0.56 | 0.61 | 0.6 |
| | | | | | |
| 3.06 | 430.78 | 311.81 | 0.46 | 0.21 | 0.21 |
| 3.48 | 7179.19 | 5686.76 | 0.49 | 0.35 | 0.34 |
| 4.39 | 11468.85 | 6028.59 | 0.49 | 0.49 | 0.48 |
| | | | | | |
| 2.18 | 606.23 | 607.17 | 0.38 | 0.17 | 0.17 |
| 3.55 | 7019.52 | 4786.76 | 0.49 | 0.37 | 0.37 |
| 4.28 | 11735.96 | 6131.33 | 0.47 | 0.48 | 0.48 |
| | | | | | |
| 1.51 | 874.73 | 1907.81 | 0.39 | 0.09 | 0.09 |
| 3.38 | 7345.63 | 4656.99 | 0.42 | 0.31 | 0.31 |
| 4.46 | 11194.29 | 5188.35 | 0.46 | 0.47 | 0.46 |
| | | | | | |
| 2.58 | 511.33 | 753.1 | 0.55 | 0.26 | 0.26 |
| 4.01 | 6184.42 | 3653.53 | 0.52 | 0.46 | 0.46 |
| 5.27 | 9463.61 | 5180.63 | 0.6 | 0.71 | 0.71 |
| | | | | | |
| 3.08 | 428.77 | 298.6 | 0.45 | 0.3 | 0.3 |
| 3.86 | 6421.13 | 4312.6 | 0.56 | 0.46 | 0.46 |
| 4.86 | 10283.52 | 4539.5 | 0.56 | 0.63 | 0.62 |
| | | | | | |
| 2.28 | 578.56 | 906.81 | 0.5 | 0.22 | 0.22 |
| 3.87 | 6413.21 | 3818.48 | 0.52 | 0.5 | 0.49 |
| 4.99 | 10037.69 | 4060.52 | 0.56 | 0.74 | 0.73 |
| | | | | | |
| 2.91 | 453.53 | 477.46 | 0.53 | 0.32 | 0.32 |
| 4.79 | 5180.84 | 2688.53 | 0.61 | 0.65 | 0.65 |
| 5.26 | 9481.15 | 4587.31 | 0.65 | 0.67 | 0.67 |
| | | | | | |
| 3.39 | 389.07 | 281.61 | 0.5 | 0.35 | 0.35 |
| 3.56 | 6963.77 | 4116.42 | 0.48 | 0.31 | 0.31 |
| 4.34 | 11506.43 | 4588.64 | 0.48 | 0.46 | 0.46 |
| | | | | | |
| 2.43 | 542.43 | 603.4 | 0.44 | 0.18 | 0.18 |
| 4.11 | 6028.56 | 3155.05 | 0.52 | 0.45 | 0.45 |
| 4.69 | 10637.89 | 4813.84 | 0.55 | 0.56 | 0.56 |
| | | | | | |
| 1.39 | 948.55 | 1469.22 | 0.3 | 0.08 | 0.08 |

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|---|---|---|---|---|---|---|---|---|
| studyarea | 15585 | Q2yr | 24800 | 126.86 | 133.14 | 131.92 | 133.28 | 0.00226 |
| studyarea | 15585 | Q100yr | 49990 | 126.86 | 134.21 | 132.82 | 134.43 | 0.002308 |
| studyarea | 14954 | Q50% | 1320 | 125.58 | 128.44 | 127.93 | 128.53 | 0.003674 |
| studyarea | 14954 | Q2yr | 24800 | 125.58 | 131.39 | 130.38 | 131.58 | 0.003257 |
| studyarea | 14954 | Q100yr | 49990 | 125.58 | 132.38 | 131.33 | 132.67 | 0.003417 |
| studyarea | 14549 | Q50% | 1320 | 123.46 | 126.51 | 125.93 | 126.68 | 0.005665 |
| studyarea | 14549 | Q2yr | 24800 | 123.46 | 130.22 | 129.13 | 130.38 | 0.002678 |
| studyarea | 14549 | Q100yr | 49990 | 123.46 | 131.26 | 130.06 | 131.49 | 0.00241 |
| studyarea | 14361 | Q50% | 1320 | 121.31 | 125.81 | 124.57 | 125.92 | 0.002914 |
| studyarea | 14361 | Q2yr | 24800 | 121.31 | 129.99 | 128.45 | 130.06 | 0.00101 |
| studyarea | 14361 | Q100yr | 49990 | 121.31 | 131.05 | 129.22 | 131.18 | 0.001029 |
| studyarea | 13473 | Q50% | 1320 | 119.92 | 124.81 | 122.39 | 124.86 | 0.000628 |
| studyarea | 13473 | Q2yr | 24800 | 119.92 | 128.45 | 127.38 | 128.62 | 0.003004 |
| studyarea | 13473 | Q100yr | 49990 | 119.92 | 129.56 | 128.34 | 129.78 | 0.002655 |
| studyarea | 13165 | Q50% | 1320 | 120.12 | 124.41 | 122.75 | 124.49 | 0.003144 |
| studyarea | 13165 | Q2yr | 24800 | 120.12 | 127.63 | 126.48 | 127.81 | 0.002293 |
| studyarea | 13165 | Q100yr | 49990 | 120.12 | 128.77 | 127.5 | 129.01 | 0.002327 |
| studyarea | 12754 | Q50% | 1320 | 119.46 | 122.86 | 122.07 | 122.97 | 0.004387 |
| studyarea | 12754 | Q2yr | 24800 | 119.46 | 125.95 | 125.46 | 126.35 | 0.006018 |
| studyarea | 12754 | Q100yr | 49990 | 119.46 | 126.92 | 126.47 | 127.45 | 0.006909 |
| studyarea | 12593 | Q50% | 1320 | 119.38 | 122.04 | 121.5 | 122.17 | 0.005773 |
| studyarea | 12593 | Q2yr | 24800 | 119.38 | 124.84 | 124.54 | 125.27 | 0.007467 |
| studyarea | 12593 | Q100yr | 49990 | 119.38 | 126.05 | 125.4 | 126.46 | 0.00516 |
| studyarea | 12482 | Q50% | 1320 | 118.53 | 121.12 | 120.84 | 121.35 | 0.009189 |
| studyarea | 12482 | Q2yr | 24800 | 118.53 | 124.58 | 123.53 | 124.76 | 0.002415 |
| studyarea | 12482 | Q100yr | 49990 | 118.53 | 125.8 | 124.35 | 126.05 | 0.002262 |
| studyarea | 12247 | Q50% | 1320 | 116.13 | 120.45 | 118.78 | 120.53 | 0.001695 |
| studyarea | 12247 | Q2yr | 24800 | 116.13 | 123.85 | 122.76 | 124.12 | 0.002951 |
| studyarea | 12247 | Q100yr | 49990 | 116.13 | 124.98 | 123.88 | 125.39 | 0.003327 |
| studyarea | 11982 | Q50% | 1320 | 116.31 | 119.83 | 118.86 | 119.96 | 0.002785 |
| studyarea | 11982 | Q2yr | 24800 | 116.31 | 123.06 | 122.12 | 123.32 | 0.003076 |
| studyarea | 11982 | Q100yr | 49990 | 116.31 | 124.13 | 123.15 | 124.5 | 0.003315 |
| studyarea | 11759 | Q50% | 1320 | 116.28 | 118.96 | 118.23 | 119.14 | 0.005025 |
| studyarea | 11759 | Q2yr | 24800 | 116.28 | 122.29 | 121.47 | 122.56 | 0.003741 |
| studyarea | 11759 | Q100yr | 49990 | 116.28 | 123.32 | 122.49 | 123.7 | 0.003872 |
| studyarea | 11538 | Q50% | 1320 | 115.14 | 118.32 | 117.37 | 118.4 | 0.002215 |
| studyarea | 11538 | Q2yr | 24800 | 115.14 | 121.33 | 120.53 | 121.6 | 0.005135 |
| studyarea | 11538 | Q100yr | 49990 | 115.14 | 122.3 | 121.54 | 122.71 | 0.005302 |
| studyarea | 11402 | Q50% | 1320 | 114.89 | 117.78 | 117.35 | 117.92 | 0.006299 |

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|---|---|---|---|---|---|
| 3.07 | 8076.69 | 4402.33 | 0.4 | 0.26 | 0.26 |
| 3.76 | 13286.74 | 5193.22 | 0.41 | 0.37 | 0.37 |
| | | | | | |
| 2.35 | 560.9 | 718.52 | 0.46 | 0.18 | 0.18 |
| 3.55 | 6992.53 | 4142.53 | 0.48 | 0.35 | 0.35 |
| 4.33 | 11577.66 | 5314.82 | 0.5 | 0.49 | 0.48 |
| | | | | | |
| 3.37 | 391.67 | 375.08 | 0.58 | 0.37 | 0.37 |
| 3.23 | 7743.16 | 4952.12 | 0.44 | 0.29 | 0.28 |
| 3.85 | 13187.74 | 5988.35 | 0.43 | 0.37 | 0.36 |
| | | | | | |
| 2.6 | 508.08 | 436.25 | 0.42 | 0.21 | 0.21 |
| 2.2 | 11308.35 | 5689.5 | 0.27 | 0.13 | 0.13 |
| 2.87 | 17454.3 | 5993.84 | 0.29 | 0.19 | 0.19 |
| | | | | | |
| 1.75 | 753.26 | 426.93 | 0.23 | 0.07 | 0.07 |
| 3.29 | 7567.54 | 4697.94 | 0.45 | 0.31 | 0.3 |
| 3.75 | 13434.34 | 5542.51 | 0.42 | 0.41 | 0.41 |
| | | | | | |
| 2.19 | 604.05 | 753.4 | 0.43 | 0.16 | 0.16 |
| 3.42 | 7278.61 | 4579 | 0.45 | 0.25 | 0.25 |
| 3.99 | 12627.42 | 5663.3 | 0.44 | 0.38 | 0.37 |
| | | | | | |
| 2.72 | 485.88 | 509.78 | 0.49 | 0.26 | 0.26 |
| 5.1 | 4863.19 | 3121.32 | 0.7 | 0.61 | 0.61 |
| 5.86 | 8535.49 | 4868.68 | 0.74 | 0.84 | 0.84 |
| | | | | | |
| 2.89 | 456.92 | 555.4 | 0.56 | 0.3 | 0.3 |
| 5.25 | 4726.6 | 3416.76 | 0.79 | 0.65 | 0.65 |
| 5.14 | 9740.44 | 5010.77 | 0.63 | 0.66 | 0.65 |
| | | | | | |
| 3.89 | 339.49 | 371.31 | 0.72 | 0.52 | 0.52 |
| 3.34 | 7423.15 | 3844.5 | 0.42 | 0.29 | 0.29 |
| 4.01 | 12476.85 | 4585.12 | 0.42 | 0.39 | 0.39 |
| | | | | | |
| 2.16 | 610.6 | 443.44 | 0.32 | 0.14 | 0.14 |
| 4.21 | 6063.43 | 3025.72 | 0.49 | 0.42 | 0.37 |
| 5.23 | 10149.51 | 4213.34 | 0.55 | 0.57 | 0.51 |
| | | | | | |
| 2.81 | 469.85 | 399.53 | 0.45 | 0.21 | 0.21 |
| 4.06 | 6130.18 | 3459.77 | 0.52 | 0.36 | 0.36 |
| 4.87 | 10327.38 | 4804.01 | 0.56 | 0.49 | 0.48 |
| | | | | | |
| 3.35 | 393.86 | 382.63 | 0.58 | 0.32 | 0.32 |
| 4.23 | 5871.84 | 3360.74 | 0.56 | 0.41 | 0.41 |
| 4.94 | 10119 | 4621.87 | 0.58 | 0.54 | 0.54 |
| | | | | | |
| 2.32 | 570.12 | 452.23 | 0.36 | 0.17 | 0.17 |
| 4.23 | 5861.27 | 3405.36 | 0.57 | 0.55 | 0.55 |
| 5.09 | 9816.39 | 4464.35 | 0.61 | 0.73 | 0.73 |
| | | | | | |
| 3 | 439.36 | 544.13 | 0.59 | 0.32 | 0.32 |

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|---|---|---|---|---|---|---|---|---|
| studyarea | 15585 | Q2yr | 24800 | 128 | 133.21 | 131.89 | 133.33 | 0.002543 |
| studyarea | 15585 | Q100yr | 49900 | 128 | 134.27 | 132.82 | 134.47 | 0.002363 |
| | | | | | | | | |
| studyarea | 14954 | Q50% | 1320 | 126 | 128.87 | 128.48 | 128.94 | 0.003365 |
| studyarea | 14954 | Q2yr | 24800 | 126 | 131.47 | 130.64 | 131.65 | 0.002784 |
| studyarea | 14954 | Q100yr | 49900 | 126 | 132.31 | 131.33 | 132.63 | 0.003663 |
| | | | | | | | | |
| studyarea | 14549 | Q50% | 1320 | 124 | 126.38 | 126.25 | 126.65 | 0.01115 |
| studyarea | 14549 | Q2yr | 24800 | 124 | 130.15 | 129.14 | 130.33 | 0.003851 |
| studyarea | 14549 | Q100yr | 49900 | 124 | 131.16 | 130.2 | 131.38 | 0.002492 |
| | | | | | | | | |
| studyarea | 14361 | Q50% | 1320 | 122 | 125.88 | 124.77 | 125.98 | 0.001552 |
| studyarea | 14361 | Q2yr | 24800 | 122 | 129.93 | 128.47 | 130 | 0.000868 |
| studyarea | 14361 | Q100yr | 49900 | 122 | 130.95 | 129.07 | 131.07 | 0.001016 |
| | | | | | | | | |
| studyarea | 13473 | Q50% | 1320 | 120 | 124.94 | 122.9 | 125 | 0.000806 |
| studyarea | 13473 | Q2yr | 24800 | 120 | 128.49 | 127.33 | 128.66 | 0.003181 |
| studyarea | 13473 | Q100yr | 49900 | 120 | 129.42 | 128.47 | 129.67 | 0.0027 |
| | | | | | | | | |
| studyarea | 13165 | Q50% | 1320 | 120 | 124.5 | 123.04 | 124.56 | 0.003096 |
| studyarea | 13165 | Q2yr | 24800 | 120 | 127.78 | 126.6 | 127.92 | 0.001856 |
| studyarea | 13165 | Q100yr | 49900 | 120 | 128.69 | 127.43 | 128.91 | 0.002225 |
| | | | | | | | | |
| studyarea | 12754 | Q50% | 1320 | 120 | 123.18 | 122.48 | 123.27 | 0.003148 |
| studyarea | 12754 | Q2yr | 24800 | 120 | 126.28 | 125.49 | 126.58 | 0.007013 |
| studyarea | 12754 | Q100yr | 49900 | 120 | 127.05 | 126.61 | 127.47 | 0.006084 |
| | | | | | | | | |
| studyarea | 12593 | Q50% | 1320 | 120 | 122.31 | 122.15 | 122.46 | 0.009348 |
| studyarea | 12593 | Q2yr | 24800 | 120 | 125.08 | 124.72 | 125.42 | 0.007458 |
| studyarea | 12593 | Q100yr | 49900 | 120 | 126.16 | 125.47 | 126.55 | 0.005305 |
| | | | | | | | | |
| studyarea | 12482 | Q50% | 1320 | 119.06 | 121.46 | 120.94 | 121.64 | 0.005895 |
| studyarea | 12482 | Q2yr | 24800 | 119.06 | 124.77 | 123.62 | 124.95 | 0.002282 |
| studyarea | 12482 | Q100yr | 49900 | 119.06 | 125.86 | 124.63 | 126.14 | 0.002363 |
| | | | | | | | | |
| studyarea | 12247 | Q50% | 1320 | 118 | 121 | 119.47 | 121.04 | 0.001272 |
| studyarea | 12247 | Q2yr | 24800 | 118 | 124.06 | 122.97 | 124.31 | 0.003257 |
| studyarea | 12247 | Q100yr | 49900 | 118 | 125.17 | 124.2 | 125.51 | 0.003016 |
| | | | | | | | | |
| studyarea | 11982 | Q50% | 1320 | 118 | 120.48 | 119.7 | 120.54 | 0.003117 |
| studyarea | 11982 | Q2yr | 24800 | 118 | 123.2 | 122.33 | 123.44 | 0.003327 |
| studyarea | 11982 | Q100yr | 49900 | 118 | 124.18 | 123.22 | 124.58 | 0.004098 |
| | | | | | | | | |
| studyarea | 11759 | Q50% | 1320 | 118 | 119.57 | 119.11 | 119.69 | 0.004694 |
| studyarea | 11759 | Q2yr | 24800 | 118 | 122.39 | 121.55 | 122.64 | 0.003891 |
| studyarea | 11759 | Q100yr | 49900 | 118 | 123.39 | 122.57 | 123.73 | 0.003436 |
| | | | | | | | | |
| studyarea | 11538 | Q50% | 1320 | 116 | 118.78 | 118.34 | 118.85 | 0.003031 |
| studyarea | 11538 | Q2yr | 24800 | 116 | 121.4 | 120.79 | 121.7 | 0.004614 |
| studyarea | 11538 | Q100yr | 49900 | 116 | 122.36 | 121.61 | 122.81 | 0.00499 |
| | | | | | | | | |
| studyarea | 11402 | Q50% | 1320 | 116 | 118.28 | 117.53 | 118.33 | 0.00491 |

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|---|---|---|---|---|---|
| 2.81 | 8812.2 | 4704.12 | 0.36 | 0.3 | 0.3 |
| 3.59 | 13918.62 | 5308.79 | 0.38 | 0.42 | 0.42 |
| | | | | | |
| 2.07 | 636.9 | 835.21 | 0.42 | 0.16 | 0.16 |
| 3.39 | 7306.16 | 4059.43 | 0.44 | 0.32 | 0.32 |
| 4.51 | 11084.96 | 5654.03 | 0.54 | 0.5 | 0.49 |
| | | | | | |
| 4.13 | 319.46 | 381.33 | 0.8 | 0.58 | 0.58 |
| 3.38 | 7379.64 | 5864.62 | 0.52 | 0.32 | 0.31 |
| 3.8 | 13276.16 | 5944.23 | 0.44 | 0.36 | 0.35 |
| | | | | | |
| 2.54 | 520.01 | 277.46 | 0.33 | 0.18 | 0.18 |
| 2.12 | 11720.27 | 5365.04 | 0.25 | 0.12 | 0.12 |
| 2.84 | 17566.32 | 5962.14 | 0.29 | 0.19 | 0.19 |
| | | | | | |
| 1.82 | 727.15 | 392.71 | 0.24 | 0.09 | 0.09 |
| 3.29 | 7586.63 | 5348.92 | 0.48 | 0.29 | 0.28 |
| 4 | 12528.96 | 5451.59 | 0.46 | 0.4 | 0.4 |
| | | | | | |
| 1.94 | 679.53 | 918.31 | 0.4 | 0.14 | 0.14 |
| 2.94 | 8426.97 | 4526.05 | 0.38 | 0.22 | 0.22 |
| 3.81 | 13198.92 | 5784.08 | 0.43 | 0.34 | 0.33 |
| | | | | | |
| 2.45 | 539.28 | 517.28 | 0.42 | 0.2 | 0.2 |
| 4.39 | 5688.22 | 4959.23 | 0.72 | 0.51 | 0.5 |
| 5.26 | 9582.1 | 5324.76 | 0.68 | 0.7 | 0.69 |
| | | | | | |
| 3.12 | 422.59 | 671.59 | 0.69 | 0.38 | 0.38 |
| 4.68 | 5297.6 | 3839.93 | 0.7 | 0.65 | 0.65 |
| 5.02 | 9941.88 | 5582.58 | 0.64 | 0.64 | 0.63 |
| | | | | | |
| 3.45 | 382.85 | 351.88 | 0.58 | 0.4 | 0.4 |
| 3.43 | 7233.89 | 4084.4 | 0.45 | 0.26 | 0.26 |
| 4.26 | 11728.84 | 4498.33 | 0.46 | 0.4 | 0.4 |
| | | | | | |
| 1.66 | 796.45 | 641.69 | 0.26 | 0.1 | 0.1 |
| 4.03 | 6186.12 | 4034.97 | 0.56 | 0.32 | 0.32 |
| 4.65 | 10764.42 | 4609.92 | 0.52 | 0.46 | 0.46 |
| | | | | | |
| 1.92 | 688.25 | 1018.05 | 0.41 | 0.13 | 0.13 |
| 3.96 | 6312.29 | 3476.89 | 0.5 | 0.4 | 0.4 |
| 5.06 | 9930.82 | 5272.02 | 0.6 | 0.57 | 0.57 |
| | | | | | |
| 2.72 | 485.05 | 507.56 | 0.49 | 0.28 | 0.28 |
| 3.99 | 6210.07 | 4391.74 | 0.59 | 0.34 | 0.34 |
| 4.67 | 10701.64 | 4575.75 | 0.54 | 0.5 | 0.5 |
| | | | | | |
| 2.18 | 604.92 | 690.59 | 0.41 | 0.17 | 0.17 |
| 4.36 | 5688.63 | 3318.42 | 0.58 | 0.5 | 0.5 |
| 5.33 | 9360.24 | 4588.74 | 0.65 | 0.64 | 0.64 |
| | | | | | |
| 1.85 | 713.83 | 1378.37 | 0.45 | 0.16 | 0.16 |

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|---|---|---|---|---|---|---|---|---|
| studyarea | 11402 | Q2yr | 24800 | 114.89 | 120.81 | 119.89 | 121.02 | 0.003446 |
| studyarea | 11402 | Q100yr | 49990 | 114.89 | 121.8 | 120.81 | 122.11 | 0.003349 |
| studyarea | 11216 | Q50% | 1320 | 114.27 | 117.22 | 116.37 | 117.29 | 0.002005 |
| studyarea | 11216 | Q2yr | 24800 | 114.27 | 120.31 | 119.22 | 120.47 | 0.002403 |
| studyarea | 11216 | Q100yr | 49990 | 114.27 | 121.34 | 120.11 | 121.58 | 0.002259 |
| studyarea | 10942 | Q50% | 1320 | 113.63 | 116.59 | 115.88 | 116.66 | 0.002648 |
| studyarea | 10942 | Q2yr | 24800 | 113.63 | 119.59 | 118.56 | 119.78 | 0.002611 |
| studyarea | 10942 | Q100yr | 49990 | 113.63 | 120.61 | 119.47 | 120.9 | 0.002745 |
| studyarea | 10759 | Q50% | 1320 | 113.19 | 116.25 | 115.19 | 116.3 | 0.001476 |
| studyarea | 10759 | Q2yr | 24800 | 113.19 | 119.13 | 118.12 | 119.3 | 0.002582 |
| studyarea | 10759 | Q100yr | 49990 | 113.19 | 120.13 | 118.99 | 120.41 | 0.002578 |
| studyarea | 10549 | Q50% | 1320 | 112.87 | 115.72 | 115.17 | 115.81 | 0.004315 |
| studyarea | 10549 | Q2yr | 24800 | 112.87 | 118.27 | 117.73 | 118.57 | 0.004677 |
| studyarea | 10549 | Q100yr | 49990 | 112.87 | 119.25 | 118.53 | 119.68 | 0.004607 |
| studyarea | 10360 | Q50% | 1320 | 112.47 | 114.86 | 114.44 | 114.97 | 0.004489 |
| studyarea | 10360 | Q2yr | 24800 | 112.47 | 117.45 | 116.75 | 117.73 | 0.004226 |
| studyarea | 10360 | Q100yr | 49990 | 112.47 | 118.35 | 117.65 | 118.8 | 0.004783 |
| studyarea | 10198 | Q50% | 1320 | 111.43 | 114.06 | 113.69 | 114.16 | 0.005532 |
| studyarea | 10198 | Q2yr | 24800 | 111.43 | 116.55 | 116.07 | 116.87 | 0.006793 |
| studyarea | 10198 | Q100yr | 49990 | 111.43 | 117.35 | 116.91 | 117.85 | 0.007343 |
| studyarea | 10051 | Q50% | 1320 | 111.38 | 113.28 | 112.93 | 113.37 | 0.005193 |
| studyarea | 10051 | Q2yr | 24800 | 111.38 | 115.61 | 115.22 | 115.9 | 0.006288 |
| studyarea | 10051 | Q100yr | 49990 | 111.38 | 116.36 | 115.92 | 116.81 | 0.006502 |
| studyarea | 9861 | Q50% | 1320 | 110 | 112.23 | 111.89 | 112.33 | 0.005918 |
| studyarea | 9861 | Q2yr | 24800 | 110 | 114.45 | 114.04 | 114.73 | 0.006062 |
| studyarea | 9861 | Q100yr | 49990 | 110 | 115.3 | 114.72 | 115.7 | 0.005165 |
| studyarea | 9686 | Q50% | 1320 | 109.3 | 111.22 | 110.92 | 111.31 | 0.005612 |
| studyarea | 9686 | Q2yr | 24800 | 109.3 | 113.56 | 112.96 | 113.84 | 0.004366 |
| studyarea | 9686 | Q100yr | 49990 | 109.3 | 114.42 | 113.8 | 114.86 | 0.004484 |
| studyarea | 9510 | Q50% | 1320 | 107.1 | 110.77 | 109.97 | 110.8 | 0.001647 |
| studyarea | 9510 | Q2yr | 24800 | 107.1 | 113.03 | 112.18 | 113.21 | 0.002713 |
| studyarea | 9510 | Q100yr | 49990 | 107.1 | 113.87 | 112.99 | 114.16 | 0.003107 |
| studyarea | 9237 | Q50% | 1320 | 107.5 | 109.99 | 109.57 | 110.06 | 0.005185 |
| studyarea | 9237 | Q2yr | 24800 | 107.5 | 112.04 | 111.54 | 112.25 | 0.00465 |
| studyarea | 9237 | Q100yr | 49990 | 107.5 | 112.85 | 112.22 | 113.16 | 0.004413 |
| studyarea | 8965 | Q50% | 1320 | 106.85 | 108.77 | 108.38 | 108.83 | 0.004047 |
| studyarea | 8965 | Q2yr | 24800 | 106.85 | 111.24 | 110.32 | 111.35 | 0.002362 |
| studyarea | 8965 | Q100yr | 49990 | 106.85 | 112.05 | 110.94 | 112.24 | 0.002501 |
| studyarea | 8450 | Q50% | 1320 | 103.99 | 106.72 | 106.07 | 106.84 | 0.003664 |

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|---|---|---|---|---|---|
| 3.68 | 6774.45 | 3976.85 | 0.5 | 0.37 | 0.37 |
| 4.54 | 11113.66 | 4623.53 | 0.51 | 0.51 | 0.5 |
| | | | | | |
| 2.15 | 613.63 | 562.88 | 0.36 | 0.14 | 0.14 |
| 3.19 | 7776.58 | 4439.05 | 0.42 | 0.26 | 0.26 |
| 3.94 | 12674.65 | 4816.39 | 0.43 | 0.37 | 0.37 |
| | | | | | |
| 2.1 | 628.02 | 680.54 | 0.39 | 0.15 | 0.15 |
| 3.44 | 7203.43 | 4093.61 | 0.46 | 0.29 | 0.29 |
| 4.29 | 11655.58 | 4504.18 | 0.47 | 0.45 | 0.45 |
| | | | | | |
| 1.76 | 751.57 | 725.34 | 0.3 | 0.1 | 0.1 |
| 3.34 | 7418.54 | 4256.75 | 0.44 | 0.28 | 0.28 |
| 4.24 | 11802.17 | 4631.28 | 0.46 | 0.43 | 0.43 |
| | | | | | |
| 2.36 | 559.4 | 743.73 | 0.48 | 0.2 | 0.2 |
| 4.41 | 5745.32 | 3619.99 | 0.6 | 0.48 | 0.46 |
| 5.36 | 9545.46 | 4217.5 | 0.61 | 0.68 | 0.67 |
| | | | | | |
| 2.71 | 486.59 | 605.11 | 0.53 | 0.22 | 0.22 |
| 4.27 | 5939.09 | 3463.19 | 0.56 | 0.48 | 0.45 |
| 5.45 | 9537.39 | 4343.23 | 0.62 | 0.71 | 0.66 |
| | | | | | |
| 2.61 | 505.72 | 679.2 | 0.53 | 0.26 | 0.26 |
| 4.54 | 5464.11 | 3795.79 | 0.67 | 0.61 | 0.61 |
| 5.62 | 8892.31 | 4566.94 | 0.71 | 0.9 | 0.89 |
| | | | | | |
| 2.43 | 543.57 | 750.68 | 0.5 | 0.23 | 0.23 |
| 4.31 | 5798.83 | 4405.77 | 0.65 | 0.53 | 0.52 |
| 5.42 | 9379.06 | 5026.03 | 0.68 | 0.8 | 0.76 |
| | | | | | |
| 2.51 | 526.35 | 821.02 | 0.55 | 0.24 | 0.24 |
| 4.24 | 6025.66 | 4707.96 | 0.62 | 0.55 | 0.48 |
| 5.19 | 10389.31 | 5424.96 | 0.61 | 0.73 | 0.62 |
| | | | | | |
| 2.43 | 544.1 | 875.94 | 0.54 | 0.22 | 0.22 |
| 4.31 | 6279.47 | 4406.51 | 0.55 | 0.52 | 0.39 |
| 5.58 | 10538.25 | 5469.75 | 0.59 | 0.77 | 0.54 |
| | | | | | |
| 1.44 | 918.72 | 1194.98 | 0.29 | 0.08 | 0.08 |
| 3.54 | 7963.75 | 5248.67 | 0.44 | 0.34 | 0.26 |
| 4.66 | 12854.62 | 6344.28 | 0.49 | 0.54 | 0.4 |
| | | | | | |
| 2.22 | 599.92 | 980.46 | 0.5 | 0.2 | 0.2 |
| 3.88 | 7101.11 | 5798.18 | 0.55 | 0.45 | 0.35 |
| 4.72 | 12248.33 | 6597.35 | 0.55 | 0.63 | 0.51 |
| | | | | | |
| 2.08 | 648.1 | 1023.83 | 0.45 | 0.17 | 0.16 |
| 2.7 | 9586.27 | 6777.45 | 0.37 | 0.24 | 0.22 |
| 3.53 | 14931.76 | 7341.76 | 0.4 | 0.38 | 0.35 |
| | | | | | |
| 2.85 | 462.67 | 486.42 | 0.51 | 0.22 | 0.22 |

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|---|---|---|---|---|---|---|---|---|
| studyarea | 11402 | Q2yr | 24800 | 116 | 120.98 | 120.2 | 121.15 | 0.003118 |
| studyarea | 11402 | Q100yr | 49900 | 116 | 121.93 | 120.83 | 122.22 | 0.003204 |
| studyarea | 11216 | Q50% | 1320 | 116 | 117.56 | 116.87 | 117.65 | 0.002891 |
| studyarea | 11216 | Q2yr | 24800 | 116 | 120.41 | 119.36 | 120.6 | 0.00278 |
| studyarea | 11216 | Q100yr | 49900 | 116 | 121.4 | 120.4 | 121.68 | 0.00263 |
| studyarea | 10942 | Q50% | 1320 | 114 | 116.76 | 116.29 | 116.82 | 0.003072 |
| studyarea | 10942 | Q2yr | 24800 | 114 | 119.68 | 118.69 | 119.84 | 0.002708 |
| studyarea | 10942 | Q100yr | 49900 | 114 | 120.67 | 119.45 | 120.94 | 0.002736 |
| studyarea | 10759 | Q50% | 1320 | 114 | 116.38 | 115.23 | 116.42 | 0.001599 |
| studyarea | 10759 | Q2yr | 24800 | 114 | 119.22 | 118.42 | 119.38 | 0.002347 |
| studyarea | 10759 | Q100yr | 49900 | 114 | 120.2 | 119.02 | 120.47 | 0.002428 |
| studyarea | 10549 | Q50% | 1320 | 114 | 115.82 | 115.16 | 115.95 | 0.003323 |
| studyarea | 10549 | Q2yr | 24800 | 114 | 118.44 | 117.73 | 118.71 | 0.004312 |
| studyarea | 10549 | Q100yr | 49900 | 114 | 119.4 | 118.65 | 119.8 | 0.004053 |
| studyarea | 10360 | Q50% | 1320 | 114 | 115.17 | 114.69 | 115.26 | 0.003878 |
| studyarea | 10360 | Q2yr | 24800 | 114 | 117.65 | 116.94 | 117.91 | 0.00413 |
| studyarea | 10360 | Q100yr | 49900 | 114 | 118.48 | 117.75 | 118.93 | 0.005296 |
| studyarea | 10198 | Q50% | 1320 | 112 | 114.37 | 114.19 | 114.46 | 0.006532 |
| studyarea | 10198 | Q2yr | 24800 | 112 | 116.67 | 116.41 | 117 | 0.008038 |
| studyarea | 10198 | Q100yr | 49900 | 112 | 117.41 | 117.04 | 117.92 | 0.007325 |
| studyarea | 10051 | Q50% | 1320 | 112 | 113.34 | 113 | 113.5 | 0.006394 |
| studyarea | 10051 | Q2yr | 24800 | 112 | 115.67 | 115.16 | 115.96 | 0.006116 |
| studyarea | 10051 | Q100yr | 49900 | 112 | 116.36 | 115.94 | 116.86 | 0.007038 |
| studyarea | 9861 | Q50% | 1320 | 110.02 | 112.54 | 112.27 | 112.59 | 0.003478 |
| studyarea | 9861 | Q2yr | 24800 | 110.02 | 114.58 | 114.2 | 114.81 | 0.00582 |
| studyarea | 9861 | Q100yr | 49900 | 110.02 | 115.37 | 114.77 | 115.72 | 0.0048 |
| studyarea | 9686 | Q50% | 1320 | 110 | 111.12 | 111.09 | 111.39 | 0.018385 |
| studyarea | 9686 | Q2yr | 24800 | 110 | 113.56 | 113.06 | 113.85 | 0.005209 |
| studyarea | 9686 | Q100yr | 49900 | 110 | 114.33 | 113.82 | 114.79 | 0.005813 |
| studyarea | 9510 | Q50% | 1320 | 108 | 110.9 | 110.26 | 110.92 | 0.000825 |
| studyarea | 9510 | Q2yr | 24800 | 108 | 113.07 | 112.3 | 113.2 | 0.002384 |
| studyarea | 9510 | Q100yr | 49900 | 108 | 113.81 | 112.85 | 114.04 | 0.002732 |
| studyarea | 9237 | Q50% | 1320 | 108 | 110.26 | 110.2 | 110.33 | 0.013072 |
| studyarea | 9237 | Q2yr | 24800 | 108 | 112.07 | 111.45 | 112.28 | 0.00501 |
| studyarea | 9237 | Q100yr | 49900 | 108 | 112.75 | 112.25 | 113.06 | 0.004872 |
| studyarea | 8965 | Q50% | 1320 | 108 | 109.03 | 108.54 | 109.08 | 0.002331 |
| studyarea | 8965 | Q2yr | 24800 | 108 | 111.09 | 110.5 | 111.21 | 0.003047 |
| studyarea | 8965 | Q100yr | 49900 | 108 | 111.85 | 110.96 | 112.05 | 0.002743 |
| studyarea | 8450 | Q50% | 1320 | 106 | 107.04 | 106.69 | 107.15 | 0.006853 |

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|---|---|---|---|---|---|
| 3.34 | 7431.04 | 4183.11 | 0.44 | 0.35 | 0.35 |
| 4.31 | 11575.3 | 4548.38 | 0.47 | 0.51 | 0.51 |
| | | | | | |
| 2.4 | 549.53 | 460.87 | 0.39 | 0.21 | 0.21 |
| 3.48 | 7287.06 | 4765.98 | 0.47 | 0.29 | 0.27 |
| 4.27 | 12028.4 | 4816.98 | 0.46 | 0.44 | 0.41 |
| | | | | | |
| 2.03 | 651.25 | 741.09 | 0.38 | 0.17 | 0.17 |
| 3.24 | 7663.63 | 4110.95 | 0.42 | 0.32 | 0.32 |
| 4.16 | 12007.71 | 4470.15 | 0.45 | 0.46 | 0.46 |
| | | | | | |
| 1.72 | 766.88 | 809.33 | 0.31 | 0.09 | 0.09 |
| 3.17 | 7813.71 | 4344.07 | 0.42 | 0.26 | 0.26 |
| 4.11 | 12134.54 | 4644.64 | 0.44 | 0.41 | 0.41 |
| | | | | | |
| 2.9 | 455.6 | 353.38 | 0.45 | 0.27 | 0.27 |
| 4.23 | 5989.09 | 4009.19 | 0.58 | 0.44 | 0.4 |
| 5.18 | 9881.51 | 4092.11 | 0.57 | 0.65 | 0.61 |
| | | | | | |
| 2.4 | 549.56 | 651.58 | 0.46 | 0.21 | 0.21 |
| 4.15 | 6079.96 | 3380.69 | 0.53 | 0.5 | 0.47 |
| 5.44 | 9411.83 | 4394.91 | 0.63 | 0.77 | 0.71 |
| | | | | | |
| 2.45 | 538.55 | 988.5 | 0.58 | 0.23 | 0.23 |
| 4.6 | 5416.29 | 4318.18 | 0.72 | 0.64 | 0.63 |
| 5.75 | 8762.8 | 4638.35 | 0.73 | 0.89 | 0.87 |
| | | | | | |
| 3.24 | 407.95 | 481.78 | 0.59 | 0.37 | 0.37 |
| 4.29 | 5788.97 | 4038.16 | 0.63 | 0.56 | 0.55 |
| 5.68 | 9007.95 | 5175.63 | 0.71 | 0.88 | 0.77 |
| | | | | | |
| 1.69 | 781.67 | 1392.92 | 0.4 | 0.12 | 0.12 |
| 3.91 | 6424.62 | 5164.32 | 0.6 | 0.48 | 0.45 |
| 4.82 | 10559.51 | 5347.91 | 0.59 | 0.63 | 0.6 |
| | | | | | |
| 4.18 | 315.55 | 509.22 | 0.94 | 0.71 | 0.71 |
| 4.3 | 5783.84 | 3887.89 | 0.62 | 0.49 | 0.49 |
| 5.48 | 9444.84 | 5677.93 | 0.69 | 0.72 | 0.6 |
| | | | | | |
| 1.1 | 1201.82 | 1412.05 | 0.21 | 0.04 | 0.04 |
| 2.85 | 8782.31 | 5792.32 | 0.4 | 0.24 | 0.23 |
| 3.86 | 13200.84 | 6288.44 | 0.45 | 0.39 | 0.37 |
| | | | | | |
| 2.09 | 630.37 | 2235.01 | 0.69 | 0.23 | 0.23 |
| 3.63 | 6854.57 | 6530.8 | 0.61 | 0.35 | 0.33 |
| 4.5 | 11246.69 | 6574.83 | 0.6 | 0.54 | 0.52 |
| | | | | | |
| 1.76 | 751.06 | 961.05 | 0.35 | 0.12 | 0.12 |
| 2.82 | 8792.36 | 7002.41 | 0.43 | 0.25 | 0.25 |
| 3.6 | 13856.16 | 7226.1 | 0.44 | 0.36 | 0.36 |
| | | | | | |
| 2.76 | 478.76 | 547.2 | 0.52 | 0.38 | 0.38 |

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|---|---|---|---|---|---|---|---|---|
| studyarea | 8450 | Q2yr | 24800 | 103.99 | 109.44 | 108.86 | 109.62 | 0.005015 |
| studyarea | 8450 | Q100yr | 49990 | 103.99 | 110.2 | 109.52 | 110.48 | 0.004931 |
| studyarea | 8225 | Q50% | 1320 | 103.35 | 106.22 | 105.3 | 106.27 | 0.001763 |
| studyarea | 8225 | Q2yr | 24800 | 103.35 | 108.6 | 107.8 | 108.73 | 0.003092 |
| studyarea | 8225 | Q100yr | 49990 | 103.35 | 109.38 | 108.51 | 109.58 | 0.003179 |
| studyarea | 7691 | Q50% | 1320 | 106.77 | 104.53 | 104.27 | 104.65 | 0.006166 |
| studyarea | 7691 | Q2yr | 24800 | 106.77 | 106.77 | 106.17 | 106.93 | 0.003742 |
| studyarea | 7691 | Q100yr | 49990 | 106.77 | 107.48 | 106.8 | 107.72 | 0.003804 |
| studyarea | 7474 | Q50% | 1320 | 100.92 | 103.57 | 102.83 | 103.66 | 0.003503 |
| studyarea | 7474 | Q2yr | 24800 | 100.92 | 105.97 | 105.29 | 106.11 | 0.003764 |
| studyarea | 7474 | Q100yr | 49990 | 100.92 | 106.68 | 105.92 | 106.91 | 0.003677 |
| studyarea | 7203 | Q50% | 1320 | 98.13 | 102.58 | 101.66 | 102.65 | 0.003944 |
| studyarea | 7203 | Q2yr | 24800 | 98.13 | 104.85 | 104.2 | 104.99 | 0.004629 |
| studyarea | 7203 | Q100yr | 49990 | 98.13 | 105.59 | 104.8 | 105.8 | 0.004587 |
| studyarea | 6951 | Q50% | 1320 | 97.91 | 101.41 | | 101.51 | 0.005226 |
| studyarea | 6951 | Q2yr | 24800 | 97.91 | 103.76 | | 103.9 | 0.004062 |
| studyarea | 6951 | Q100yr | 49990 | 97.91 | 104.49 | | 104.68 | 0.004216 |
| studyarea | 6671 | Q50% | 1320 | 97.94 | 100.18 | | 100.28 | 0.003762 |
| studyarea | 6671 | Q2yr | 24800 | 97.94 | 102.82 | | 102.92 | 0.003015 |
| studyarea | 6671 | Q100yr | 49990 | 97.94 | 103.5 | | 103.65 | 0.003201 |
| studyarea | 6301 | Q50% | 1320 | 95.67 | 98.35 | | 98.51 | 0.006188 |
| studyarea | 6301 | Q2yr | 24800 | 95.67 | 100.79 | 100.43 | 101.02 | 0.010253 |
| studyarea | 6301 | Q100yr | 49990 | 95.67 | 101.43 | | 101.71 | 0.009901 |
| studyarea | 5874 | Q50% | 1320 | 93.24 | 96.92 | | 96.97 | 0.002297 |
| studyarea | 5874 | Q2yr | 24800 | 93.24 | 99.23 | | 99.3 | 0.002077 |
| studyarea | 5874 | Q100yr | 49990 | 93.24 | 99.96 | | 100.06 | 0.001943 |
| studyarea | 5183 | Q50% | 1320 | 91.8 | 94.94 | | 95.01 | 0.0036 |
| studyarea | 5183 | Q2yr | 24800 | 91.8 | 97.27 | | 97.41 | 0.003785 |
| studyarea | 5183 | Q100yr | 49990 | 91.8 | 98 | | 98.18 | 0.004017 |
| studyarea | 4907 | Q50% | 1320 | 90.38 | 93.92 | | 93.99 | 0.003779 |
| studyarea | 4907 | Q2yr | 24800 | 90.38 | 96.18 | | 96.29 | 0.004242 |
| studyarea | 4907 | Q100yr | 49990 | 90.38 | 96.91 | | 97.05 | 0.004135 |
| studyarea | 4577 | Q50% | 1320 | 89.72 | 92.62 | | 92.67 | 0.004238 |
| studyarea | 4577 | Q2yr | 24800 | 89.72 | 94.78 | | 94.9 | 0.004221 |
| studyarea | 4577 | Q100yr | 49990 | 89.72 | 95.45 | | 95.63 | 0.004531 |
| studyarea | 4345 | Q50% | 1320 | 88.61 | 91.42 | 90.97 | 91.48 | 0.006429 |
| studyarea | 4345 | Q2yr | 24800 | 88.61 | 93.67 | | 93.78 | 0.005552 |
| studyarea | 4345 | Q100yr | 49990 | 88.61 | 94.29 | | 94.44 | 0.005758 |
| studyarea | 4061 | Q50% | 1320 | 85.78 | 89.67 | | 89.8 | 0.005448 |

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|---|---|---|---|---|---|
| 3.47 | 7274.73 | 5953.37 | 0.54 | 0.41 | 0.39 |
| 4.27 | 12094.49 | 7083.33 | 0.53 | 0.61 | 0.55 |
| | | | | | |
| 1.8 | 771.59 | 803.08 | 0.29 | 0.13 | 0.11 |
| 3.16 | 8734.1 | 6806.12 | 0.43 | 0.32 | 0.25 |
| 3.86 | 14415.67 | 7684.81 | 0.44 | 0.47 | 0.38 |
| | | | | | |
| | 461.07 | 719.31 | 0 | | 0.25 |
| | 7753.64 | 6377.34 | 0 | | 0.28 |
| 1.07 | 12766.61 | 7585.6 | 0.28 | 0.11 | 0.41 |
| | | | | | |
| 2.45 | 538.3 | 554.21 | 0.44 | 0.21 | 0.21 |
| 3.08 | 8331.93 | 6678.24 | 0.47 | 0.32 | 0.3 |
| 3.92 | 13480.11 | 7900.8 | 0.49 | 0.45 | 0.41 |
| | | | | | |
| 2.19 | 602.73 | 845.77 | 0.46 | 0.17 | 0.17 |
| 3.02 | 8242.77 | 6803.78 | 0.47 | 0.36 | 0.36 |
| 3.72 | 13548.71 | 8209.22 | 0.49 | 0.52 | 0.5 |
| | | | | | |
| 2.49 | 529.53 | 766.95 | 0.53 | 0.22 | 0.22 |
| 2.97 | 8349.65 | 7022.74 | 0.48 | 0.3 | 0.3 |
| 3.54 | 14201.08 | 8835.27 | 0.49 | 0.43 | 0.42 |
| | | | | | |
| 2.56 | 521.72 | 602.22 | 0.48 | 0.21 | 0.2 |
| 2.48 | 10152.62 | 8427.51 | 0.39 | 0.23 | 0.23 |
| 3.08 | 16586.48 | 9982.6 | 0.41 | 0.34 | 0.33 |
| | | | | | |
| 3.22 | 409.44 | 456.17 | 0.6 | 0.35 | 0.35 |
| 3.84 | 6459.38 | 6666.32 | 0.69 | 0.62 | 0.62 |
| 4.26 | 11721.28 | 9610.72 | 0.68 | 0.75 | 0.75 |
| | | | | | |
| 1.68 | 801.02 | 1197.76 | 0.36 | 0.1 | 0.1 |
| 2.09 | 12124.11 | 10031.17 | 0.33 | 0.16 | 0.16 |
| 2.52 | 20338.33 | 11836.35 | 0.34 | 0.21 | 0.21 |
| | | | | | |
| 2.04 | 647.3 | 947.52 | 0.43 | 0.15 | 0.15 |
| 2.9 | 8564.01 | 6940.03 | 0.46 | 0.29 | 0.29 |
| 3.37 | 14849.84 | 10431.88 | 0.5 | 0.36 | 0.36 |
| | | | | | |
| 2.04 | 647.86 | 786.54 | 0.39 | 0.19 | 0.19 |
| 2.66 | 9355.41 | 8332.88 | 0.44 | 0.3 | 0.3 |
| 3.05 | 16489.29 | 11220.66 | 0.44 | 0.39 | 0.38 |
| | | | | | |
| 1.9 | 701.62 | 1016.98 | 0.4 | 0.18 | 0.18 |
| 2.84 | 8809.26 | 7424.09 | 0.46 | 0.31 | 0.31 |
| 3.43 | 14760.76 | 10575.16 | 0.51 | 0.4 | 0.39 |
| | | | | | |
| 2.07 | 638.42 | 1016.76 | 0.46 | 0.25 | 0.25 |
| 2.7 | 9193.73 | 9108.77 | 0.47 | 0.35 | 0.35 |
| 3.1 | 16125.12 | 13054.53 | 0.49 | 0.45 | 0.44 |
| | | | | | |
| 2.88 | 460.52 | 587.36 | 0.56 | 0.28 | 0.26 |

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|---|---|---|---|---|---|---|---|---|
| studyarea | 8450 | Q2yr | 24800 | 106 | 109.36 | 108.74 | 109.51 | 0.003567 |
| studyarea | 8450 | Q100yr | 49900 | 106 | 110.07 | 109.3 | 110.32 | 0.004178 |
| studyarea | 8225 | Q50% | 1320 | 104 | 106.25 | 105.31 | 106.3 | 0.002321 |
| studyarea | 8225 | Q2yr | 24800 | 104 | 108.71 | 108.14 | 108.81 | 0.002609 |
| studyarea | 8225 | Q100yr | 49900 | 104 | 109.34 | 108.56 | 109.53 | 0.00291 |
| studyarea | 7691 | Q50% | 1320 | 102.12 | 104.74 | 104.33 | 104.8 | 0.003445 |
| studyarea | 7691 | Q2yr | 24800 | 102.12 | 106.77 | 106.37 | 106.93 | 0.004979 |
| studyarea | 7691 | Q100yr | 49900 | 102.12 | 107.49 | 106.83 | 107.72 | 0.003976 |
| studyarea | 7474 | Q50% | 1320 | 102 | 103.63 | 103.2 | 103.85 | 0.005641 |
| studyarea | 7474 | Q2yr | 24800 | 102 | 105.87 | 105.17 | 106.04 | 0.003482 |
| studyarea | 7474 | Q100yr | 49900 | 102 | 106.6 | 105.83 | 106.83 | 0.004224 |
| studyarea | 7203 | Q50% | 1320 | 100 | 102.73 | 102.25 | 102.78 | 0.002684 |
| studyarea | 7203 | Q2yr | 24800 | 100 | 104.78 | 104.38 | 104.94 | 0.004801 |
| studyarea | 7203 | Q100yr | 49900 | 100 | 105.5 | 104.84 | 105.73 | 0.003916 |
| studyarea | 6951 | Q50% | 1320 | 98 | 101.68 | | 101.79 | 0.006034 |
| studyarea | 6951 | Q2yr | 24800 | 98 | 103.68 | | 103.84 | 0.003978 |
| studyarea | 6951 | Q100yr | 49900 | 98 | 104.37 | | 104.62 | 0.004998 |
| studyarea | 6671 | Q50% | 1320 | 98 | 100.45 | 100.14 | 100.51 | 0.003549 |
| studyarea | 6671 | Q2yr | 24800 | 98 | 102.76 | | 102.85 | 0.003008 |
| studyarea | 6671 | Q100yr | 49900 | 98 | 103.35 | | 103.5 | 0.00315 |
| studyarea | 6301 | Q50% | 1320 | 96 | 98.63 | 98.38 | 98.76 | 0.006547 |
| studyarea | 6301 | Q2yr | 24800 | 96 | 100.63 | 100.49 | 100.87 | 0.011901 |
| studyarea | 6301 | Q100yr | 49900 | 96 | 101.09 | | 101.48 | 0.0114 |
| studyarea | 5874 | Q50% | 1320 | 94 | 97 | 96.39 | 97.06 | 0.00262 |
| studyarea | 5874 | Q2yr | 24800 | 94 | 99.13 | | 99.19 | 0.001839 |
| studyarea | 5874 | Q100yr | 49900 | 94 | 99.82 | | 99.92 | 0.00164 |
| studyarea | 5183 | Q50% | 1320 | 92.61 | 95.29 | | 95.32 | 0.002423 |
| studyarea | 5183 | Q2yr | 24800 | 92.61 | 97.24 | | 97.36 | 0.004115 |
| studyarea | 5183 | Q100yr | 49900 | 92.61 | 97.87 | | 98.09 | 0.004827 |
| studyarea | 4907 | Q50% | 1320 | 92 | 94.21 | 93.72 | 94.25 | 0.007102 |
| studyarea | 4907 | Q2yr | 24800 | 92 | 96.14 | | 96.28 | 0.003785 |
| studyarea | 4907 | Q100yr | 49900 | 92 | 96.65 | | 96.85 | 0.004159 |
| studyarea | 4577 | Q50% | 1320 | 90 | 92.72 | | 92.77 | 0.003128 |
| studyarea | 4577 | Q2yr | 24800 | 90 | 94.6 | | 94.76 | 0.005778 |
| studyarea | 4577 | Q100yr | 49900 | 90 | 95.27 | | 95.48 | 0.004208 |
| studyarea | 4345 | Q50% | 1320 | 90 | 91.67 | | 91.81 | 0.005541 |
| studyarea | 4345 | Q2yr | 24800 | 90 | 93.53 | | 93.66 | 0.003915 |
| studyarea | 4345 | Q100yr | 49900 | 90 | 94.2 | | 94.37 | 0.005429 |
| studyarea | 4061 | Q50% | 1320 | 86 | 90.21 | 89.37 | 90.26 | 0.005189 |

| | | | | | |
|---|---|---|---|---|---|
| 3.08 | 8090.88 | 6010.76 | 0.46 | 0.3 | 0.3 |
| 4.05 | 12522.32 | 7767.06 | 0.53 | 0.47 | 0.44 |
| | | | | | |
| 1.75 | 752.97 | 1135.41 | 0.38 | 0.1 | 0.1 |
| 2.61 | 9501.84 | 7582.09 | 0.41 | 0.2 | 0.2 |
| 3.49 | 14291.95 | 7660.92 | 0.45 | 0.34 | 0.34 |
| | | | | | |
| 1.98 | 668.17 | 954.59 | 0.42 | 0.15 | 0.15 |
| 3.2 | 7749.05 | 7039.85 | 0.54 | 0.34 | 0.34 |
| 3.85 | 12959.75 | 7387.38 | 0.51 | 0.44 | 0.44 |
| | | | | | |
| 3.73 | 353.66 | 311.05 | 0.59 | 0.44 | 0.44 |
| 3.34 | 7414.88 | 4959.44 | 0.48 | 0.33 | 0.33 |
| 3.9 | 12847.67 | 8360.06 | 0.54 | 0.42 | 0.42 |
| | | | | | |
| 1.8 | 733.88 | 977.07 | 0.37 | 0.13 | 0.13 |
| 3.23 | 7765.8 | 7133.85 | 0.53 | 0.34 | 0.33 |
| 3.92 | 12946.94 | 7747.7 | 0.51 | 0.44 | 0.43 |
| | | | | | |
| 2.7 | 488.86 | 520.32 | 0.49 | 0.35 | 0.35 |
| 3.28 | 7904.48 | 5756.01 | 0.48 | 0.36 | 0.34 |
| 4.18 | 13280.78 | 9395.44 | 0.55 | 0.55 | 0.44 |
| | | | | | |
| 2 | 660.85 | 1094.44 | 0.45 | 0.13 | 0.13 |
| 2.41 | 10301.92 | 9242.04 | 0.4 | 0.21 | 0.21 |
| 3.13 | 15923.68 | 9830.73 | 0.43 | 0.32 | 0.32 |
| | | | | | |
| 2.82 | 468.55 | 668.75 | 0.59 | 0.29 | 0.29 |
| 3.97 | 6250.92 | 7730.52 | 0.78 | 0.6 | 0.6 |
| 4.96 | 10051.64 | 8540.97 | 0.81 | 0.84 | 0.84 |
| | | | | | |
| 1.89 | 698.28 | 902.11 | 0.38 | 0.13 | 0.13 |
| 1.98 | 12496.58 | 10626.26 | 0.32 | 0.13 | 0.13 |
| 2.47 | 20165.84 | 11388.55 | 0.33 | 0.18 | 0.18 |
| | | | | | |
| 1.36 | 968.11 | 932.41 | 0.24 | 0.16 | 0.16 |
| 2.88 | 8766.5 | 6541.28 | 0.43 | 0.36 | 0.34 |
| 3.85 | 13231.38 | 7548.29 | 0.5 | 0.55 | 0.53 |
| | | | | | |
| 1.69 | 757.96 | 2400.62 | 0.54 | 0.14 | 0.14 |
| 3.1 | 8708.08 | 11345.49 | 0.57 | 0.22 | 0.18 |
| 3.71 | 14747.5 | 12019.37 | 0.55 | 0.37 | 0.32 |
| | | | | | |
| 1.85 | 721.68 | 1236.27 | 0.43 | 0.11 | 0.11 |
| 3.23 | 7854.56 | 8373.9 | 0.58 | 0.35 | 0.34 |
| 3.65 | 13952.36 | 9843.73 | 0.54 | 0.38 | 0.37 |
| | | | | | |
| 3.05 | 432.39 | 370.56 | 0.5 | 0.4 | 0.4 |
| 2.86 | 8696.24 | 7227.42 | 0.46 | 0.29 | 0.29 |
| 3.29 | 15198.73 | 14780.2 | 0.57 | 0.35 | 0.35 |
| | | | | | |
| 1.68 | 783.62 | 1956.63 | 0.47 | 0.13 | 0.13 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| studyarea | 4061 | Q2yr | 24800 | 85.78 | 92.05 | | 92.18 | 0.005714 |
| studyarea | 4061 | Q100yr | 49990 | 85.78 | 92.69 | | 92.85 | 0.005435 |
| | | | | | | | | |
| studyarea | 3671 | Q50% | 1320 | 84.7 | 88 | 87.37 | 88.06 | 0.0036 |
| studyarea | 3671 | Q2yr | 24800 | 84.7 | 90.32 | 89.54 | 90.42 | 0.003605 |
| studyarea | 3671 | Q100yr | 49990 | 84.7 | 91.01 | 90.18 | 91.13 | 0.003601 |

| | | | | | |
|---|---|---|---|---|---|
| 2.77 | 8846.62 | 8885.68 | 0.49 | 0.35 | 0.35 |
| 3.08 | 16016.04 | 12990.6 | 0.49 | 0.41 | 0.42 |
| | | | | | |
| 2.03 | 651.78 | 922.54 | 0.42 | 0.16 | 0.16 |
| 2.53 | 9822.26 | 9390.44 | 0.43 | 0.24 | 0.23 |
| 2.82 | 17797.7 | 13729.69 | 0.44 | 0.29 | 0.29 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| studyarea | 4061 | Q2yr | 24800 | 86 | 92.3 | | 92.38 | 0.005107 |
| studyarea | 4061 | Q100yr | 49900 | 86 | 92.71 | 92.23 | 92.85 | 0.005135 |
| | | | | | | | | |
| studyarea | 3671 | Q50% | 1320 | 86 | 88.24 | 87.5 | 88.28 | 0.005004 |
| studyarea | 3671 | Q2yr | 24800 | 86 | 90.31 | 89.4 | 90.41 | 0.005006 |
| studyarea | 3671 | Q100yr | 49900 | 86 | 90.72 | 90.34 | 90.88 | 0.005002 |

| | | | | | |
|---|---|---|---|---|---|
| 2.38 | 10429.49 | 14210.05 | 0.49 | 0.23 | 0.23 |
| 3.03 | 16470.71 | 14763.48 | 0.51 | 0.36 | 0.36 |
| | | | | | |
| 1.63 | 817.36 | 2096.83 | 0.45 | 0.13 | 0.12 |
| 2.41 | 9938.37 | 13486.39 | 0.5 | 0.22 | 0.23 |
| 3.11 | 15755.69 | 14743.99 | 0.53 | 0.33 | 0.33 |

# APPENDIX F

*Stability Analysis/Sediment Transport*

MWH

# MATANUSKA RIVER EROSION ASSESSMENT
# PROGRESS REPORT-BANK EROSION MAPPING

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# 1 INTRODUCTION

## 1.1 Scope of Work

This report summarizes work in progress on the Matanuska River erosion assessment project. The main purpose of this report is to document historic rates of bank erosion and lateral channel shifting between 1949 and 2000. The information is used to predict the rate and extent of erosion that could be expected over the next 50 years. The report describes the methodology used and summarizes the available mapping data. Based on historic rates and patterns of lateral channel movement, a map of projected future erosion is presented. The predictions of future bank erosion should be considered preliminary at this time since other hydrotechnical investigations related to channel hydraulics, channel stability, and sediment transport need to be completed. The predicted channel changes will eventually be used as a guide for defining future mitigation works to reduce erosion, including bank hardening and gravel removal strategies.

## 1.2 Previous Studies

The reconnaissance report by nhc (2003) provided general information on the nature of the erosion problems, channel characteristics and sediment transport processes along the river. There have also been a number of previous studies on bank erosion problems along the Matanuska River. In 1998, Long prepared an overview of historical bank erosion for the City of Palmer using air photo interpretation and interviews with local residents[1]. Peratrovich, Nottingham & Drage prepared a pre-feasibility report in 1991 to assess using gravel extraction as a means of controlling bank erosion along the river[2]. Hulbert (1989) assessed sedimentation in the lower Matanuska River using historical observations and described the impacts of floodplain structures on sedimentation[3].

## 1.3 Background Information

The Matanuska River drains a large (2,070 sq. miles) glaciated watershed bounded by the Chugach and Talkeetna Mountain ranges north of Anchorage, Alaska. Since the Matanuska River and its major tributaries are heavily glacierized along their headwaters, large quantities of sediment are introduced and mobilized along the channel. Landslides and bank erosion are additional important sediment sources in the basin. Along its mainstem length, the river has formed a series of partly confined braided alluvial reaches separated by narrow bedrock gorges or relict glacial terraces. One of these gorges is located at the highway bridge near Palmer, Alaska

[1] Palmer, W., 1998. “Channel Shifting and Bank Erosion of the Matanuska River Near Palmer” report to NHawthorne Engineering and City of Palmer, 19pg.
[2] Peratrovich, Nottingham & Drage, 1991. “Matanuska River Erosion Control”, report to Matanuska-Susitna Borough, November 1991.
[3] Hulber, R., 1989. “Sedimentation in the Lower Matanuska River”, Dept. of Civil Engineering, University of Alaska, Anchorage.

and extends 3.5 miles downstream to a second narrowing (see Figure 1). Sediments transported from upstream pass through this gorge at high water and are deposited as a series of massive gravel bars. Typically, sediments are deposited in the center of the channel and deflect currents around them, but the channel also migrates from bank to bank over time. Both of these processes lead to erosion of floodplain and terraces along the outer channel banks. This erosion has been identified as a continuing problem and major concern to the citizens of Palmer, since it threatens homes and infrastructure along the river.

# 2 METHOD OF APPROACH

## 2.1 Available Data

The primary source of data for morphometric analysis of historic channel changes is a set of scanned and printed photo maps (mono coverage) of the study area. In addition, two sets of stereo aerial photographs were provided for pre- and post-freshet periods in 1981. A complete list of source materials is given below.

**Table 1: Map Data Used in Analysis**

| Year | Date | Scale: | Notes |
|---|---|---|---|
| 1949 | Aug 14 | 1:15,840 | B&w; poor coverage below reach 1 |
| 1960 | June 6 | 1:22,600 | b&w; incomplete coverage below Glenn Hwy bridge |
| 1975 | Oct 9 | 1:22,200 | b&w; full coverage |
| 1981 | Apr 13 | 1:12,000 | b&w; full coverage |
| 1981 | Oct 1 | 1:12,000 | colour; full coverage |
| 1985 | Sept 21 | 1:36,000 | colour; full coverage |
| 2000 | May 9 | 1:24,000 | colour; full coverage |

## 2.2 Mapping Methods

In order to compare images of different scale and orientation, all images must first be converted to the same coordinate system. This is accomplished by digitizing a set of well-spaced control points on each image. Coordinates for each control point were obtained from 1:25,000 scale USGS digital maps of the study area (Anchorage C-6 SE, SW) since more accurate orthophoto maps were not available. The USGS topographic maps use the UTM coordinate system and NAD27 datum for this region of Alaska. All map units are metric (units meters) which requires additional post-processing to convert distance and area measures to feet. Absolute registration accuracy for the 2000 photo map was roughly 5-meters RMS (16 feet). All subsequent maps were registered using coordinates derived from the 2000 map since this reduces relative errors to roughly 2 meters (6.5 feet). Between two consecutive dates, the maximum displacement of a digitized feature (e.g. outer channel bank) will be ±10 feet by mapping error. Although these errors may appear substantial, they are small compared to the width of the channel, which ranges from 1500 feet to 6000 feet over the study area.

Each registered image was digitized on-screen using ArcView GIS. The location of outer channel banks, exposed (above water) gravel bars, and well-vegetated bars (islands) were traced and coded as a series of lines. All digitized data were subsequently transferred to Arc/Info GIS for additional geo-processing to produce polygon maps for 1949, 1975, 1985 and 2000 (see example, Figure 2). The 1960 photos were not processed because of the large gap in reach coverage. Individual maps are used to illustrate changes in channel morphology over time, and are analysed to show changes in channel width. By overlaying successive maps, changes in channel morphology and rates of bank erosion and deposition can be calculated. This is discussed in the following section.

The stereo photographs have been digitized using an analytic stereoplotter, a device which mathematically relates two-dimensional positions on the photos to their real-world, three-dimensional equivalents. The stereoplotter further provides a magnified, 3-dimensional view of the landscape, which greatly aids interpretation of ground features. All photo sets are tied to the 2000 photo map (x,y coordinates) while elevations were recorded from the USGS maps. Since the dates of the stereo photos (both in 1981) are within the period of channel changes mapped from the mono photographs, they are not required for this analysis.

# 3 ASSESSMENT OF BANK EROSION

## 3.1 Historical Bank Erosion Rates

### 3.1.1 Reach Extent

All of the mapped photo sets extend from just upstream of Glenn highway bridge to the sewage disposal ponds south of Palmer, a total distance of 28,000 feet or 5.3 miles as measured along the channel centerline. The 1949 map, however, does not extend towards the south bank of the river and so interpretation of changes there is limited. The study area has been broken into two separate reaches, or sections of channel within which the morphology of the channel remains reasonably constant. Reach breaks are normally made where large tributaries enter, since these affect both the flow and sediment inputs to the channel (the main factors which alter channel morphology). Since no large tributaries enter the study area, reaches were defined by significant changes in boundary materials, such as occurs where the channel narrows (see Figure 1).

The first reach extends a total length of 18,800 feet, while the second reach extends downstream an additional 9100 feet. The average gradient for both sections of channel is 0.004, based on elevation changes from the December, 2003 LiDAR data. Note that the downstream boundary of reach 2 is not based on changes in channel morphology (i.e. it is not a true morphologic reach), but merely reflects the end of photo coverage.

### 3.1.2 Channel Width Changes

Over time, the average width of the reach changes in response to bank erosion and deposition, and the growth and destruction of channel islands. As the channel thalweg, or path of deepest, fastest flow migrates between outer channel banks in response to sediment inputs and storage along bars, both bank erosion and deposition will occur. If the channels become wider, bank erosion must be occurring at a greater rate than bank deposition. Table 1 below provides a comparison of total channel width (the average distance between banks) and active channel width (the average width of the bars and water surface excluding vegetated islands). Averages are calculated as total area divided by reach length. Active channel width reflects that part of the bed which is mobile at high flows. Width increases are generally observed during periods (years or longer) of above-average flows, as banks and channel islands are eroded. Conversely, narrowing is observed during periods of below-average flows as vegetation becomes established and matures on elevated bar surfaces.

**Table 2: Changes in Channel Width Over Time**

| Year | Total width (feet) | | Active channel width (feet) | |
|---|---|---|---|---|
| | Reach 1 | Reach 2 | Reach 1 | Reach 2 |
| 1949 | 3617 | -- | 3420 | -- |
| 1975 | 3586 | 4561 | 3450 | 3803 |
| 1985 | 3595 | 4576 | 3348 | 3459 |
| 2000 | 3684 | 4667 | 3283 | 3479 |

Changes in active channel width over time are largely paralleled by changes in island cover. A decrease in island area from 1949 to 1975 resulted in an expected increase in width, while continued island growth since 1975 has resulted in steady channel narrowing along reach 1 (interpretation is restricted to reach 1 since mapping is incomplete along the entire length of reach 2). Along alluvial channels, this pattern is normally associated with an increase in channel stability. However, total channel width has increased since 1975 despite a trebling of the island coverage. This circumstance can be explained by an increase in the rate of erosion along the outer banks, but this pattern is unusual. Preliminary investigation suggests that growth of the single, large island complex in the mid-channel (which is responsible for the observed active channel narrowing) serves to split the flow around either side. Consequently, bank erosion still occurs along both outer banks around the island. In fact, most erosion is observed along the downstream end of reach 1 where the river is forced into an abrupt bend. The present channel alignment below the bridge reinforces this situation.

### 3.1.3 Bank Erosion Rates

Changes in total channel width provide an incomplete picture of the magnitude of bank erosion, since erosion may still occur even if the channel becomes narrower overall. This commonly occurs during periods of below-average flood flows as vegetation encroaches on bars adjacent to channel banks and new floodplain is established, or as side channels separating islands from the floodplain are abandoned. Reported bank erosion rates typically include the loss of both outer bank floodplain and channel islands. However, as erosion of channel islands is not of concern here, the following analyses and discussion is restricted to erosion along the outer channel banks only. Bank erosion is calculated from the overlay maps, and is defined as land classified as floodplain on the earlier date, and as water or gravel bars on the following date. The total area of loss, divided by reach length and the time (in years) between mapping dates gives the reach-averaged erosion rate. These data are summarized in Table 3. Figure 3 summarizes changes in the location of the outer banks and growth of islands over time.

**Table 3: Reach Averaged Rates of Outer Bank Erosion**

| Period | Total erosion (sq. feet) | | Erosion rate (feet / yr) | |
|---|---|---|---|---|
| | Reach 1 | Reach 2 | Reach 1 | Reach 2 |
| 1949-1975 | 122,902 | 110,530 | 2.71 | 7.15 |
| 1975-1985 | 128,119 | 37,856 | 7.35 | 4.47 |
| 1985-2000 | 263,184 | 81,601 | 10.06 | 6.42 |

In total, 16.8 acres of floodplain and terrace land was lost due to erosion of the outer river banks between 1949 and 2000. The quantities do not include areas of islands or bars eroded inside the active channel zone. Reach-average rates of erosion have steadily increased along Reach 1, reaching a maximum of 10 feet per year from 1985 to 2000. The rates are modest for a large braided channel. However, most of the total area eroded in this period occurred along a mile long strip of left bank near the downstream end of reach 1 (Figure 3), where the channel shifted as much as 465 feet in 15 years (31 feet/year) , and up to 650 feet since 1949 (13 feet/year). Other area of significant concern include the right bank at the downstream limit of reach 1 (nearly 200 feet since 1985; 700 feet since 1949 or 14 feet/year) and along the left bank of reach 2 upstream of the end of the mapping (nearly 300 feet since 1985 or 20 feet/year). Erosion at this location destroyed developed lands and prompted mitigative action through construction of a series of wing dikes. Historically, significant erosion has also occurred near the sewage treatment facilities along the right bank of Reach 2 (up to 350 feet lost between 1949 and 1985). Little additional erosion has been recorded since 1985, and the treatment plant is currently protected by riprap dikes.

### 3.2 Future Bank Erosion

Although the occurrence of erosion and deposition is largely random along the channel, sites of persistent erosion (or deposition) tend to develop along large rivers in response to the general alignment of the channel. Therefore, a record of past channel migration can provide an indication of locations where erosion is likely in the future. A preliminary channel migration map has been prepared from the historical bank erosion rates. The following steps were used to complete this assessment:

1. overlay maps of channel bankline changes were prepared (Figure 3)
2. vectors were established perpendicular to the channel along the prevailing direction of erosion and the average erosion rate for each vector was calculated (Figure 4)
3. the erosion vectors were extended by a distance equal to the average rate extrapolated to 50 years from the present channel location where the channel is unconfined or to the limits of erosion resistant features (Figure 4)
4. the adopted 50-year erosion boundaries were then digitized and plotted (Figure 5)

Outer channel banklines were extracted from each morphologic map, saved to separate line coverages and overlaid in Arcview using different line colors to distinguish them. An erosional site was identified wherever the most recent bankline (2000) was located beyond the outer extent of at least the 1985 bankline. A vector was then digitized across the banklines perpendicular to the channel thalweg, starting from the date when erosion first started. At sites of persistent erosion, the vector would simply extend from the 1949 to the 2000 bankline, crossing both 1975 and 1985 banklines. Erosion vectors were also digitized where the channel was erosional (i.e. 1949 to 1985) but is presently stable, and where the channel may have experienced past deposition but is presently eroding. If the most recent bankline was closer to the current active channel than the previous (1985) bankline, the site was termed depositional, and no vector as drawn (although erosion may have taken place in the past). Each erosional vector, therefore, represents the total distance eroded between 1949 and 2000, regardless of when the erosion actually took place. The location of digitized erosion vectors is shown in Figure 4.

Erosion vectors were exported from the GIS and analyzed using a text-based programming script that calculates the distance between the start and end point of each vector (based on vector coordinates) and divides by the length of the study period (51 years) to determine the average erosion rates for each. This rate is then multiplied by the length of the prediction period (50 years) and a new vector endpoint coordinate is established – the effect is to 'stretch' each vector in the direction of prevailing erosion. The predicted vectors are next re-imported to the GIS and overlaid on the most recent channel map, along with all natural and artificial channel restrictions. The predicted erosion zone is then calculated by connecting the outer extent of the stretched vectors to the current active channel margins. The outer boundary is adjusted to conform to natural channel curvature and further modified to account for locations where the predicted vectors extend past non-erodible boundaries. Considerable judgement and interpretation was applied to produce the final adopted bank erosion line. In general, the adopted bank retreat lines "envelope" the local erosion rates. Therefore, in some locations bank erosion were assumed to occur, even though no significant erosion was recorded during the last 50 years. The projected future bank erosion is shown in Figure 5.

The draft erosion map assumes that future erosion rates will be similar to past rates. However, any significant changes to the flow or sediment regimes in the watershed will affect future erosion rates. The effect of future mitigation measures has also not been considered.

It should be emphasized that the 50-year projections are based on averages, and considerable annual variation in the rate of erosion is possible. Further, the draft map shows several areas where no future erosion is apparently expected. Aside from locations that are protected by structural improvements or are naturally resistant to erosion (such as along bedrock outcrops), all outer banks have the potential to be eroded. A conservative approach to reducing risk in these areas is to establish a minimum setback for development based on the long term average rates of erosion for the entire reach, projected 50 years into the future. These setbacks are equivalent to 90 feet in Reach 1 and Reach 2.

### 3.3 Additional Work Required

The draft bank erosion map shown in Figure 5 is preliminary. The map is intended only to indicate general trends in future bank erosion that might be expected to occur. The results are not intended for defining the magnitude of the erosion hazard at specific lots or localized sites.

In order to finalize the results, some additional investigations need to be completed. The 2003 Lidar data (Figure 6) will be used for defining the present bank positions rather than the 2000 air photos. Ground inspections will need to be carried out to verify the overall reasonableness of the bank erosion predictions. Additional hydrotechnical investigations are also required to assess the stability of the banks. This will require further hydraulic modeling and sediment transport computations. This work is currently underway.

# 4 CONCLUSIONS

Historic rates of bank erosion and lateral channel shifting along the Matanuska River have been measured between 1949 and 2000. The information was used to predict the rate and extent of erosion that could be expected over the next 50 years. Long-term reach- average rates of bank retreat have ranged from 2.7 feet/year to 10.0 feet/year in the study reach. Local rates of erosion have averaged up to 30 feet/year at some sections. Short-term erosion rates due to extreme flood events may exceed these long-term average rates considerably. However, in terms of predicting future (50-year) bank positions, the long-term average rates are more appropriate. In total, approximately 17 acres of river banks was eroded over the period 1949 to 2000. These quantities represent only erosion of floodplain or terraces adjacent to the outer river banks. The quantities do not represent erosion of island or bars inside the active channel zone.

The historical patterns of bank erosion were assessed in order to produce vectors of bank retreat. The vectors were then extrapolated to provide a generalized indication of future bank positions. It was assumed that the erosion rate would be similar to the long-term average values and that no mitigation measures were carried out.

The draft bank erosion map shown in Figure 5 is preliminary and additional investigations need to be completed before the map can be finalized. The 2003 LiDAR data will be used for defining the present bank positions rather than the 2000 air photos. Ground inspections will need to be carried out to verify the overall reasonableness of the bank erosion predictions. Additional hydrotechnical investigations are also required to assess the stability of the banks.

# FIGURES

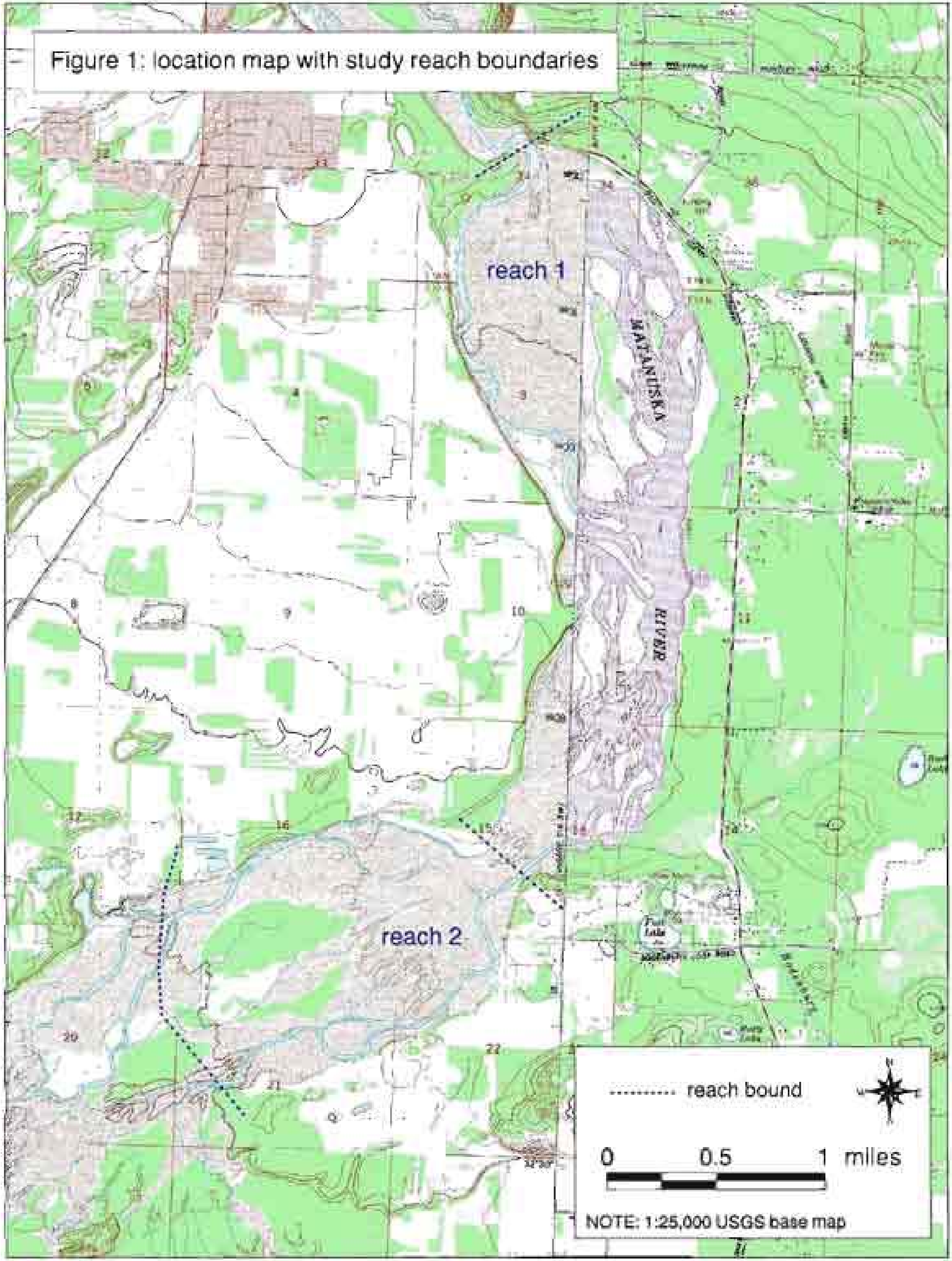


Figure 1: location map with study reach boundaries
reach 1
reach 2
MATANUSKA
RIVER
reach bound
0
0.5
1 miles
NOTE: 1:25,000 USGS base map

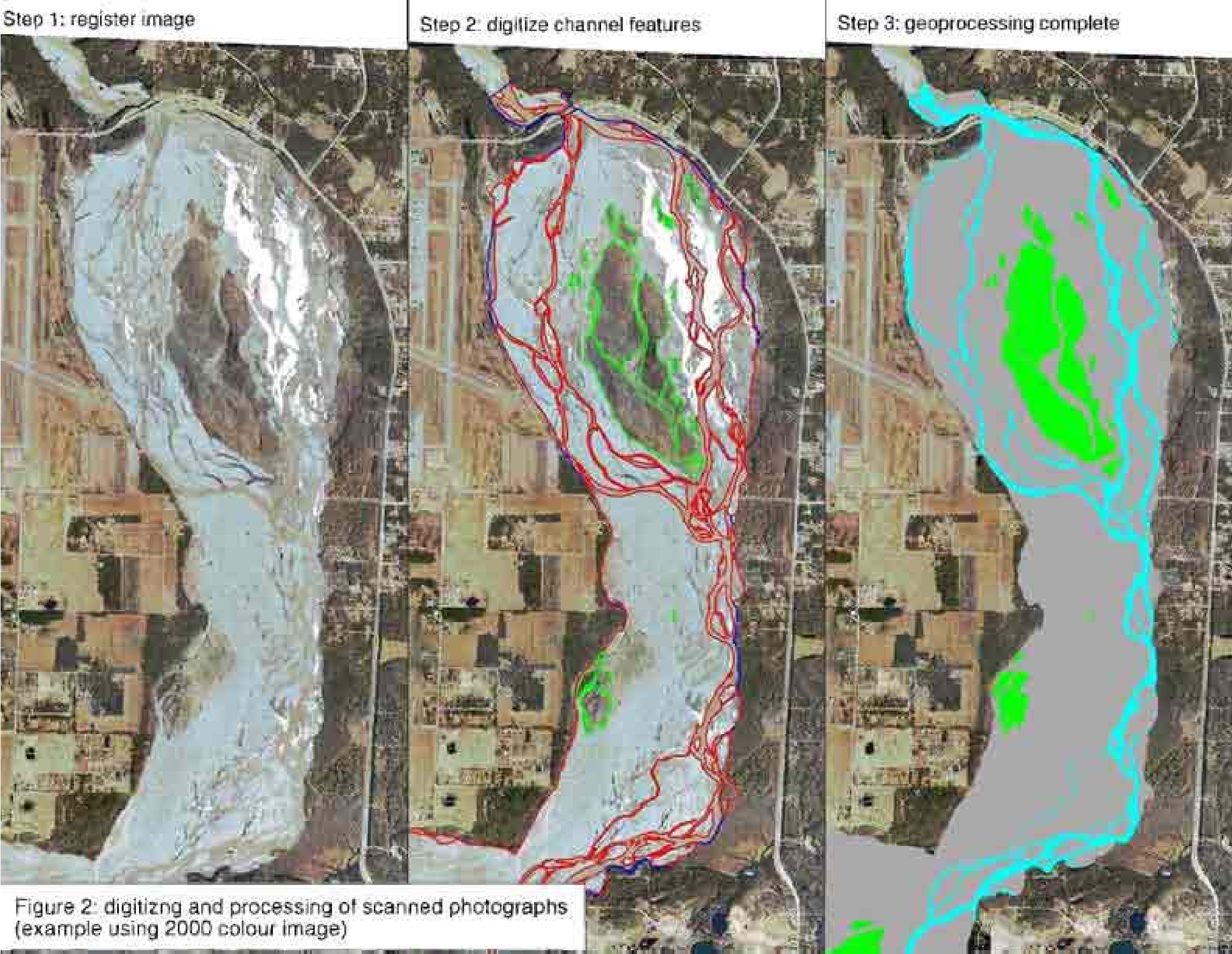
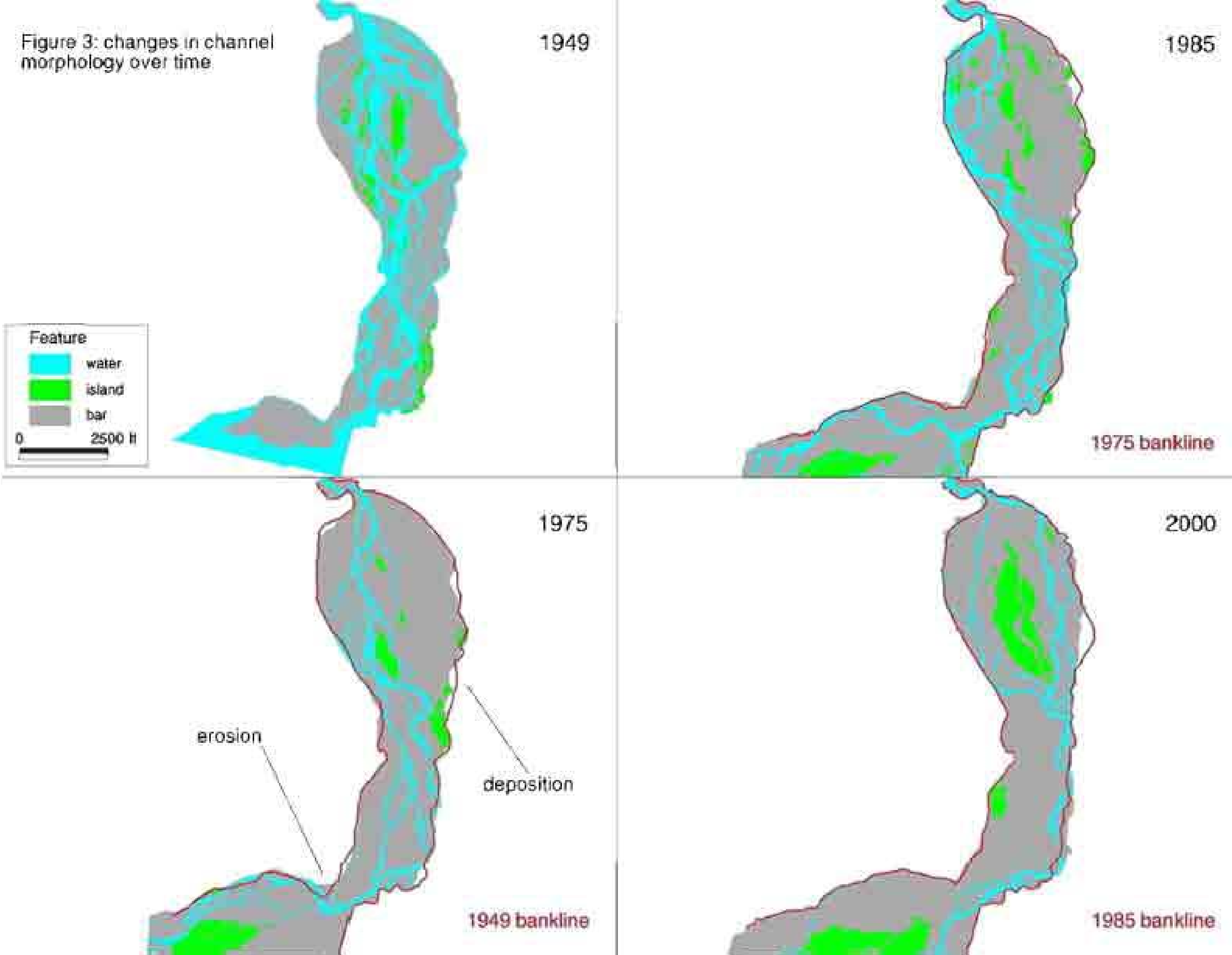



Figure 2: digitizng and processing of scanned photographs (example using 2000 colour image)

Figure 3: changes in channel morphology over time



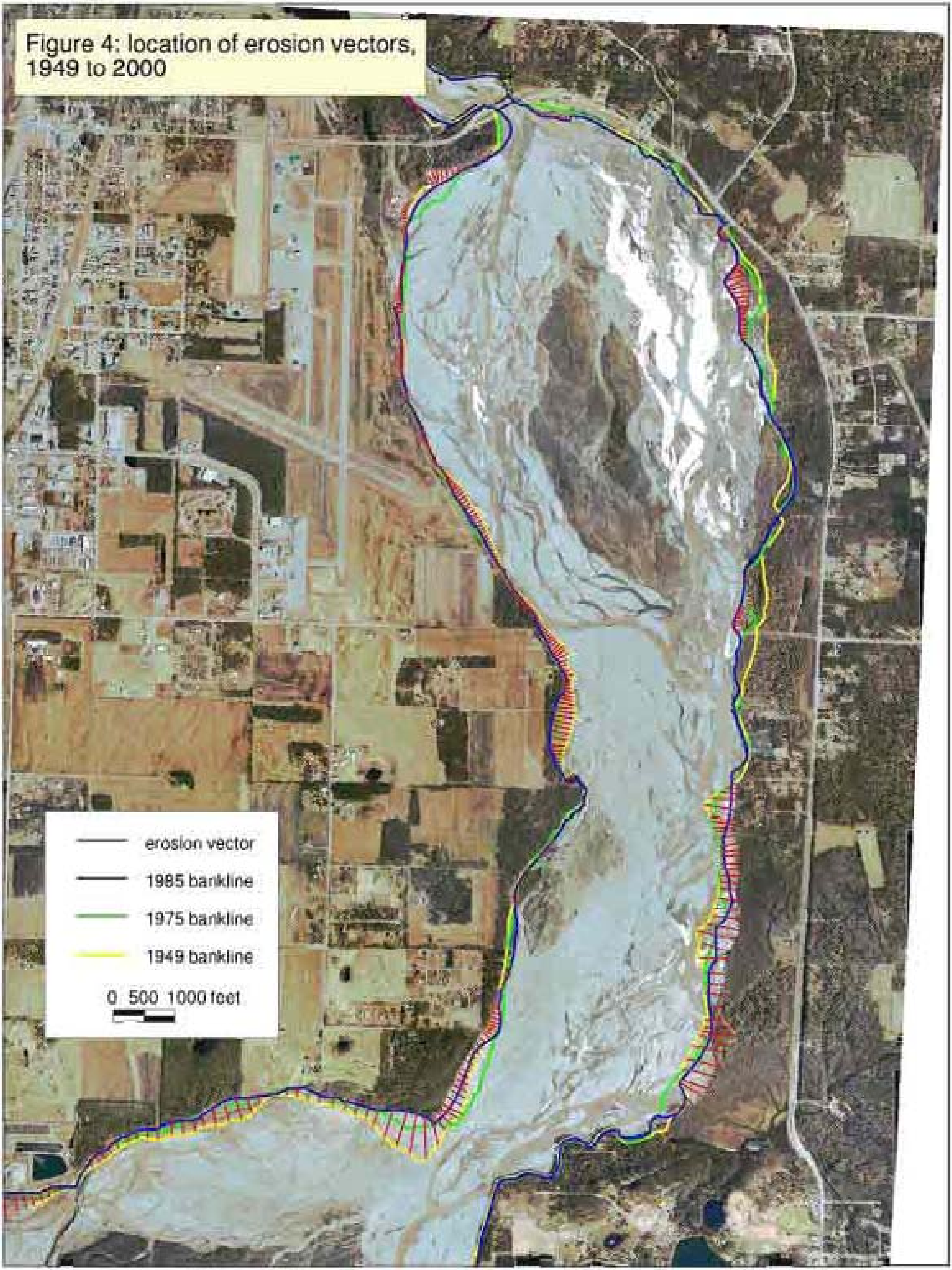


Figure 4: location of erosion vectors, 1949 to 2000

FIGURE 5
Matanuska River
Predicted erosion vectors and outer (50 year) erosion boundary

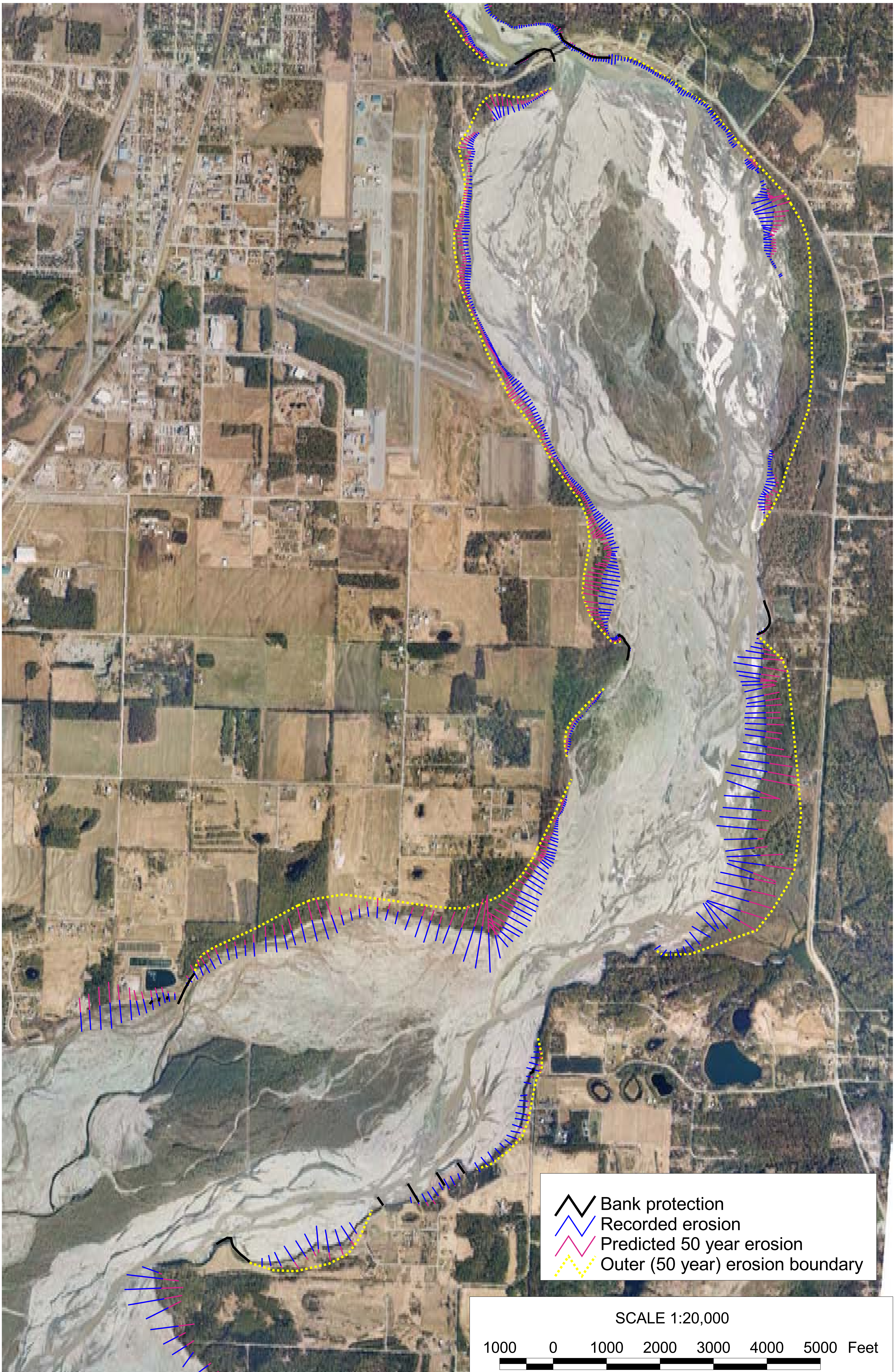
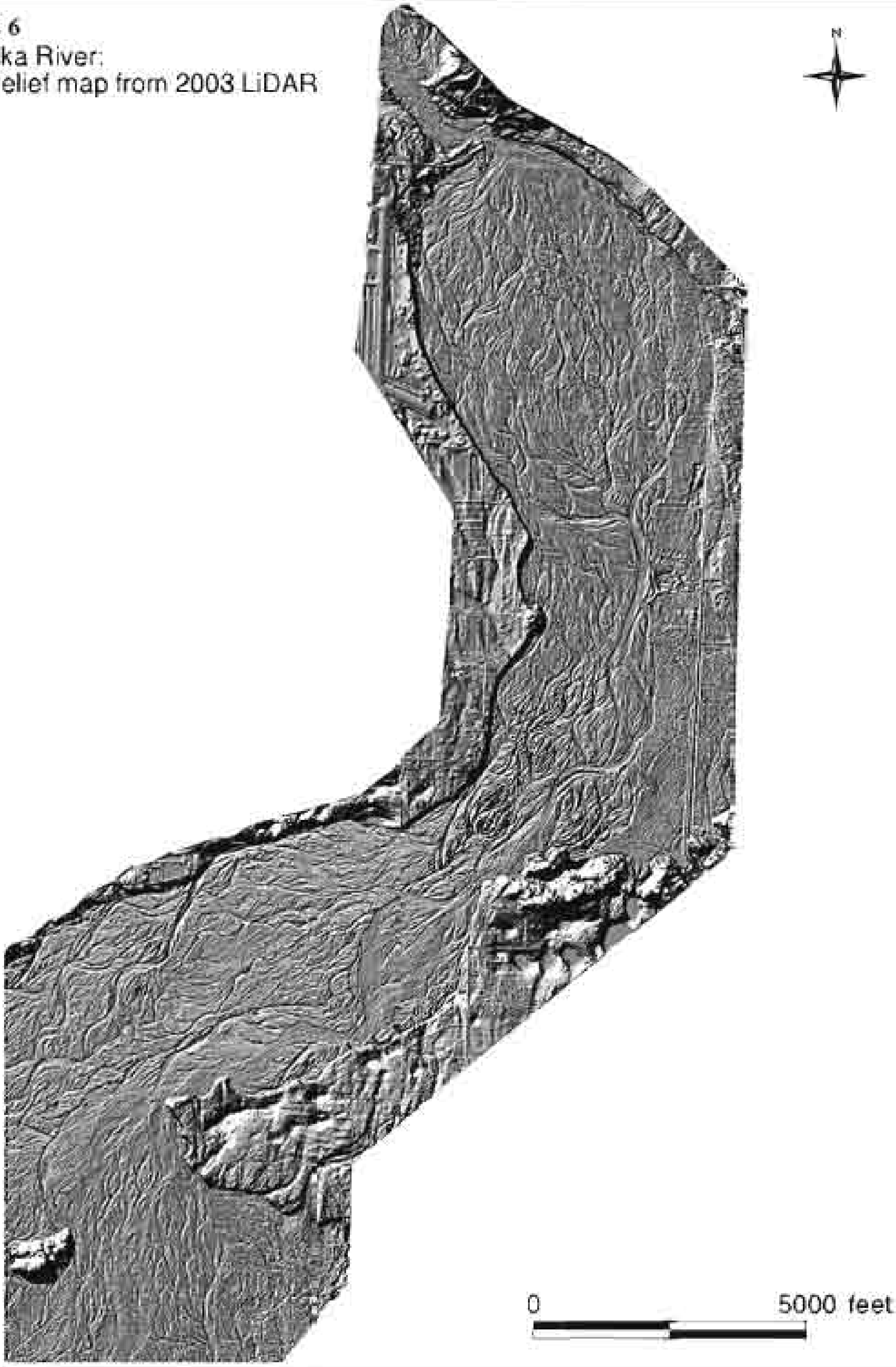


**FIGURE 6**
Matanuska River:
shaded relief map from 2003 LiDAR



# Matanuska River Erosion Assessment
# Gravel Removal and Bank Protection
# Progress Report

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# 1 INTRODUCTION

## 1.1 Purpose

Northwest Hydraulic Consultants (NHC) and MWH Americas Inc (MWH) are conducting a comprehensive investigation to assess the feasibility of controlling bank erosion hazards along the Matanuska River near Palmer. The overall goal of the project is to formulate potential gravel mining strategies that can reduce bank erosion, as well as to develop a viable gravel supply business which will function within existing environmental regulations. However, other strategies for controlling bank erosion through local river training have also been considered. The overall study is being conducted by a multi-disciplinary team of engineers, river geomorphologists, economic planners and fisheries biologists.

This progress report summarizes results of hydrotechnical studies that have been carried out to May 2004. The results are preliminary and are intended primarily to apprise other members of the study team and other interested stakeholders about key findings to-date. Comments and input received will be incorporated into the final comprehensive report.

## 1.2 Review of Previous Work

NHC river engineering specialists made a site visit and field inspection in November 2003. A field trip report was issued describing the river characteristics, identifying key technical issues and outlining data requirements for future work (NHC, 2003). Air photos between 1949-2000 were compiled and were used to assess the historical pattern of bank shifting and erosion. Preliminary predictions of potential future bank erosion and channel shifting were then made, based on the historical rates of channel shifting (NHC, 2004). A comprehensive LiDAR survey was undertaken by MWH and was subsequently used to compare with the earlier mapping data. MWH also conducted hydrological analysis and bed material sampling and summarized this information in technical memos. A HEC-RAS backwater model was also developed by MWH from the LiDAR data.

## 1.3 Outline of Present Work

In order to assess the strategy of gravel removal to control channel shifting and bank erosion, it is necessary to determine the following:

- Sites where bank erosion has occurred in the past,
- Sites where further bank erosion is expected in coming years, and
- The volume of annual bed material that enters the reach past Old Glenn Highway Bridge

The first two items were described previously (NHC, 2004). This progress report provides preliminary estimates of long-term gravel bed load transport rates using several different methods. Additional work has also been carried to refine our assessment of future bank erosion patterns along the river. On the basis of these results, three options for controlling erosion have been identified.

# 2. CHANNEL STABILITY ASSESSMENT

## 2.1 Up-dated Work

LiDAR mapping data collected in December, 2003 has now been incorporated to update previous results. The LiDAR data were processed using a TIN model in Arc/Info GIS, and then converted to a regular grid array at 8 feet (2.5 meter) resolution for subsequent display and analysis. This resolution is slightly coarser than the spatial density of the raw LiDAR data but is more than adequate for visualizing channel features. During comparisons with ground surveys, it was noted that the vertical datum for the LiDAR data was not standard NVD88. It is our understanding that some adjustments are still being made by the survey company to transform the data. However, these adjustments will not significantly affect their use for plan-form mapping purposes.

A new 2003 bankline was interpreted from these maps based on (1) large changes in relative elevation and (2) cells with slopes greater than mean channel slopes. These criteria reliably delimit locations where the channel is bounded by high terraces or bedrock, both of which define the outer channel banks. The interpretation is, however, complicated along parts of the eastern channel margin in study Reach 1 where the active channel is bounded by low-elevation floodplain and distinct breaks are not always clear. At these locations, the 2000 bankline was superimposed on the elevation and slope maps to look for discontinuities in either. For example, if flat slopes along the active channel appeared to extend beyond the 2000 bank position, it was assumed that lateral erosion had taken place and the 2000 bankline was correspondingly modified.

Based on the above interpretation, several sites of new erosion have been defined along the left bank in Reach 1. Maximum erosion rates extend to 150 feet (50 ft / yr) with a maximum of 300 feet (100 ft / yr) near the downstream extent of the large mid-channel island. Right bank erosion is comparatively modest over this same period.

The LiDAR interpretive maps appear to show substantial right-bank erosion along the Reach 1/2 boundary, an area of persistent erosion since at least 1949. However, oblique photographs taken during our site inspections in November, 2003 show that this area is actually low-lying floodplain and has not been eroded.

In Reach 2, there has been no detectable recent downstream erosion along either bank indicating that existing bank protection structures appear sufficient to address short-term channel shifting given the current channel alignment. Given the occurrence of relatively large floods (approximately 10-year return periods) in 2001 and 2001, this assertion seems reasonable. Nevertheless, future erosion is still likely along unprotected lengths of both banks and along protected banks if these structures are not maintained.

## 2.2 Projected Future Erosion

Preliminary maps showing areas of expected erosion were presented in NHC (2004). Following the interpretation of 2003 banklines, these maps have been updated to account for new left bank erosion in Reach 1. The up-dated map is shown in Figure 1. The map was created by digitizing vectors corresponding to the length and location of erosion from 1949 to 2000, and then projecting erosion vectors 50 years into the future. The outer boundary of projected erosion was modified to account for channel curvature, non-erodible boundaries, and further extrapolated along channel margins to create an envelope curve that averaged out considerable spatial variability in maximum local erosion rates.

## 2.3 Variability of Erosion Rates

The projected future erosion limits assume that future rates and locations of erosion will be similar to the past pattern of channel shifting. Channel erosion depends on the flow frequency, flow magnitude and sedimentation patterns, all of which are highly variable over time. There are several issues that complicate such predictions. For example, long-term fluctuations in river discharge are associated with climatic patterns such as the Pacific Decadal Oscillation. During extended periods of above average discharges, rivers will respond by widening through bank erosion or stripping of established vegetation from gravel bars. Similarly, channel narrowing usually occurs during periods of below average flood flows as new floodplain is established and vegetation matures on gravel bars.

Discharge data from the Little Susitna River, a glaciated tributary of Matanuska River were used to assess the past variations in discharge in the Matanuska watershed (large gaps in the historic data records do not permit this type of analysis on the mainstem of the Matanuska River). An analysis of discharge records on the larger Susitna River (at Gold Creek) confirms the general trend.

The March progress report (NHC, 2004) showed that width increased along Matanuska River from 1949 to 1975, then subsequently declined in both 1975 to 1985 and 1985 to 2000 mapping periods. These changes are roughly coincident with observed flow trends except from 1975 to 1985 when the channel narrowed despite a sequence of consistently above-average floods. Since no major bank protection works were constructed during this period (Expedited Reconnaissance Study, 2003) which could explain this anomaly, further investigation is required. Potential impacts of global warming on future runoff and sediment yields also need to be considered.

# 3 GRAVEL TRANSPORT

## 3.1 Purpose

The main objective of the gravel-removal plan will be to re-direct active channels away from eroding banks in order to increase channel stability and reduce bank erosion. The annual volume of gravel mined from an aggrading river reach should be similar to the annual gravel inflow to the reach. Removing much greater volumes over several years may harm the riverine ecosystem and promote long-term changes to the river morphology. Therefore, it is important to develop quantitative estimates of the annual gravel transport rate. The following section of the report describes efforts to predict the annual gravel transport rate using three different methods:

- direct measurements of bed load
- predictions using bed load formulae
- predictions using morphologic methods

## 3.2 Sediment Transport Measurements

### 3.2.1 Available Data

The USGS has periodically collected sediment data at Gage 15284000, Matanuska River at Palmer. Bed load and suspended bed load values were extracted from this data record, sediment transport rating curves were then developed and an average annual bed material transport rate was calculated.

The USGS first recorded sediment data by grain size classification in October 1953, and a total of 51 samples were recorded through October 1986. The majority of the sediment sampling occurred between 1959 and 1967, with multiple sampling events each year. Suspended sediment load characteristics were measured until 1985; bed load characteristics were also measured a total of nine times in 1985 and 1986. The types of sediment sampling equipment were not noted in the data records.

### 3.2.2 Hydraulic Geometry

Gaging records from the periodic USGS hydrometric measurements at the Palmer Bridge were used to estimate the hydraulic conditions at the bridge section. This section is confined in a single channel and has a relatively simple, uniform geometry compared to the wide, braided channel further downstream. This feature makes it a good site both for measuring sediment loads and for estimating bed load using theoretical equations.

Hydraulic geometry relations were established from the direct field measurements of flow width, depth and velocity from the available records. For each date of measurement, the entire set of measurements was excluded if a value for any of the variables was not recorded. Initial plots showed significant scatter at discharges less than 2,500 cfs because measurements are taken downstream of the bridge crossing where the channel is less confined (USGS). By eliminating the low flow records, the scatter was greatly reduced and the following relations were established from the remaining 455 measurements:

$w = 17.346\ Q^{0.293}$ W is the channel top width
$d = 0.541\ Q^{0.265}$ d is the hydraulic mean depth
$v = 0.107\ Q^{0.442}$ V is the mean velocity

The maximum measured velocity at the gage is 10.97 ft /sec on August 25, 1959 at a discharge of 34,000 cfs. During the breakout flood of August, 1971, flow velocities would have reached an estimated 16 feet / sec. Derived hydraulic geometry relations based on the field data are shown in Figure 3.

### 3.2.3 Suspended Load

The measured suspended load data were separated into two classes to determine the proportion of the total suspended load that corresponds to:

- the sand load, defined as the load coarser than 0.063 mm, and
- the silt/clay load, defined as the load finer than 0.063 mm

The silt and clay fraction of the load (material finer than 0.063 mm) is considered to be all wash load, and travels through the reach without being deposited in the channel (though some may become trapped on islands and floodplain surfaces or settle in areas of quiet water). The sand fraction of the load (coarser than 0.063 mm) constitutes suspended bed material load and makes up a portion of the channel bar and island deposits. For example, samples of the river bed material by MWH in 2003 indicated the sand fraction (0.063 mm to 2.0 mm) typically accounted for between 10% and 40% of the sediments and averaged around 30%.

The total suspended sand load in tons/day was determined for each sample and plotted versus flow in cfs (Figure 4). A line was fit to the data and a flow-suspended bed load rating curve was generated from the following equation:

$$G_{sand} = 3.7E10^{-7}\ Q_{flow}{}^{2.61}$$

The average annual suspended sand load is estimated as 1,630,000 tons based on 27 years of daily flow data. For comparison, the total annual suspended load was estimated as 6,650,000 tons, roughly 4 times greater. The total suspended load is therefore comprised of 80% silt-clay and 20% sand. Interestingly, the proportion of sand sized material dominates at low discharges (below 3,000 cfs, but the silt and clay fraction increases with discharge above this value. This pattern must reflect the differing supply conditions for the two materials (i.e. the fine sediments are not available for transport until the flows increase).

### 3.2.4 Bed Load

Direct measurements of bedload were made by the USGS in 1985 and 1986 at the bridge over discharges ranging from 880 to 18,100 cfs. Material trapped in the samplers ranges from fine sand to coarse gravel (maximum size 76 mm). Samples taken at low daily discharges (< 1500 cfs) consisted mainly of sands, with a median grain size less than 1 mm. The median grain size of collected samples generally increased with discharge, and reached a maximum of 16 mm. The average $D_{50}$ of the nine USGS samples was 7 mm. For comparison, the average of six small bulk samples collected by MWH shows a median grain size of 12 mm for sub-surface bed material, with only 10% of collected material greater than 37 mm (maximum 76 mm). More significant, the samples contained 27% by weight material finer than 2 mm (sand). The average bedload size distribution agreed very closely to the bulk sub-surface bed material samples collected in 2003 (Figure 5).

Measured bed load data were also plotted versus flow (Figure 6) and a line was fit to the data to develop a flow-bed load rating curve. The resultant equation follows:

$$G_{bedload} = 2E10^{-5}\ Q_{flow}{}^{2} + 0.1043\ Q_{flow}$$

A relatively long daily average flow record was available for Gage 15284000, extending over the following time periods: 1949-1973, 1985-1986, 1991-1992, and 2000-2002. Daily bed load and suspended bed load volumes were determined over these time periods by applying the corresponding rating curves to the flow record. Sediment transport volumes were then summed for each complete water year; incomplete water years were omitted from the calculations. An average annual total bed load of approximately 420,000 tons was calculated based on 27 years of available flow data. This represents about 6.3% of the total annual suspended load and 26% of the suspended sand load.

## 3.3 Bed load Formula Estimates

### 3.3.1 Method

Predictions of gravel bed load transport rate from theoretical equations are generally considered to be "order of magnitude" estimates and are subject to considerable uncertainty (Gomez and Church, 1989). However, the availability of actual measured loads at the site data provides a means for testing and verifying some of the methods that are available. The main variables used in most theoretical equations include flow width and depth, channel gradient, and characteristic bed material size (usually $D_{50}$). Several different equations that have been recommended for use on gravel bed rivers were tested including Parker (1981), Levi equation and Bagnold's equation (1980). The Parker equation uses bed shear stress and was derived specifically for gravel-bed river applications. The Bagnold (1980) equation is the best known stream power relation and is attractive to use because the required input variables are relatively easy to calculate or estimate.

The hydraulic geometry data from the periodic USGS hydrometric measurements at the Palmer Bridge were used to estimate the hydraulic conditions at the bridge section. This section is confined in a single channel and has a relatively simple, uniform geometry compared to the wide, braided channel further downstream. This feature makes it a good site both for measuring sediment loads and for estimating bed load using theoretical equations. A channel gradient of 0.0038 was estimated from a best-fit regression line through the long profile of the channel. A value of 12 mm was used for the $D_{50}$ after results presented in the March, 2004 MWH technical memorandum.

For each date of recorded channel discharge, a transport rate was calculated to provide a total daily mass. The values were then summed to estimate the annual transport rate.

### 3.3.2 Results

Figure 6 compares the predicted bed load transport rates along with the measured data. It was found that the Levi equation and Bagnold equation both fit the measured data quite closely, while the Parker equation appeared to seriously over-predict the loads. The Bagnold equation was subsequently used to estimate annual loads.

The equations predict that bed load transport occurs when the flows exceed 450 cfs, though the actual transport at low discharge is modest. Based on the Bagnold equation, the largest daily influx was estimated as 70,000 tons during the 1971 breakout flood, while annual yields range from 380,000 tons (1969) to 980,000 tons (2000). The average over the period of record was 685,000 tons/ year.

## 3.4 Morphologic Estimates

The 'morphologic approach' uses estimates of bank and island erosion quantities to estimate long-term volumetric sediment transport rates. The method was introduced by Neill (1971) and was subsequently used to estimate gravel bed load along a meandering bend of Tanana River, Alaska (Neill, 1984). Neill found that an estimate of local sediment transport could be made by measuring the rate of bank retreat, combined with an assumption of travel distance for the eroded material, estimated as one-half the downstream meander wavelength. The relation between bend erosion and sediment transport was expressed as:

$Q_b = L_e * h * de/dt$ where $Q_b$ is the volumetric transport rate, $L_e$ is the transport length, h is the bank height, and de/dt is the bank recession rate.

Carson and Griffiths (1989) modified the technique for the braided Waimakariri River, New Zealand using a mean travel distance approach. Planform changes including erosional and depositional areas for bars and banks were measured from sequential aerial photographs, and then converted to volumes using representative scour and fill depths from available cross-sections. Volumetric transport estimates were provided by assuming travel distances were equivalent to the average distance between major scour and fill zones. Ashmore and Church (1998) note that the technique is well suited to braided channels because of the difficulties of collecting direct samples of material in transit, and of developing functional estimates of bedload transport in rivers with complex, transient morphology.

This approach is limited by the time interval between available photography on the Matanuska River (1949, 1975, 1981 [2 dates], 1985 and 2000). Over long periods of time, intervening erosion and deposition that occurs between surveys can not be detected, and only a lower bound estimate of transport can be made. Reliable estimates are also affected by different flows on each date of mapping. A condition of low water on one date, and high water on a later date will result in interpretation of erroneously large erosion zones even if no sediment actually moved. All photo sets were taken in months with modest flows (except the August 1949 set) which minimize this problem.

The preliminary morphologic transport rate was calculated by determining the bulk volume stored within the reach in 1975, then calculating the percentage of that volume which was reworked by channel shifting over the following 25 years. Since the reach is not obviously aggrading or degrading, it is assumed that the volume evacuated (i.e. the turnover volume) is similar in magnitude to the volume that must have entered the reach past Old Glenn Highway Bridge. The stored volume in 1975 is calculated as the total area of bars and islands (58.77 million feet$^2$) multiplied by the reach-averaged thickness of bar deposits (10 feet), based on an average of 10 cross-sections extracted from the 2003 LiDAR data. Based on the mapped photo overlays, it is estimated that one-third of this volume was removed over 25 years, for an average annual bed material volume of 7,801,000 feet$^3$. Converting this volume to mass units yields an average annual sediment transport rate of 426,000 tons. This estimate agrees closely to the values determined from direct measurements and the predictions by the Levi equation and Bagnold equation.

## 3.5 Summary

Based on the available USGS measurements and predictions using bed-load equations and morphological methods, the following estimates of annual loads have been derived:

| | |
|---|---|
| total suspended load: | 6,650,000 tons/year |
| suspended sand load: | 1,630,000 tons/year |
| gravel bedload: | 420,000 tons/year (direct measurement) |
| gravel bedload: | 685,000 tons/year (Bagnold equation) |
| gravel bedload: | 426,000 tons/year (morphologic method) |

The agreement between the various methods for predicting the gravel bedload transport may be somewhat fortuitous. However, the results provide a reasonable degree of confidence that the long-term average gravel replenishment rate is in the order of 0.5 million tons/year. Furthermore, the year to year variation in gravel transport rates appears to be relatively small compared to many other gravel-bed rivers. This means the rate of infilling should also be relatively constant from year to year.

# 4. ALTERNATIVE BANK PROTECTION MEASURES

## 4.1 Past Bank Protection Work

A summary of bank protection works previously constructed on the Matanuska River has been compiled by the Matanuska-Susitna Borough, Alaska in the report "Matanuska River Erosion (2003). Following is an excerpt of those works found within the immediate study area.

1. *Dikes along Old Glenn Highway / Ye Old River Road.* A series of three dikes were constructed along the left bank of Matanuska river near Ye Old River Road. The first of these dikes, 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 built 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 to low-lying areas (which would increase flooding).

2. *Bank Protection at Old Glenn Highway Bridge*. Riprap bank protection has been placed in the area of the bridge just north of Palmer to protect the bridge approaches.

3. *Spur dikes at Circle View Estates*. In April 1992, the Matanuska-Sustina Borough initiated the construction of four finger dikes on the Matanuska left bank in the vicinity of Circle View Estates. These dikes were originally designed as a series of eight dikes but were cut back to four due to a lack of funding. The dikes are still in place and have provided some protection to properties in the Estates. A permit application in 1995 shows a plan that would add 6 additional spur dikes, bringing the total to 10 spur dikes.

4. *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 Bodenburg Butte. After the dike was broken during the 1971 flood, the dike was enlarged.

5. *Palmer Sewage Lagoon Bank Protection*. Under Section 14 of the Flood Control Act of 1946, emergency bank protection consisting of three rock-filled groins was placed in 1969 along the right bank of Matanuska River adjacent to the Palmer wastewater treatment lagoons. The project protects approximately 457 m of bank.

The location of these structures is shown in the 2003 erosion report (Figure 2). The condition of existing works and flood protection dikes will be briefly examined during an upcoming site visit.

## 4.2 Alternative Measures

Three preliminary structural alternatives have been identified for controlling future bank erosion and channel instability in the study reach. These include:

- Option 1: gravel removal only
- Option 2: combination of gravel removal with local bank protection
- Option 3: bank protection without gravel removal

Each option may be modified, depending on local issues and requirements and other economic and environmental factors. Requirements to avoid or mitigate potential impacts to fish habitat may be of critical importance in defining the measures that can be implemented. Therefore, it is important to integrate the fisheries and habitat issues into the planning process. Identifying and laying out these options represents a first step in the process.

### 4.3 Option 1: Gravel Removal Only

Wide, braided channel systems with a large gravel influx are naturally unstable. The multiple channels will continue to sweep across and fill (or partly fill) excavated reaches. This concept, therefore, needs to have an upstream gravel trap that reduces the gravel load downstream. This allows the excavated downstream channels to function as re-directed deep water channels until the upstream trap is filled. The trap should be located just downstream from the bridge and should be large enough to accommodate the accumulated total of several years of average annual inputs or the input from a single large gravel input (eg. 20 year flood). This will allow the re-directed channels to flow with a reduced gravel load that will induce the channel to degrade and widen until the upstream trap fills. There may also be some lag time between gravel trap filling and a re-establishment of the original gravel inflow to the re-directed channel.

The location of the proposed gravel pit trap is shown in Figure 8. Given a diameter of 1,150 feet excavated to a maximum depth of 16 feet with 2:1 side slopes, a total of 600,000 cubic yards would be removed. The total removal mass of roughly 890,000 tons represents two years worth of annual gravel influx. In addition, the gravel mining option would include several trench cuts designed to route flows through large bar deposits into the pit trap, and away from currently threatened banks at the downstream boundary of Reach 1, and in Reach 2 near Bodenburg Butte (Figure 8). Each trench cut would be 10 feet in depth (estimated as the mean thickness of the bed material deposits in the study area) and 500 feet wide (roughly the width of the current dominant channel) to re-route the main flow channel and maintain flow conveyance. Trenches would be variable in length as required to effectively re-align the channel. The three illustrated trenches have lengths of 2,500 feet, 3,300 feet and 6,500 feet respectively, and would have a total excavated volume of 2.2 million cubic yards, or 3.3 million tons. Maintenance of both the pit trap and trench channels would be necessary every two years on average to ensure their long-term effectiveness.

### 4.4 Option 2: Channel Excavation with Bank Protection

An alternative approach involves a combination of channel re-alignment and new bank protection to address the most serious erosion concerns along the left bank of Reach 1, and the right bank at the downstream boundary of Reach 1. This option includes the construction of 6 new spur dikes along the left bank of reach 1, three spur dykes along the left bank and a single short (1,000 foot) length of riprap bank protection along the right bank in the middle of Reach 1. The new bank protection structures should mitigate persistent lateral erosion at each location.

The location of proposed bank protection work is shown in Figure 9. The recommendation to build new spur dikes is based on the apparent effectiveness of the existing spurs constructed at Circle View Estates in 1992 for limiting bank erosion. As well, the dikes appear to have been built with sufficient integrity to maintain their effectiveness over the past decade (although it is not known what maintenance has been performed). The proposed spurs could be based on existing design specifications as given by PN&D (1995). The material required to construct the dikes could be derived from in-stream gravel sources such as the excavated trench (590,000 cubic yards) or smaller localized removals. The proposed 1995 dikes used 8,000 cubic yards for the main gravel embankments, while additional material to complete construction (i.e. Class A and B riprap) would be supplied from an outside source.

The middle 0.6 mile trench cut shown in Figure 8 would be retained to re-align flows through the narrow channel bend where the highest rates of historic erosion have been measured. Excavation of this trench should eliminate the requirement to build additional spur dykes near Circle View Estates and along the right bank at the downstream reach boundary (where the channel narrows northwest of Bodenburg Butte). This approach would also prove beneficial if the total removal volumes described above are not approved or are not feasible.

### 4.5 Option 3: Bank protection Without Gravel Removal

In the event that no gravel mining is permitted because of environmental regulations, fisheries concerns, or hydraulic ineffectiveness, additional bank protection structures will have to be constructed near the middle trench site to control local erosion (Figure 10). Given this option, all the bank protection works proposed in Reach 1 under Option 2 would be retained. New spurs would be required along the right bank at the downstream boundary of Reach 1, as this site has experienced considerable erosion in the past as flows are deflected across the channel away from the erosion resistant left bank. Construction of these spurs is expected, in turn, to partly deflect current towards Circle View Estates downstream. Therefore, 4 additional spurs are proposed along the left bank at Circle View Estates to protect this area. This bank protection should maintain the current channel alignment.

# 5 FURTHER WORK REQUIRED

The morphologic estimates do not yet include a comparison of the October, 1981 river conditions with the April 1981 conditions. It is known that braided rivers change quite rapidly, with active sediment exchange between bars occurring at time intervals far shorter that the multi-year comparison used in the calculations. As the time interval between survey dates increases, sediment that is moved through the system at shorter-term periods will be missed. Therefore, the morphologic estimates also represent a lower-bound estimate of the true transport rate. By comparing channel changes over the two mapping dates in 1981, this bias can be reduced.

The sketches of channel excavations and bank protection works are also provided without complete knowledge of local bank conditions. There are several locations along the channel where no bank erosion has been recorded over the past 50 years. Some of these sites appear to be bedrock controlled, but this can not be verified without field checking. Other sites that have not experienced significant erosion may have banks comprised of erosion-resistant materials, or may simply not have come under direct attack from flows. General bank conditions will be inspected during a site visit in June 2004.

It is important to integrate the fisheries and habitat assessments into the planning process to further refine the various erosion control concepts and options. These environmental studies will also help to determine additional requirements that will need to be included for mitigation/compensation and permitting approvals.

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# FIGURES


NOTES:

1) Background orthophoto dated May 9, 2000
2) Predicted bankline based on average yearly erosion rates and bank conditions
3) 2003 bankline interpretation based on LIDAR data analysis
4) Other bankline interpretations based on orthophoto analysis

FIGURE 1

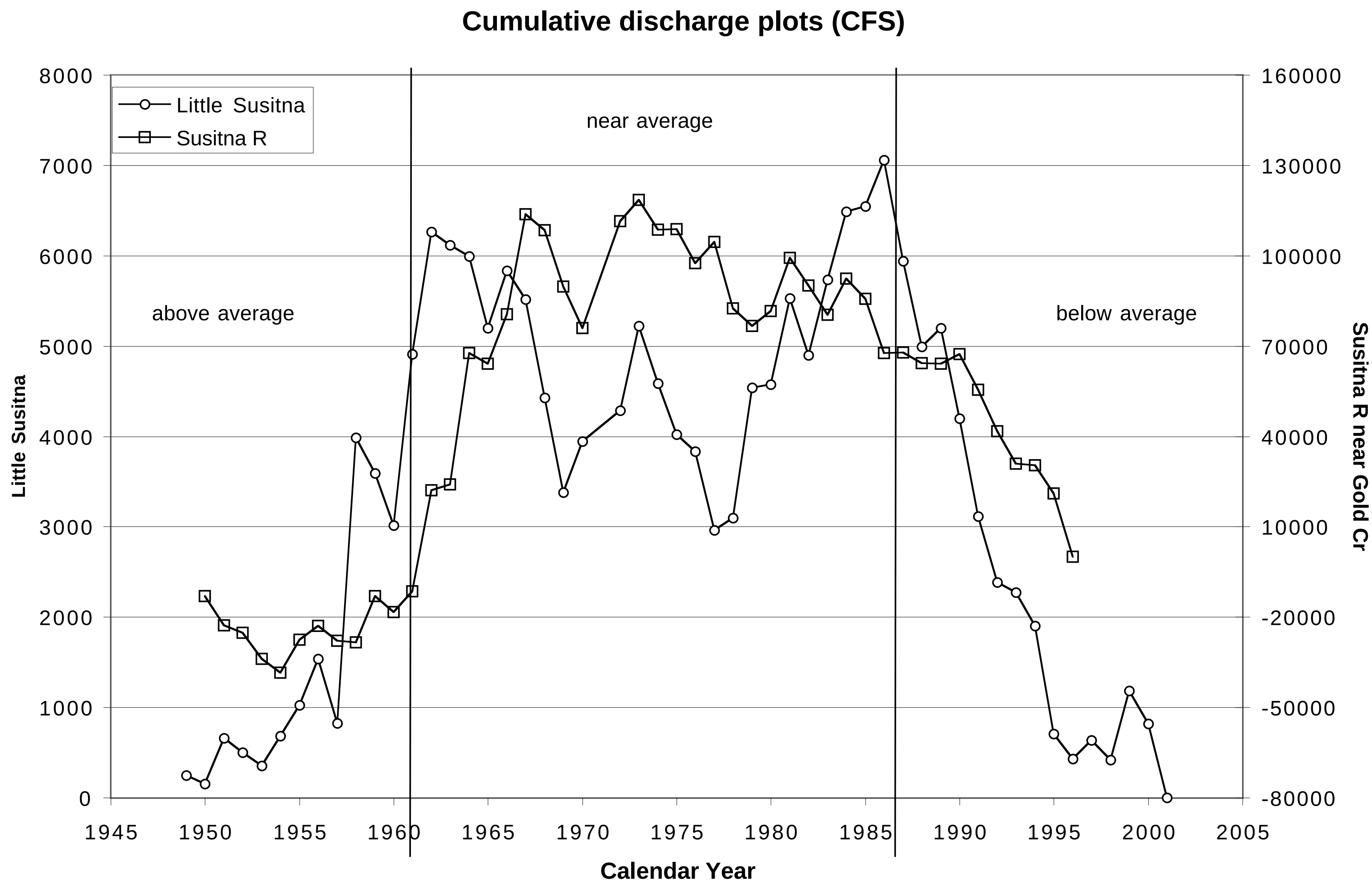
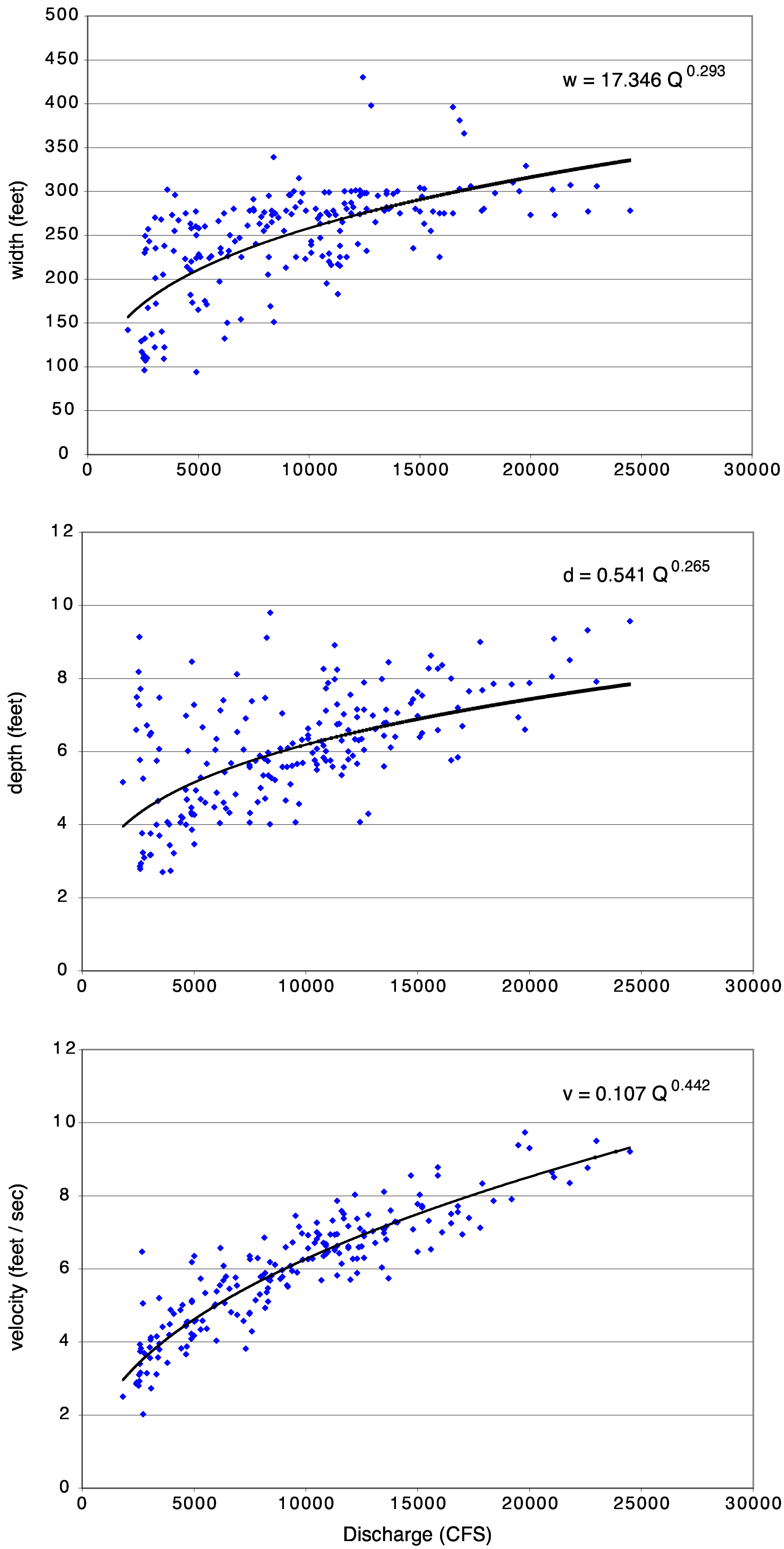
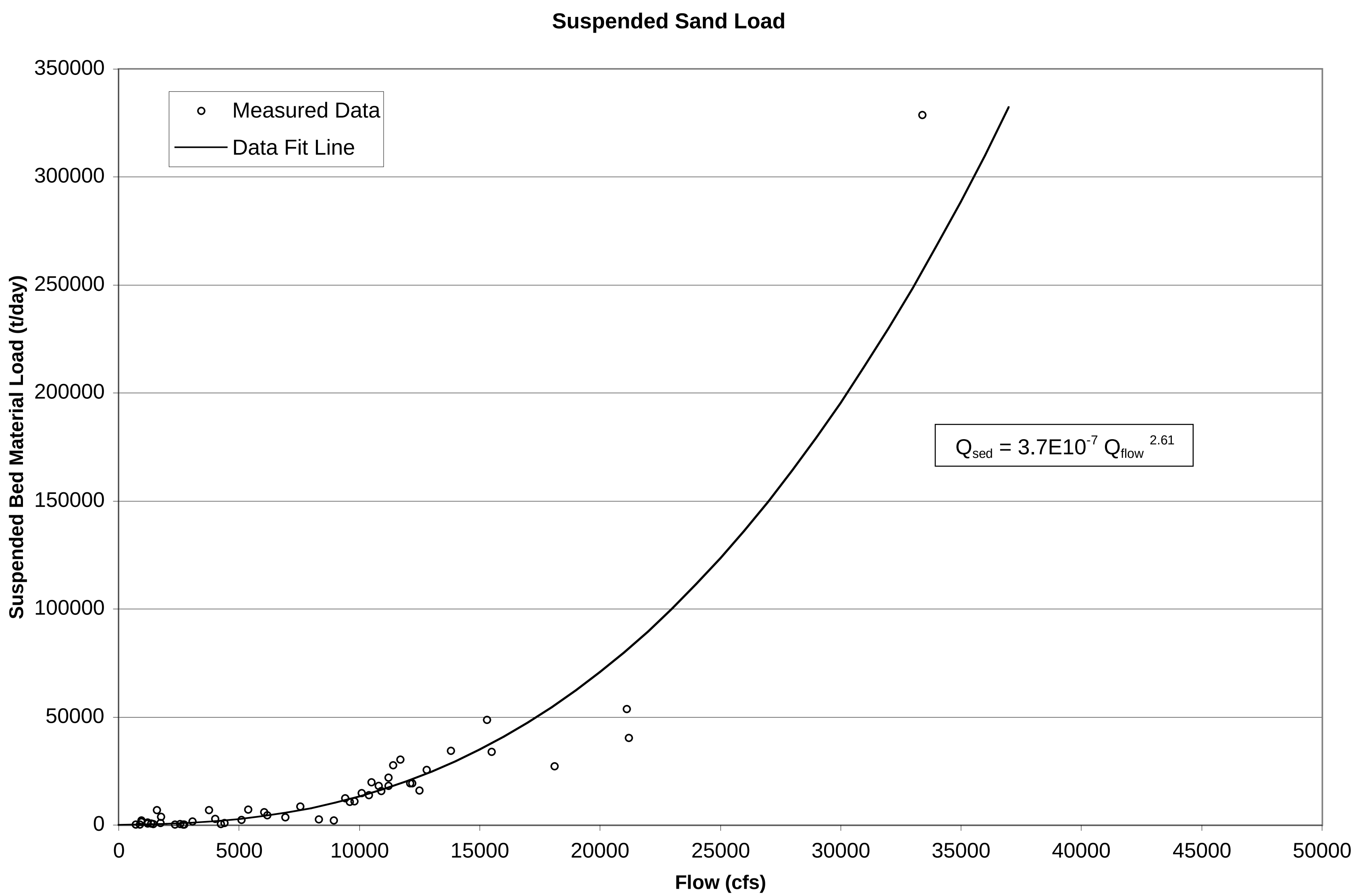

Cumulative discharge plots (CFS)
Little Susitna
Susitna R
near average
above average
below average
Little Susitna
Susitna R near Gold Cr
Calendar Year
8000
7000
6000
5000
4000
3000
2000
1000
0
160000
130000
100000
70000
40000
10000
-20000
-50000
-80000
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005

FIGURE 2



w = 17.346 Q 0.293
width (feet)
d = 0.541 Q 0.265
depth (feet)
v = 0.107 Q 0.442
velocity (feet / sec)
Discharge (CFS)


FIGURE 3



Suspended Sand Load
Measured Data
Data Fit Line
$Q_{sed} = 3.7E10^{-7}\ Q_{flow}^{\ 2.61}$
Suspended Bed Material Load (t/day)
350000
300000
250000
200000
150000
100000
50000
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
Flow (cfs)


FIGURE 4

Comparison of bed load and bed material size distribution

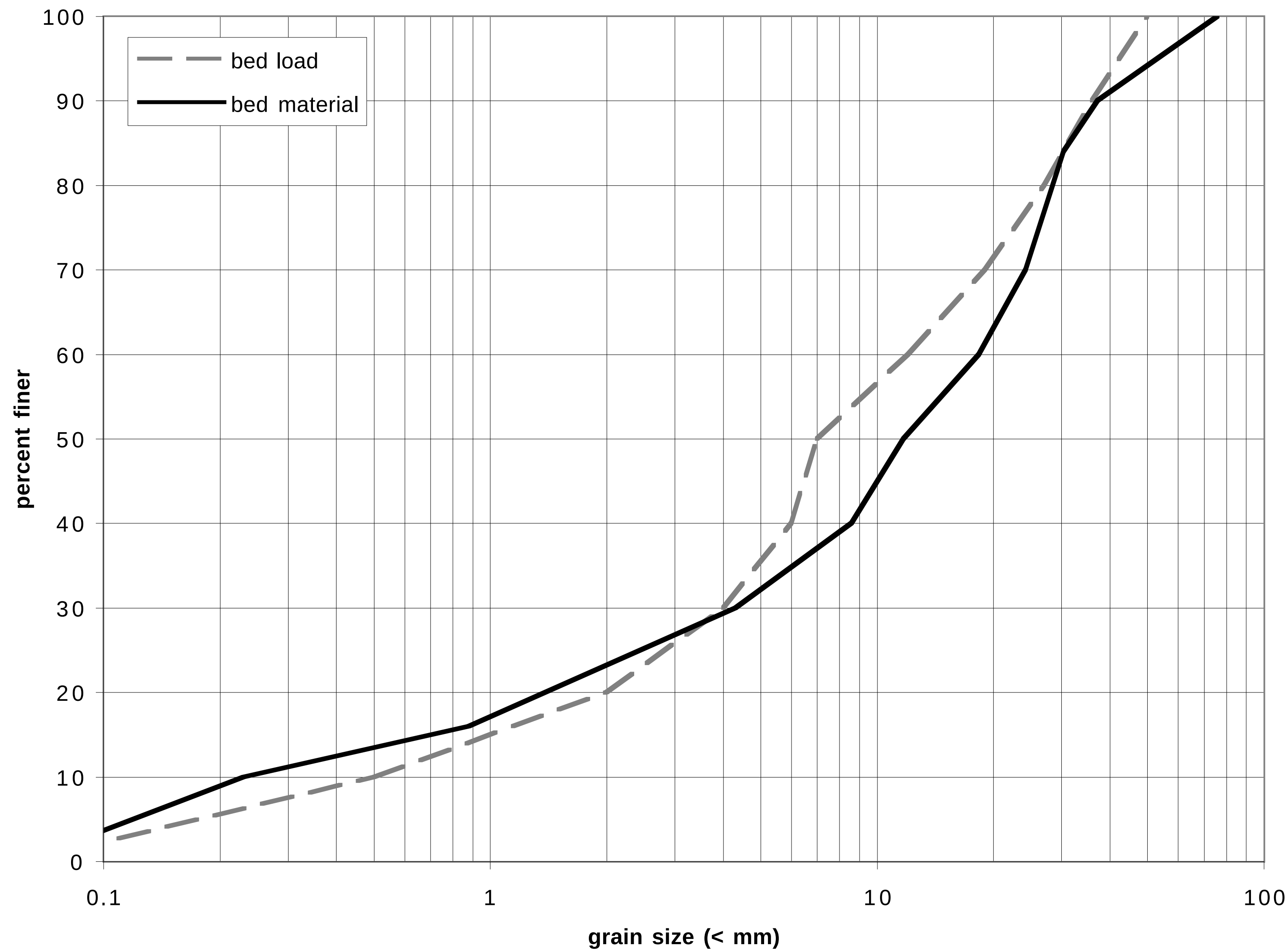
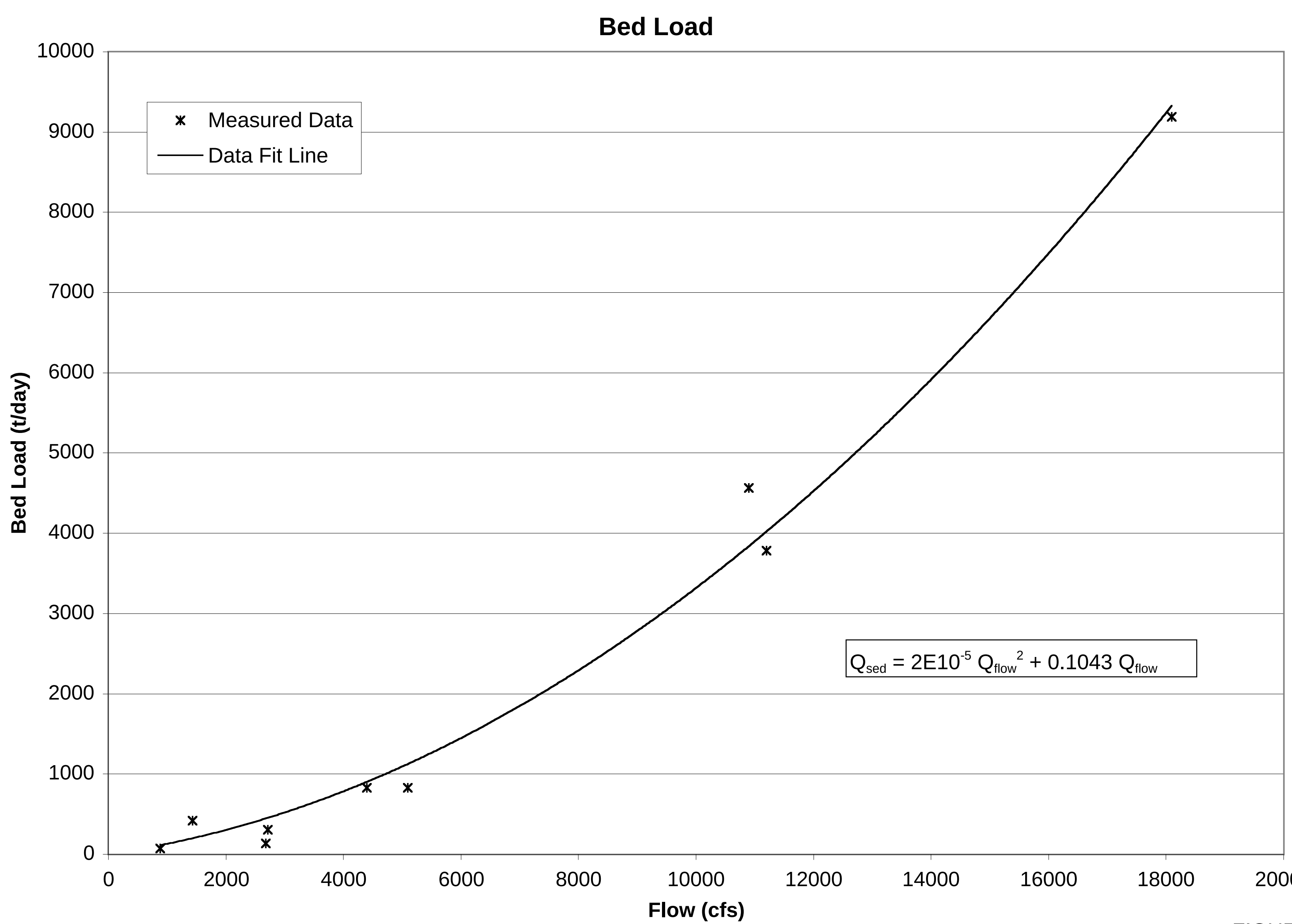
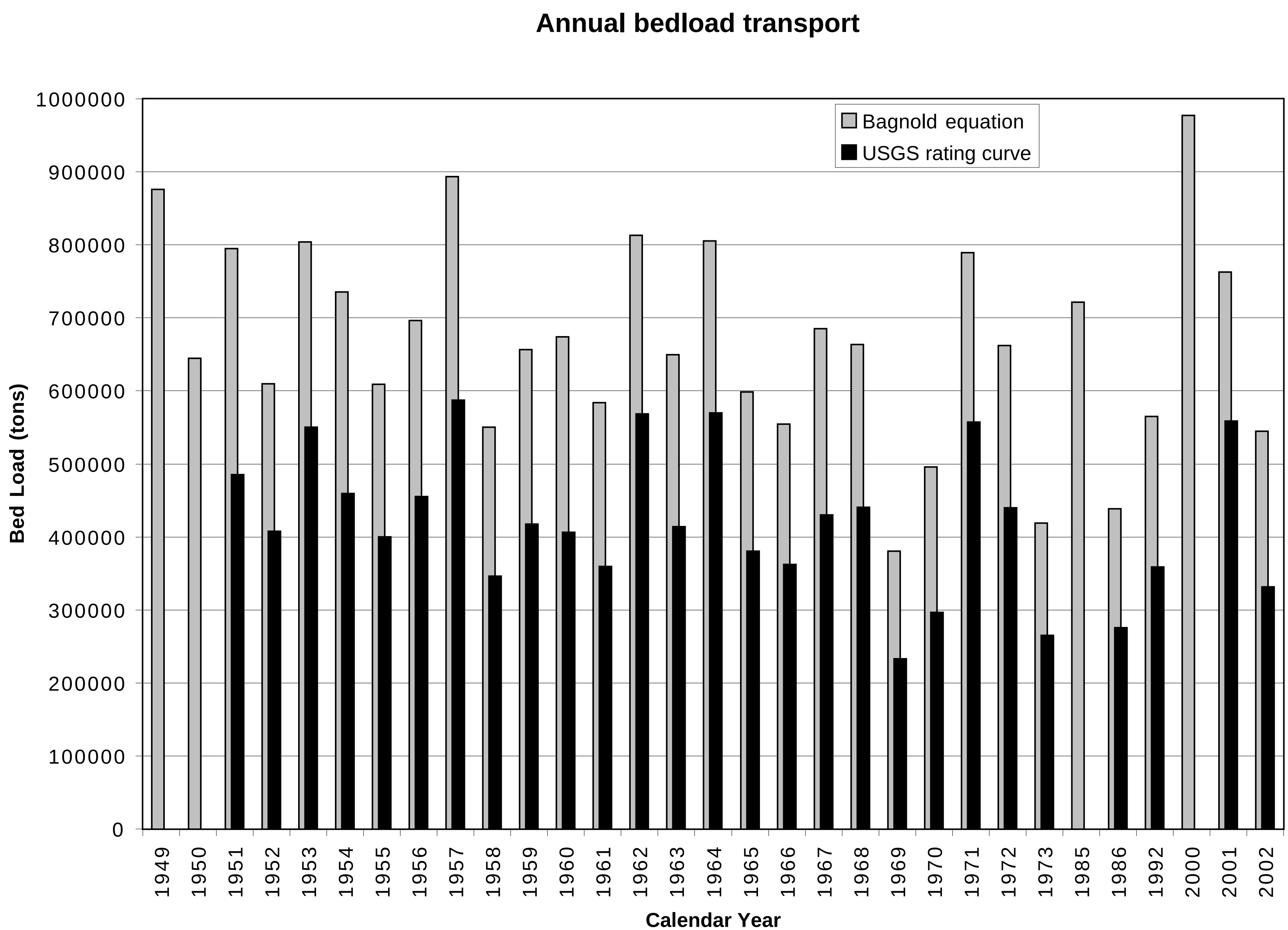



FIGURE 5



Bed Load
Measured Data
Data Fit Line
$Q_{sed}$ = 2E10$^{-5}$ $Q_{flow}^{2}$ + 0.1043 $Q_{flow}$
Bed Load (t/day)
Flow (cfs)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000


FIGURE 6



Annual bedload transport
Bagnold equation
USGS rating curve
Bed Load (tons)
1000000
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
1949
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1985
1986
1992
2000
2001
2002
Calendar Year


FIGURE 7

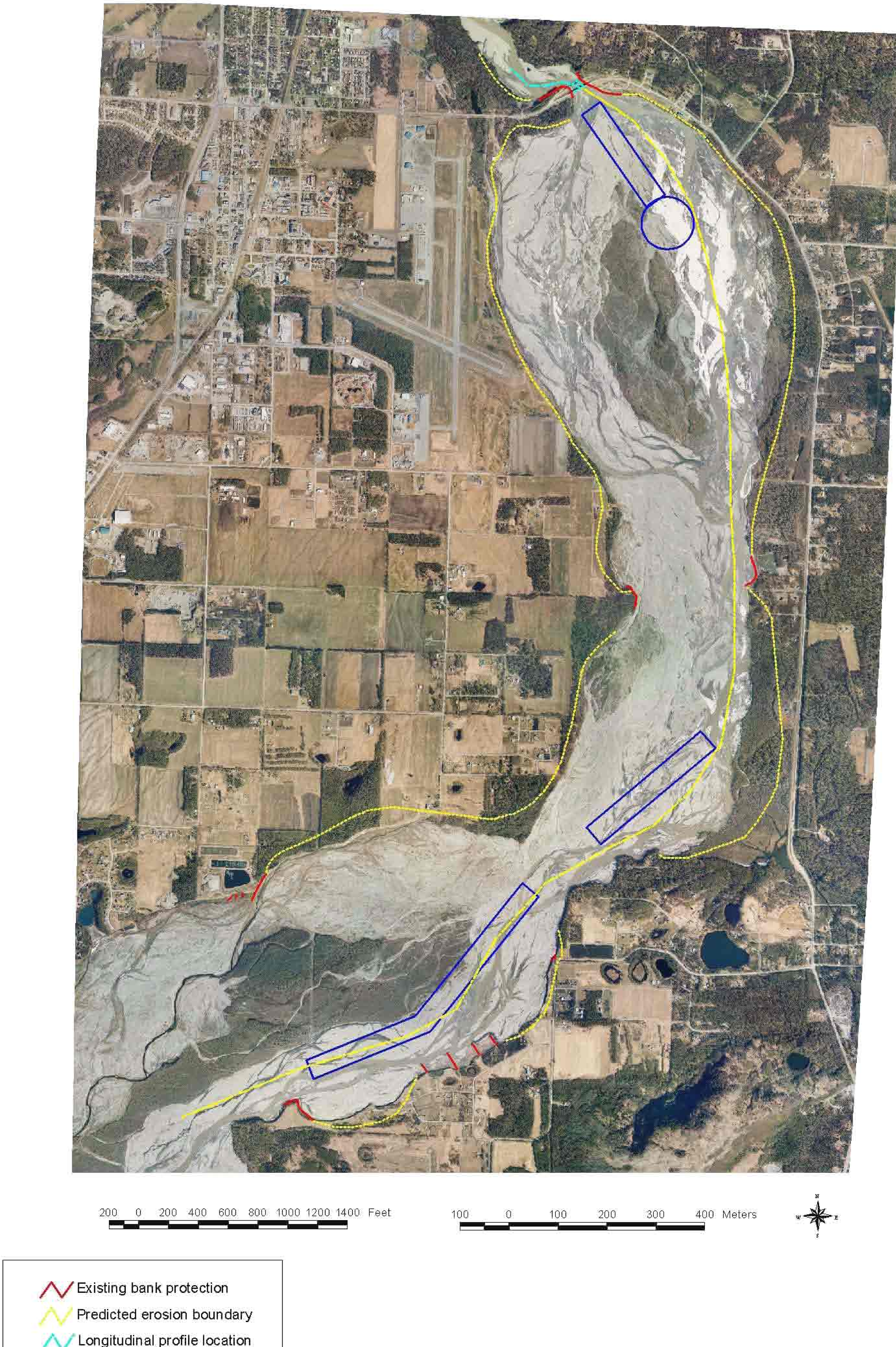
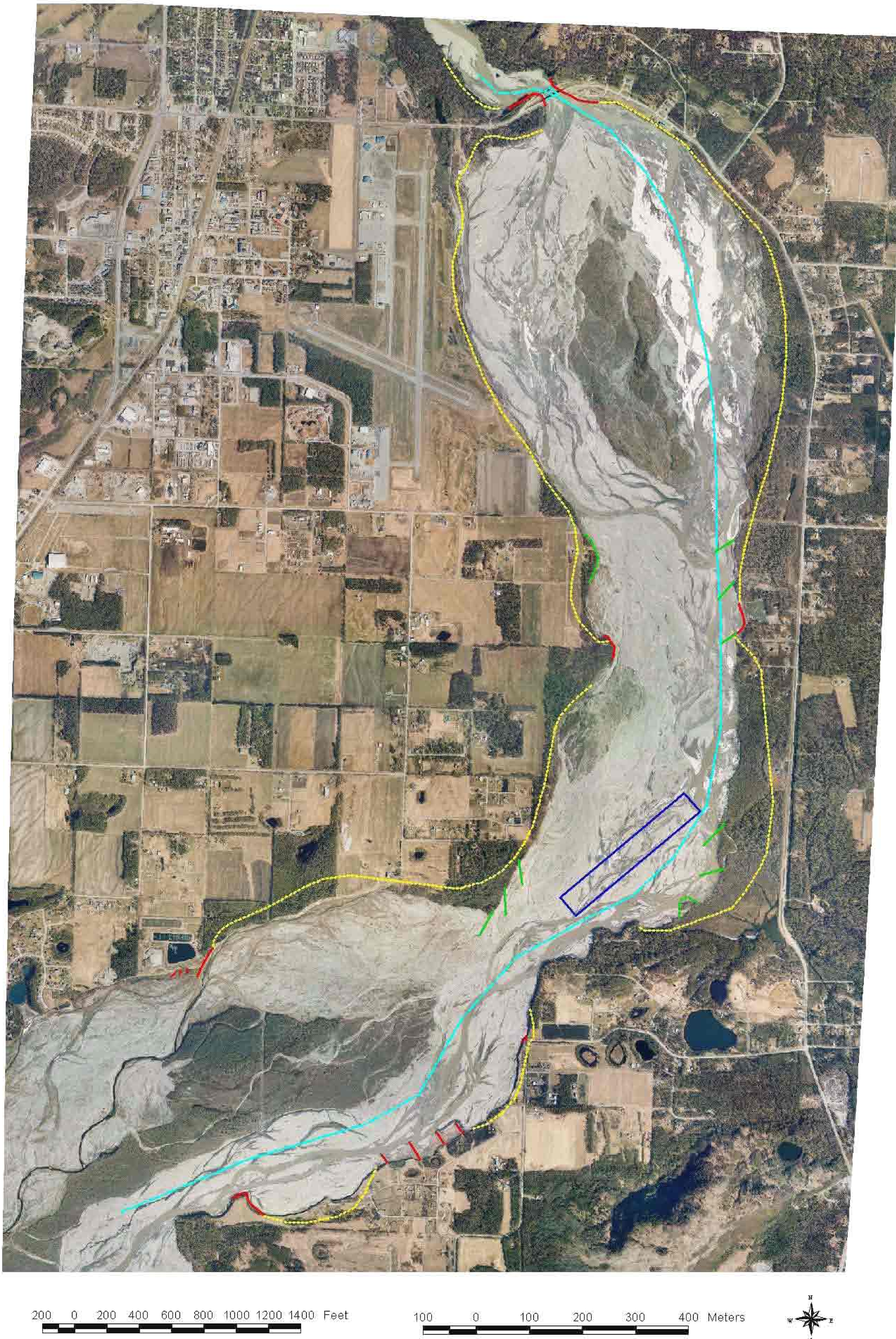



Figure 8
Option 1 - Gravel Removal




- Existing bank protection
- Predicted erosion boundary
- Longitudinal profile location
- Spur location
- Bank protection
- Trench cut location

Figure 9
Option 2 - Gravel Removal and Bank Protection


Figure 10
Option 3 - Bank Protection

**TECHNICAL MEMORANDUM**

| | | | |
|---|---|---|---|
| **To:** | File | **Date:** | October 26, 2004 |
| **From:** | Nick Smith | **Reference:** | 1851040.010107/6.1 |
| **Subject:** | **Matanuska River Erosion Project – Bank Stabilization Techniques** | | |

## OVERVIEW

This technical memorandum discusses general methods for stream bank stabilization and protection and analyzes each method for applicability to the Matanuska River from the Old Glenn Highway Bridge to just downstream of the Palmer sewage treatment plant. The analysis for each method will account for expected habitat effects, reliability of method, effectiveness on the Matanuska River, cost, expected construction effort needed, and permitting cost.

General erosion protection methods are listed in Table 1. Impractical methods were eliminated from further detail and review.

**Table 1 Bank Stabilization Techniques**

| Techniques | Detailed Further? | Comment |
|---|---|---|
| **Flow-Redirection Techniques** | | |
| Channel Relocation | Yes | |
| Groins (Spur Dikes) | Yes | |
| Buried Groins | Yes | |
| Barbs | Yes | |
| Porous (Rock Vane) Weirs | Yes | |
| Engineered Log Jams | No | Impractical for application as the river system is too large for this method. |
| Drop Structures | No | Impractical for application as material volumes may overwhelm the structure. |
| Retarder Field | No | Typically for light debris waterways |
| **Structural Techniques** | | |
| Riprap/Grouted Riprap | Yes | |
| Roughened-Rock Toes | Yes | |
| Log Cribwalls | Yes | |
| Bulkheads | Yes | |
| Log Toes | Yes | |
| Concrete Filled Mat | Yes | |

**Table 1 (cont.) Bank Stabilization Techniques**

| Techniques | Detailed Further? | Comment |
|---|---|---|
| **Flow-Redirection Techniques (cont.)** | | |
| Soil Reinforcement | Yes | |
| Gabions | No | Expensive, labor intensive and subject to scour failure |
| Sacked Concrete | No | Impractical for application due to high cost and labor required |
| Roughness Trees | No | Impractical for application due to high cost and labor required |
| Anchor Points | No | Impractical for application due to high cost and labor required |
| Heavy Timber Pile | No | Labor intensive and costly |
| **Biotechnical Techniques** | | |
| Woody Plantings | No | Impractical for application due to ineffectiveness as river bank is highly erodable. |
| Herbaceous Cover | No | Impractical for application due to ineffectiveness as river bank is highly erodable. |
| Coir Logs | No | Impractical for application as system may be too dynamic for this approach. |
| **Other Techniques** | | |
| Subsurface Drainage Systems | No | Impractical for application, flows and river system too large. |
| Floodplain Roughness | No | Impractical for application, due to dynamics of river system. |
| Floodplain Grade Control | No | Impractical for application, due to dynamics of river system. |
| Floodplain Flow Spreaders | No | Impractical for application, due to dynamics of river system. |

In the table below, these methods are broken into several factors for future feasibility evaluation. Each technique is described in further detail.

**Table 2 Expected Relative Factors for Erosion Control Techniques**

| Techniques | Expected Habitat Effects | Expected Matanuska River Effectiveness | Expected Cost | Expected Construction Effort Needed | Permitting Difficulty |
|---|---|---|---|---|---|
| **Flow-Redirection Techniques** | | | | | |
| Channel Relocation | Neutral | | High | Moderate/High | Moderate |
| Groins (Spur Dikes) | Negative | High | Moderate | Moderate/High | Moderate |
| Buried Groins | Negative | Moderate | Moderate | Moderate/High | Moderate |
| Barbs | Negative | Moderate | Moderate | Moderate/High | Moderate |
| Porous (Rock Vane) Weirs | Neutral/Positive | Low | Low | Moderate | Moderate |

**Table 2 (cont.) Expected Relative Factors for Erosion Control Techniques**

| Techniques | Expected Habitat Effects | Expected Matanuska River Effectiveness | Expected Cost | Expected Construction Effort Needed | Permitting Difficulty |
|---|---|---|---|---|---|
| **Structural Techniques** | | | | | |
| Riprap/Grouted Riprap | Negative/Neutral | Moderate | Moderate | Moderate | Low |
| Roughened-Rock Toes | Negative | Moderate | High | High | Low |
| Log Cribwalls | Negative | Moderate | High | High | Low |
| Bulkheads | Negative | Moderate | High | High | Moderate |
| Log Toes | Neutral | Low/Moderate | Moderate | Moderate | Low |
| Concrete Filled Mat | Negative | Moderate | High | High | Moderate |
| Soil Reinforcement | Negative/Neutral | Moderate | Moderate | Moderate | Low |

## FLOW REDIRECTION TECHNIQUES

### Channel Relocation (Trenching/Gravel Excavation)

Channel relocation changes the location of the channel while preserving or recreating other characteristics, such as overall channel profile, pattern, cross section, and bed elevation. The usual purpose of channel relocation is to move a channel away from an eroding bank. Relocation may also be used where a significant building or road is directly threatened by erosion. Channel relocation is often a means to solve problems of channel encroachment and/or confinement and to foster the development of a new, stable channel with healthy riparian buffers.

A channel can be entirely relocated to a new alignment, or just moved laterally within the existing alignment. One option is to deflect the flow laterally away from the hazard area using flow-realignment techniques. Flow-realignment techniques should only be used in situations where there is no concern about impact to the channel. Realignment techniques will change the meander shape locally and for some distance downstream, making appropriate site selection critical.

This is a broad method, which will be analyzed further in other, more detailed reports.

### Groins (Spur Dikes)

Groins, also called spur dikes, are large roughness elements that project into a channel from the bank and extend above the bankfull water-surface elevation. They are usually constructed in a series and act together hydraulically to provide continuous bankline roughness. Though commonly constructed of rock, groins can be built with large woody debris or pilings that collect debris. The main functions of groins are to redirect flow away from a streambank and to reduce flow velocities near the bank, which, in turn, encourages sediment deposition. As more sediment is deposited behind the groins, banks are further protected.

**Spur Dike on the Matanuska River**

Groins tend to induce scour near their tips, and scour holes are likely to form at those locations. Depending upon factors such as the angle of attack of flood flows and depositional patterns, eddies may form between groins, which may lead to scour along the bases of groins or adjacent streambanks. In general, however, deposition can be expected between groins that are properly designed and installed in an appropriate location.

Spur Dikes have been used within the Matanuska River area near Bodenburg Butte, as shown in the above figure. They appear to be withstanding the forces well and working as designed to protect the riverbank, although a recent analysis of the dike conditions has not been performed.

Barbs and groins are often mistaken for one another because they look similar, and both function to redirect flow. The primary difference between groins and barbs is that groins are higher-profile structures that tend to deepen the thalweg and narrow the stream, while barbs have less of an effect on the cross-sectional shape of the stream.

**Buried Groins**

There are situations where property and structures are not immediately in danger from streambank erosion, but are likely to become so in the near future. In such cases, setback alignments can be constructed to protect them. One type of setback alignment is called a buried groin (also called buried rock trenches, transverse dikes, or sills). Buried groins are structures embedded in the ground, inland from the eroding bank. If channel erosion reaches the buried groin, the groin will stop or reduce the rate of erosion from progressing farther toward the property or structure to be protected. Once exposed, buried groins redirect flow away from a streambank and reduce flow velocities near the bank to protect it from erosion forces. Buried groins become groins once they are exposed. Buried groins can also provide the benefit of a wider channel-migration corridor for continued, natural channel evolution.

Buried groins may work in the Matanuska River; however, they may be difficult to install due to property issues and may need to be evaluated further.

**Barbs**

Barbs, also called vanes or bendway weirs, are low-elevation structures that are projected into the channel from a bank and angled upstream to redirect flow away from the bank and to control erosion. Barbs function similarly to weirs in that flow spills over the barb toward the center of the channel, reducing the water velocity near the bank. Barbs also increase channel roughness, which dissipates energy, reduces channel-bed shear stress, and interrupts sediment transport. Barbs are typically constructed from rock, large woody debris, or a combination of both.

**Porous (Rock Vane) Weirs**

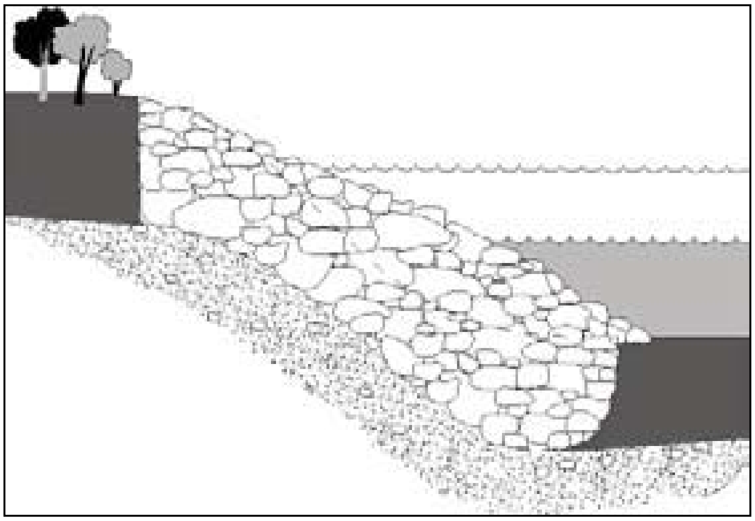
Porous weirs, also called rock vane weirs, are low-profile structures consisting of loosely arranged boulders that span the width of the channel. They are used to protect streambanks by redirecting the flow away from the bank and toward the center of the channel. This technique also provides energy dissipation and promotes increased sedimentation along streambanks.

Scour holes and pool habitat are created by flow passing through the openings in the weir structure, which, in turn, accommodates fish passage. This method is effective for smaller flow creeks, streams, and rivers.

Rock vane weirs would likely be ineffective in the Matanuska River system due to the rapid movement of the braided channels and high flows.

## STRUCTURAL TECHNIQUES

### Riprap/Grouted Riprap



Riprap, grouted or not grouted, is a type of bank armor consisting of rock, typically bedded upon a filter layer of gravel or synthetic filter fabric, with an excavated toe or launchable toe. Historically, riprap has been the most extensively used method for controlling bank erosion in the United States. Recently, however, concerns over the poor aquatic-habitat value of riprap and local and cumulative effects of riprap use on river morphology, have made the application of riprap controversial. For these reasons, riprap revetments are recommended only where bank failure would have intolerable consequences, or where site conditions are extreme. Extreme site conditions might include high erodibility, high shear stress, or mass-failure conditions. Grouted riprap can add additional effectiveness; however, costs may be a limiting factor.

Riprap may be an alternative for protection of the Matanuska River bank.

### Roughened-Rock Toes

Roughened-rock toes are structural features that prevent erosion at the toe of a streambank. The toe is where a streambank is most vulnerable because that is where the erosional forces are greatest. When roughened-rock toes are properly installed, they can withstand these forces and provide the foundation for upper-bank biotechnical treatments, such as reinforced soil lifts or vegetative plantings. Smooth-rock toes alone generally provide little habitat complexity or cover. Roughened-rock toes, by definition, are designed with angular components, which provide greater roughness. Large woody debris may be incorporated into roughened-rock toes as a habitat feature and to provide additional roughness. Roughened-rock toes extend from the maximum predicted depth of scour to the lower limit of vegetation – the point of elevation on the bank where plant growth cannot be expected to hold the soil together. A roughened-rock toe can be created by launching material from the bank during scour events, which ultimately provides the toe with protection to the depth of scour.

This method has potential to protect the Matanuska River bank.

**Log Cribwalls**

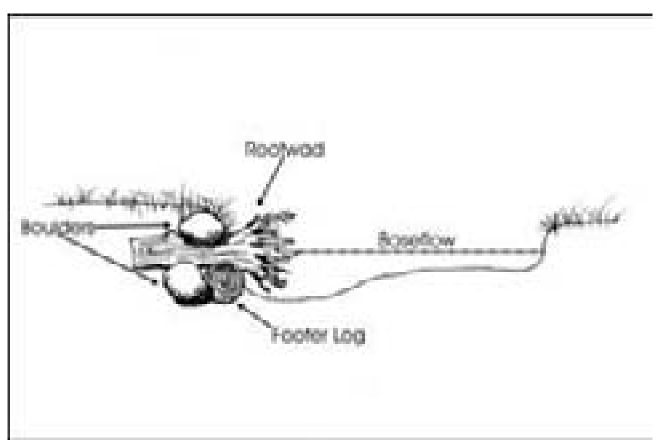
Gravity retaining walls can be useful in stabilizing streambanks. One type of gravity retaining wall is built by constructing an elongated box out of logs and backfilling the box with soils and rock. Such retaining walls are referred to as "log cribwalls." The log box is positioned with its long sides running parallel with the channel centerline and its shorter sides perpendicular to the channel centerline. The long, parallel logs are referred to as "stretchers;" and the short, perpendicular logs are called "headers." Stretchers and headers are stacked alternately to create the cribwall. Once the log cribwall is backfilled, the gaps between the successive layers of logs can serve as planting sites to create a living cribwall.

Log Cribwalls are typically used for smaller applications, but may have some effectiveness on a river such as the Matanuska.

**Bulkheads**

A bulkhead is a steep or vertical wall to support the effected area. Bulkheads systems can be used to stabilize channel banks and beds by interrupting or changing the hydraulics of the water column. There are several typical design solutions such as sheet piling or standard concrete bulkheads. This solution can be expensive due to design, labor, and material expenses.

**Log Toes (Rootwad)**




Log toes, also called rootwad, are structural features that prevent erosion at the toe of a streambank. The toe refers to that portion of the streambank that extends from the channel bottom up to the lower limit of vegetation or to a distinct break in slope between the top of the bank and the streambed. Log toes can provide the foundation for nonrock, nonstructural, upper-bank treatments such as reinforced soil or resloped banks. Log toes are generally constructed of logs and gravel fill between logs, but may also include components made of large woody debris to provide additional habitat value. Log toes may also incorporate rock material to provide added protection. Log toes differ from log cribwalls in two primary ways:

1. Log toes are not structural retaining walls, and
2. The top elevation of log toes does not exceed the lower limit of vegetation on the bank.

Log toes are installed parallel to and at the toe of a streambank, often extending under a reconstructed bank to provide protection against erosion where erosional forces are the greatest – at the toe of the streambank. Log toes can be implemented either as a stand-alone streambank-protection technique, or as the toe element for other streambank-protection techniques. Log and rootwad toes represent a more natural approach to toe protection. They may provide greater habitat value than rock for all life phases of fish and other aquatic organisms. In addition, woody toe protection will deteriorate as native vegetation matures and begins to provide support and structure to the banks – an important goal of integrated streambank protection.

This method does not appear to be effective in a river system as large and dynamic as the Matanuska River. Undercutting of the log toes is a risk to this type of protection. This application is typical for smaller waterways which are more stable.

**Concrete Filled Mat**

The concrete filled mat utilizes a double layered nylon fabric specially woven for optimum strength, stability, adhesion, and filtering characteristics. A highly fluid, fine aggregate concrete (sand/cement grout) is pumped into this fabric envelope after is has been placed on the slope to be protected. Revetments can be cast above or below water.

**Concrete filled Mat**

This method can be effective in bank protection, but can be very costly and does not allow for vegetation growth.

**Soil Reinforcement**

Soil reinforcement refers to a system of soil layers or lifts encapsulated or otherwise reinforced with a combination of natural or synthetic materials and vegetation. Most often, the lifts are oriented along the face of a bank in a series of stepped terraces. When used with degradable fabrics, the fabric will provide one- to four-year erosion protection, giving installed vegetation the time it needs to become well established for long-term bank stabilization. In situations where increased fabric strength and longevity are needed, synthetic fabrics can be used to provide both short- and long-term structural integrity. Nearly all applications of this approach are integrated with toe protection below the lower limit of vegetation. These systems are also known as fabric-encapsulated soil, fabric-wrapped soil, soil burritos, vegetated geogrids, or soil pillows. This technique is included in the structural, but it could also be considered a structural measure when designed with geotechnical components. Soil reinforcement is included among biotechnical measures because of the short lifespan of some fabric components and the importance of long-term vegetative reinforcement.

This method may offer some bank protection; however, it is labor intensive and may not be practical along a long stretch of river bank.

## SUMMARY

Recommending a method or combination of methods to protect the banks of the Matanuska River is complex and cannot be conclusively made until additional information is gathered. This memorandum provides a summary of methods that may be practical for the Matanuska River. The decision as to which method(s) to use will be made using a combination of variables for future decision-makers. These variables may include, but not be limited to, locations of needed erosion protection, funds available, property rights issues, permitting issues, aesthetics, and effectiveness of chosen method. Methods that have been determined to have potential to protect the banks along the Matanuska River include:

- Channel Relocation (analyzed in other reports and modeling)
- Groins (Spur Dikes)
- Buried Groins
- Barbs
- Riprap/Grouted Riprap
- Roughened Rock Toes
- Log Cribwalls
- Bulkheads
- Soil Reinforcement

Each of these methods will require further analysis once conclusions from the river modeling analyses have been performed. These analyses should include costing, effectiveness, property issues, aesthetic qualities, and constructability of the various protection methods.

Sources for the bank stabilization methods include:


- U.S. Army Corps of Engineers (USACE). 1991. Erosion Control of the Matanuska River near Bodenburg Butte
- Washington Department of Fish and Wildlife. Integrated Streambank Protection Guidelines**,** Chapter 6. http://www.wdfw.wa.gov/hab/ahg/ispgdoc.htm


Nick Smith
Engineer

# APPENDIX G

*Permitting, Regulatory, and Environmental Constraints*

# TECHNICAL MEMORANDUM

MWH

**To:** File **Date:** August 25, 2004

**From:** Kris Ivarson **Reference:** 1851040.010107

**Subject:** **Matanuska River Erosion Project – Permitting, Regulatory, and Environmental Constraints**

## PERMITTING, REGULATORY, AND ENVIRONMENTAL CONSTRAINTS

In-stream measures are proposed in the Alternatives for Erosion Control on the Matanuska River. Under current regulations and guidelines, various permits and operational constraints are required for operation of equipment within a stream or stream bed. These permitting, regulatory, and environmental constraints affect the institutional feasibility of the alternatives for providing erosion control along the Matanuska River. The permitting process includes obtaining federal, state, and some local permits and following a specific process. These vary from between agencies, but will affect the timing of work and the potential for specific alternatives to be accomplished.

Permits for conducting in-stream work along the Matanuska River fall into several broad categories. For the purpose of this technical memorandum, the permitting concerns are organized by those which are major concerns during planning and operation versus those that would likely have less significant impact on a project. A summary of common permits that would be required for an activity involving gravel extraction and/or bank protection along the study reach is presented below. This summary is not intended to cover all possible permits or situations. Any specific activity may trigger the need for permits and/or raise concerns not addressed.

### Anticipated Primary Considerations:

- Clean Water Act (CWA) Section 404 Permit (U.S. Army Corp of Engineers [USACE]).

  A Section 404 Permit is required for actions involving the excavation or discharges of dredged or fill material in "navigable waters." Under regulatory definition, "navigable waters" typically includes all waterways and wetlands. Part A of Section 404 specifies the authority for issuing permits. Part C of Section 404 extends the authority to fishery areas including spawning and breeding areas. To obtain this permit the applicant must provide the following information:

  - Project location with directions.
  - Nature of proposed activity including dimensions of structures, design of project, construction materials, method of work; and extraction amount proposed.

- Reason for discharge of fill materials.
- Surface area (in acres) to be affected.
- List of adjoining property owners.
- List of other applications that have been submitted.
- Illustrations with a site vicinity map, a plan view map, and a cross section map.

Following filing of the completed permit, the USACE then has 15 days to publish a public notice of the proposed action. The public must have the opportunity for public hearings, with an unspecified public comment period. In addition, other government agencies may be asked to provide comment, including the U.S. Fish and Wildlife Service (USFWS). Agencies have 120 days to provide comments.

- Formal Consultation (National Marine Fisheries Service [NMFS])

  The NMFS, a division of the National Oceanographic and Atmospheric Administration (NOAA) provides the USACE opinions of the proposed issuance of permits under Section 10 of the Rivers and Harbors Act and Section 404 of the Clean Water Act. The consultation is conducted by the USACE with all information provided through the Section 404 Permit.

- National Pollutant Discharge Elimination System (NPDES) Construction General Permit (CGP) for Discharge of Stormwater from Construction Activities (U.S. Environmental Protection Agency [EPA])

  An NPDES permit will be required if there is de-watering or discharge, etc., during the construction and operations stage of a project, in compliance with the CWA. Permit coverage is required from the "commencement of construction activities" until "final stabilization." The permit includes requirements for a notification of intent to construct, stormwater pollution prevention plan (SWPPP) development and implementation, Endangered Species Act review procedures, management activities, reporting, monitoring, operations and maintenance, and notice of termination of activities.

- Endangered Species Act (EPA and U.S. Fish and Wildlife Service [USFWS])

  The EPA must conduct a Section 7 consultation with the USFWS regarding any threatened or endangered species that might be affected by the proposed project. The level of required informal or formal consultation will depend on whether listed species occur in the project area, and, if so, whether they likely will be affected by the proposed project. If listed species occur in the area and they likely will be affected, then the EPA and USFWS will undergo the formal consultation process. This is typically an involved process that results in measures designed to minimize the impact of the project on listed species.

  The USFWS also provides technical expertise and makes comments and recommendations to federal agencies via the Fish and Wildlife Coordination Act (16 United States Code 661 et. Seq.).

- Title 41 Fish Habitat Permit Application (Alaska Department of Natural Resources [ADNR] Office of Habitat Management and Permitting [OHMP])

  Alaska Statute 41.14.840 (Fishways Act) requires that authorization is obtained from ADNR for activities within or across a stream used by fish if the department determines that such activities could represent an impediment to the efficient passage of fish. ADNR approval is required for the placement or removal of any material or structure below ordinary high water.

Alaska Statute 41.14.870 (Anadromous Fish Act) requires that an individual or governmental agency provide prior notification and obtain approval from ADNR "to construct a hydraulic project or use, divert, obstruct, pollute, or change the natural flow or bed" of a specified anadromous waterbody. The Statute also requires approval "to use wheeled, tracked, or excavating equipment or log-dragging equipment in the bed" of a specified anadromous waterbody. All activities within or across a specified anadromous waterbody, and all instream activities affecting a specified anadromous waterbody require approval from the ADNR. These activities including construction; road crossings; gravel removal; placer mining; water withdrawals; the use of vehicles or equipment in the waterway; stream realignment or diversion; bank stabilization; blasting; and the placement, excavation, deposition, disposal, or removal of any material.

The permit application must include the type of project, location, timing of operations, description of construction methods, a site rehabilitation and restoration plan, the waterbody characteristics and a hydraulic evaluation. The description of the project and proposed construction methods should include a description of the alternatives considered. In addition, detailed project plans need to be included that describe the protective measures, equipment to be used and the extent of the project work.

- Alaska Coastal Management Program Consistency Determination (ADNR Office of Project Management and Permitting [OPMP] Alaska Coastal Management Program [ACMP])

  The federal Coastal Zone Management Act of 1972 was established to promote the orderly development and protection of coastal resources. In response to the federal legislation, the State of Alaska established the Alaska Coastal Management Plan (ACMP). The ACMP requires that projects in Alaska's coastal zone be reviewed by coastal resource management professionals and found consistent with the statewide standards of the ACMP. These standards and the enforceable policies of an affected coastal district ensure that development interests observe the vision set out for the future by the state and coastal communities. Using the statewide standards (6 Alaska Administrative Code [AAC] 80) and local enforceable policies, the ACMP evaluates the effects a project will have on the coastal resources and uses.

  In addition to the federal and state requirements, the Matanuska-Susitna Borough has developed the Matanuska-Susitna Borough Coastal Zone Management Program. Due to regulation at various levels of government, the coastal zone is managed at each of the levels of government. The ACMP at the state level, however, consolidates several of these authorities and directs the permitee to the appropriate authority for review of an operation plan.

  The Consistency Review process steps are outlined as follows:

  - The applicant completes the Coastal Project Questionnaire.
  - A determination is made by the State regarding the applicability of the consistency determination to the project.

- A determination is made regarding the completeness of the application. The ACMP has 21 days to make this determination.
- The scope of the project is reviewed. This is limited to activities of the project that are subject to ADNR or ADF&G authorization, or federal consistency determination.
- Public notice is prepared and submitted.
- 30 day comment period
- The applicant distributes and considers comments, then works to resolve issues that are identified.
- The ACMP issues a proposed determination and the applicant is allowed to make revisions as needed, and otherwise respond to the agency. This may include an elevation of the process to the commissioner of the ADNR.
- The final determination is made within 90 days.

• Compliance with Section 106 of the National Historic Preservation Act of 1966, as amended, and its implementing regulations at 36 CFR 800 and AS 41.35 (Office of History and Archeology [OHA], ADNR)

Section 106 of the National Historic Preservation Act requires review of any project funded, licensed, permitted, or assisted by the federal government for impact on significant historic properties. Both federal and state authorities regulate this section. The agencies must allow the State Historic Preservation Officer and the Advisory Council on Historic Preservation, 15 days for comment on a project. The Alaska Historic Preservation Act contains a provision similar to Section 106 which mandates that any project with state involvement be reviewed in a similar manner.

The OHA will provide information on the location of sites and on cultural resources surveys previously done in an area. If the potential to discover unknown sites is high, a survey may be recommended. When there are sites in a project area, OHA consults with the agency on National Register eligibility, on how the project will affect sites, and on ways to lessen unavoidable damage.

## NATIONAL ENVIRONMENTAL POLICY ACT (NEPA) OF 1969

NEPA requires federal agencies to integrate environmental values into their decision-making processes by considering the environmental impacts of their proposed actions and reasonable alternatives to those actions. The “NEPA process” must be followed when a Federal Agency proposes a management activity and/or provided funding to an activity. This process outlines specific procedures for determining the potential effects and mitigation measures for an action.

To meet this requirement, federal agencies prepare a detailed statement. This can be either an Environmental Assessment, for small projects, or an Environmental Impact Statement (EIS). Both statements require public scoping, interdisciplinary input, public comment, and specific timing.

NEPA documents, such as an EIS, include a detailed analysis of the potential effects on different parts of the environment. This is in addition to analysis of economics and the human environment. The EIS "shall provide full and fair discussion of significant environmental impacts and shall inform decision makers and the public of the reasonable alternatives which would avoid or minimize adverse impacts or enhance the quality of the human environment" (Council on Environmental Quality [CEQ] Regulations Sec. 1502.1). The EIS must "rigorously explore and objectively evaluate all reasonable alternatives, and for alternatives which were eliminated from detailed study, briefly discuss the reasons for their having been eliminated" (CEQ Regulations Sec. 1502.14(a)). The EIS "shall serve as the means of assessing the environmental impact of proposed agency actions, rather than justifying decisions already made" (CEQ Regulations Sec. 1502.2(g)). The EIS should "devote substantial treatment to each alternative considered in detail including the proposed action so that reviewers may evaluate their comparative merits."

The standard format is as follows:

- Cover sheet
- Summary
- Table of contents.
- Purpose of and need for action
- Alternatives including proposed action
- Affected environment
- Environmental consequences
- List of preparers
- List of Agencies, Organizations, and persons to whom copies of the statement are sent
- Index
- Appendices (if any).

**Known Fisheries Issues:**

- Identify anadromous fish of concern. Matanuska River contains habitats suitable for all five species of pacific salmon as well as rainbow trout and dolly varden char.
- ADF&G may require the Applicant to demonstrate no impact to fish or fish habitat.
- NOAA Fisheries National Gravel Extraction Policy states that “gravel extraction should not be allowed within, upstream, or downstream of anadromous fish spawning grounds,” it also indicates that individual operations must be judged from a watershed management perspective.
- ADNR requires plans to be submitted and approved for any activity below the ordinary high water level and may limit work to specific time periods.
- ADNR may require a survey of the river to describe habitat use by fish in affected reach.
- Matanuska Susitna Borough’s Coastal Zone Management Program Enforceable and Administrative Policies.

The General Policies prohibit the dredging and filling of tide flats, wetlands, submerged land and water bodies important to migration, spawning, and/or rearing of anadromous and resident fish unless no reasonable and prudent alternative exists. The discharge of any dredged material into water must comply with standards in Parts 320-33-, Title 33, CFR Vol. 47, No. 141, July 22

1982. Policies specific for gravel mining will allow gravel extraction within the floodplain if no reasonable or prudent alternative to coastal extraction exists. These polices also require that the operation is conducted such that there is no significant adverse impact to fish productivity and that impacts to fish and wildlife habitats are minimized.

**Secondary Considerations:**

- Spill Prevention Control and Countermeasure (SPCC) Plan (EPA)

  For operations where storage of 1200 gallons or more of fuel is planned, a SPCC plan for fuel storage will be required under Section 40, Part 112 of the Code of Federal Regulations (40 CFR 112). Different sections of the SPCC rule apply depending on the type of facility and operation being conducted. Construction is regulated under this rule. The SPCC plan must outline procedures for oil storage, oil containment and handling, spill prevention, corrosion prevention, training, inspections and reporting, among others.

- Notice of Proposed Construction or Alteration, Form 7460-1 (Federal Aviation Administration [FAA])

  To comply with 14 CFR 77 pursuant to 49 United States Code (USC) Section 44718, the FAA Form 7460-1 must be filed for every construction project ranging from grading terrain to erecting of buildings or towers within 5 miles of an active airport. The study reach is within five miles of the Palmer Airport. The notification must be submitted 30 days prior to the proposed start of construction. The applicant must provide information on the location, duration, work schedule, lighting or marking of the site, the overall height of any structure, site elevation, nearest public use airport, direction and distance to that airport. A complete description of the proposed work must be included, with an attached U.S. Geological Survey (USGS) 7.5-minute quadrangle map marked with the precise site location and any certified survey.

- State Water Quality Certification – for compliance with Clean Water Act (CWA) Section 401 (Alaska Department of Environmental Conservation [ADEC])

  Pursuant to Section 401 of the CWA, the State of Alaska certifies permits issued by the EPA under the NPDES program. Known as a Section 401 Certification, the state is required to make the determination that the state water quality standards will not be violated by the issuance of the subject permit. As per 18 AAC 72.600, engineering plans should be submitted to ADEC for review and approval. To obtain a "letter of non-objection" an applicant must submit:

  1. Short project description containing information of:
     a. Project name
     b. Contact name, address, phone and fax numbers and e-mail address
     c. Project area (total and "soil disturbed")
     d. Receiving water body and estimated distance from the project site
     e. Methods of runoff flow and treatment (down to the discharge point)
     f. Treatment system's maintenance procedures
     g. Snow storage/disposal

2. Runoff flow calculation based on 2 years 6 hours rain event (before and after project is completed)
3. Treatment system sizing estimation (e.g. swale: length, cross section, bank and longitudinal slopes, flow velocity, detention time etc.)
4. One set of drainage plans clearly showing drainage boundaries and flow directions (please highlight them with a marker if your plans do not identify drainage boundaries and/or flow direction)
5. All engineering design and calculations will need to be stamped by Alaska licensed engineer as required by 18 AAC 72.600 and 18 AAC 72.990.(29).
6. Check payable to State of Alaska - DEC in amount determined by 18 AAC 72.955 Table D Plan Review Fees (5)(A)

- Storm Water Pollution Prevention Plan (SWPPP [ADEC])

  A SWPPP is required as a major component of the EPA NPDES permitting process, for compliance with the CWA, and must be prepared prior to submission of a Notice of Intent (NOI) to conduct construction activities. The SWPPP must be developed for each construction project covered by the Construction General Permit (CGP) issued by EPA during the NPDES permit process. The SWPPP must be prepared in accordance with good engineering practices and identify all potential sources of pollution, which may reasonably be expected to affect the quality of storm water discharges from the construction site. The SWPPP must describe practices to be used to reduce pollutants in storm water discharges from the construction site and assure compliance with the terms and conditions of the CGP.

  The requirements vary slightly depending on the type of operator. However, the general requirements include as site and activity description and controls to reduce pollutants. The SWPPP must include a description of all pollution control measures (i.e., Best Management Plans) that will be implemented as part of the construction activity to control pollutants in storm water discharges. A description of interim and permanent stabilization practices for the site, including a schedule of when the practices will be implemented must be included. The SWPPP must also include documentation supporting a determination of permit eligibility with regard to Endangered Species. Other requirements of the SWPPP are outlined in the CGP.

- Excavation Dewatering Wastewater Disposal Permits (ADEC)

  This permit is required for excavation dewatering under 18 AAC 72.050. Information required to complete this application includes the project description and contact information, dates of discharge, discharge flow rates and locations. A description of the discharge area must be included which describes: the overland distances and drainage routes to major water bodies, contaminated sites within 3 miles, sensitive areas that may be affected by the discharge, drinking water wells or surface water sources within 1 mile of the proposed discharge. In addition, the proposed treatment, disposal and monitoring must be included. The permit must be obtained in conjunction with an EPA NPDES permit.

- Water Use Permit (ADNR)

  A water right is a legal right to use surface or ground water under the Alaska Water Use Act (Alaska Statute [AS] 46.15). A water right allows a specific amount of water from a specific water source to be diverted, impounded, or withdrawn for a specific use. An application for water rights must be accompanied by the filing fee of:

- $50 for the use of 5,000 gallons per day (gpd) or less;
- $100 for the use of more than 5,000 gpd but less than 30,000 gpd;
- $200 for the use of 30,000 gpd or more but less than 100,000 gpd;
- $300 for the use of 100,000 gpd or more but less than 500,000 gpd;
- $500 for the use of 500,000 gpd or more but less than 1,000,000 gpd;
- $1,000 for the use of 1,000,000 gpd or more except $1,500 for the use of 1,000,000 gpd or more outside the hydrologic unit from which it was removed (hydrologic units are based on the most current U.S.G.S. Hydrologic Unit Map of Alaska).

To ensure that the public is notified of proposed water uses, you may be required to pay the cost of a legal advertisement in at least one issue of a local newspaper in the area of the proposed water use. Public notice is required if the appropriation is over 5,000 gallons per day; if it comes from an anadromous fish stream; or if the water source has a high level of competition among water users. In addition, permit and certificate (including temporary water use permit) holders are subject to an annual $50 water right administrative service fee for any non-domestic use of more than 500 gpd. Domestic water users of less than 1,500 gallons per day are exempt from the fee.

A temporary water use permit may be needed if the amount of water to be used is a significant amount, the use continues for less than five consecutive years, and the water to be used is not already appropriated. This permit does not establish a water right but will avoid conflicts with fisheries and existing water right holders. The application fee for a temporary water use permit is the same as for a water right.

A significant amount of water is defined by 11 AAC 93.970(14) as:

- The use of more than 5,000 gallons of water in a single day from a single water source; or,
- The regular daily or recurring seasonal use of more than 500 gallons of water per day for 10 days or more per year from a single water source; or
- The non-consumptive use of more than 30,000 gallons of water per day (0.05 cubic feet per second) from a single water source; or,
- Any water use that might adversely affect the water rights of other appropriators or the public interest.

- Air Quality Control Permits, Title V (ADEC)

  18 AAC 50 provides authorization for air quality monitoring and permitting to the ADEC. Regulations that establish the minimum standards for the state are specified in federal regulations 40 CFR part 70. The determination to require a permit is based on the source location, total emissions and changes in emissions for sources specified in 18 AAC 50.300(a). Generally, air quality must be maintained at the lowest practical concentrations of contaminants specified in the Ambient Air Quality Standards of 18 AAC 50.020(a) (suspended particulates, sulfur oxides, carbon monoxide, ozone, nitrogen dioxide, reduced sulfur compounds, and lead). The applicant for a Title V permit must submit an application and supplemental information as required by 18 AAC 50.3000(b). Air Quality Permits are

required for construction and operation activities that produce air contaminant emissions. Permits are issued for a maximum 5-year period, and are renewable by the same procedure.

The construction, modification, and operation of facilities that produce air contaminant emissions require a state Air Quality Control Permit to Construct, and a separate Air Quality Control Permit to Operate. An air quality permit to construct will be required prior to beginning pre-production activities to ready the site. Information required for the permit application include: sources of air emissions, inventory of air emissions, and assessment of the impacts on ambient air quality, usually obtained through modeling.

The application should contain information on pre-production site work (e.g., construction of roads, etc.) and full-scale production. The permit, once it is granted will cover the pre-production site work and may include the initial operation phase. Within 12 months of commencement of construction, an Application for an Air Quality Control Permit to Operate must be submitted. During review and negotiation of an Air Quality Control Permit to Operate application submitted within this timeframe, the Air Quality Control Permit to Construct remains in effect and is the mechanism that allows operations during this time period.

In addition to these two air quality control permits, open burning of cleared vegetation would require a separate permitting process. This would include obtaining a Burn Permit from ADNR, which would focus on fire control, and an Air Quality Control Permit to Open Burn from ADEC, which would focus on air quality impacts.

Therefore, the permits required for construction and operation of a facility that produce emissions, and for open burning include:

- Air Quality Control Permit to Construct
- Air Quality Control Permit to Operate
- Burn Permit
- Air Quality Permit to Open Burn

A completed Coastal Project Questionnaire Certification Form must be submitted to ADEC Air Permits with the application for an Air Quality Permit. The specific forms required for the Air Quality Permit are dependent on the project classification, determined by:

- Equipment Type and Size
- Emissions
- Location
- Owner Requested Limits

The ADEC provides specific guidance documents for preparation of the required forms based on the regulations specified in 18 AAC 50.

- Material Sale Permit (ADNR)

  Under the authorization of 11 AAC 80 and AS 38.35, a material sales permit is required for the removal of rock, crushed rock or gravel from State Lands. This applies in cases where there is more than 200 cubic yards removed and a fee usually applies.

- Flood Plain Development Permit (Matanuska – Susitna Borough)

A development permit shall be obtained before construction or development begins within any area of special flood hazard established in MSB 17.29.060, which includes the Matanuska River bottom. The permit shall be for all structures, including manufactured homes, as set forth in the definitions, and for all development including fill and other activities.

A fee established by the assembly must accompany development permit application. The application may include, but not be limited to plans in duplicate drawn to scale showing the nature, location, dimensions and elevations of the area in question; and existing or proposed structures, fill, storage of materials, drainage facilities, and the location of the foregoing. The following information is required:

- Elevation in relation to mean sea level of the lowest floor (including basement) of all structures;
- Elevation in relation to mean sea level to which any structure has been flood-proofed;
- Certification by a registered professional engineer or architect that the flood-proofing methods for any nonresidential structure meet the flood-proofing criteria in MSB 17.29.170.
- Description of the extent to which a watercourse will be altered or relocated as a result of proposed development.

• Conditional Use Permits (Matanuska – Susitna Borough)

A conditional use permit shall be obtained for activities that include the construction of towers or tall structures, noise, and traffic. The requirement for towers or tall structures applies to certain structure locations and heights and is regulated under MSB 17.60.030. Permits are required for tall structures exceeding the maximum allowable height for structures within a special land use district or, exceeding 100 feet above average grade in locations where no maximum height for structures is designated by borough code; tower farms containing two or more tall towers regulated under this section; tower line routes and tower service area grids, containing two or more towers regulated under section MSB 17.60.030; and electrical lighting towers in excess of 185 feet located within the road rights-of-way along major arterial corridors.

The standards are specified for noise in MSB 17.61.080 and for traffic under MSB 17.61.090. These standards are based on the location, level of noise and traffic, and the timing of operation.

• Shoreline Setback Exception (Matanuska – Susitna Borough)

MSB 17.55.020 regulates the setback of activities from the shoreline. In general, no structure or footing shall be located closer than 75 feet from the high water mark of a watercourse or body of water. An exception may be applied for to exempt the structure from this code.

• Building Codes (Matanuska – Susitna Borough)

The borough has adopted by reference the following codes of technical regulation for buildings and structures which are constructed, improved, or modified by the borough:

- Uniform Mechanical Code, 1997 Edition (including appendices thereto);

- Uniform Building Code, 1997 Edition (including appendices thereto);
- Uniform Plumbing Code, 1997 Edition (including appendices thereto);
- National Electrical Code, 1997 Edition (including appendices thereto); and
- Uniform Fire Code, 1997 Edition (including appendices thereto).

Application of these codes will be dependent on the type of project proposed.

Kris Ivarson
Hydrogeologist

# APPENDIX H

*Land Use and Economics*

MWH

# Matanuska River Erosion Land Use Measures

## Technical Memorandum

*Prepared for*

**MWH Americas, Inc.**

October 2004

*Prepared by*

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# Contents

# 1 SUMMARY

In this technical memorandum, Northern Economics, Inc. assesses the response to erosion from the land side perspective. The focus of the memorandum is on the planning framework that could be utilized to guide land use development and building in erosion-prone areas along the Matanuska River in the project area. This memorandum explores possible land use measures that might be undertaken by both the MSB and private property owners to respond to the effects of river erosion.

Northern Economics Inc. conferred with the engineers and hydrogeologists on the Matanuska River Erosion Assessment Gravel Removal and Bank Protection Progress Report. Existing federal and state regulations on flood hazard mitigation were reviewed. State planning authorities in Title 29, long range comprehensive land use plans, and adopted coastal management plans were referenced. These plans provide the institutional framework for dealing with erosion and land use measures for guiding development away from erosion-prone areas. Borough and state staff responsible for flood hazard mitigation were interviewed.

The cost to the public of erosion control projects such as dredging, trenching, gravel extraction, and dike construction may only partially be offset by gravel sales and property tax revenues. To minimize public expenditures for erosion controls, some non-impact land use measures are explored in this technical memorandum. Land use measures that guide growth and development represent a potentially cost effective means of addressing the impact of river erosion. This memorandum contains an overview of the planning framework that could be utilized as the foundation for land use measures to address the effects of erosion.

This memorandum recommends that the MSB prepare an updated Flood Mitigation Plan. Such a plan would enable the borough or other entities to qualify for Flood Mitigation Assistance grants. Eligible activities include elevation of structures, relocation of flood-threatened (erosion-prone) insurable structures, and acquisition. Monies are available through a state administered, cost-share program for grants that can cover planning for flood mitigation, technical assistance, and mitigation projects.

In addition, given the recurring and cyclical interest in erosion hazards along the Matanuska River and with the availability of scientific modeling and GIS, this memo recommends the following:

- Real estate disclosure is critical in apprising current homeowners and potential homebuyers about flood hazard risk. Disclosure of erosion hazard risk should be required in the real estate transaction
- Provide local realtors and lending institutions with GIS copies of the Flood Insurance Rate Maps
- Utilize GIS and other technologies (e.g. modeling) to analyze erosion risk
- MSB should consider seeking public input on utilizing property acquisition as a technique for willing sellers to sell flood-prone property
- Identify properties appropriate for protection because of flood risks. Depending on public input, MSB should pursue acquisition, conservation easements, or flood hazard protection regulations.

# 2 Study Area

The study area for the ***MWH Matanuska River Erosion Assessment*** for the USDA Natural Resources Conservation District is the reach of the Matanuska River extending from the Old Glenn Highway Bridge near Palmer to approximately six miles downstream of the bridge. This technical memorandum addresses existing land use planning and development guidelines in areas adjacent to this stretch of the river- Palmer and Butte. This memorandum also explains some alternative approaches to safeguarding property and facilities from flood hazards and erosion that may be more cost effective for the Matanuska-Susitna Borough tax payers than gravel extraction.

## 2.1 Challenge

The modern floodplains of the Matanuska (and Knik) rivers are subject to powerful and regular erosion and flooding forces.[1] According to a discussion of flooding in the adopted Mat-Su Borough Core Area Comprehensive Plan (adopted 1993, amended 1994 and 1997), there is a "temptation to ignore potentially serious hazards and develop the floodplains". Only small glacial advances are required to trap large quantities of water and re-establish extreme flooding events. Field reports from summer 2004 recorded 50 year floodplain watermarks.

Many parts of the core area are depicted on Flood Insurance Rate Maps prepared by the Federal Emergency Management Agency (FEMA). Lands immediately next to rivers and lakes are usually classified as Zone A or areas prone to a 100 year flood.

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[1] Matanuska Susitna Borough Core Area Comprehensive Plan (September 1993; Amended November 1994 and September 1997) HDR Engineering, Inc./Transport Pacific Associates/Kevin Waring and Associates.

# 3 Methodology

The existing regulatory framework for planning and development in the project area are explained in this technical memorandum. Land use measures to guide development to the most geologically stable areas are presented as information only. They are presented as potential, more cost effective alternatives to recurring trenching and extraction activities in the river.

As part of the MWH *Matanuska River Erosion Assessment,* a numerical modeling study was undertaken by Northwest Hydraulic consultants to assess the feasibility of the proposed in-channel excavations as a means of controlling bank erosion hazards along the braided gravel-bed Matanuska River near Palmer. This memorandum references the conclusions of the modeling study. The specific focus of the modeling study was to estimate the effect of the channel excavations on flow pattern and hydraulic characteristics in the study reach of the river during two flood events- two-year and ten-year peak flows.

The hydrogeological, modeling study proposed excavations that effectively intercept and redirect the floodwaters. Downstream, in the Bodenburg Butte and Circle View Estates reaches, water depth, flow velocity and sediment transport capacity along the east bank would be reduced due to the concentration of the flows along the two downstream trenches. According to the modeling study, the Matanuska River is dynamic, the gravel extraction excavations can reduce bank erosion but will not eliminate the need for bank erosion protection of key facilities, properties, and locations of direct flow impingement on bank locations. This technical memorandum explores other erosion protection measures.

Numerous planning documents were reviewed and state and borough officials who work with floodplain hazard mitigation were interviewed.

# 4 Existing Planning Guidelines

The MSB does not prohibit development in flood hazard areas. For purposes of federal flood hazard insurance, it does require a development permit for activity in the 100 year floodplain. As a second class borough MSB could invoke its planning authorities and prevent development in areas prone to flood hazard and erosion. This could be done through comprehensive land use plans, site specific land use guidelines based on underlying geology (e.g. bedrock), implementing zoning ordinances, or a flood hazard overlay zone. As an alternative to the O & M costs associated with trenching, dredging, and construction of finger dikes, this memo looks at the planning framework and land use guidelines that address the effects of erosion.

This section will explain the existing planning institutional framework. This framework provides the basis for an erosion hazard overlay zone and cooperative programs for property acquisition.

## 4.1 Mat-Su Resource Conservation & Development Area

The study area is located within the Matanuska-Susitna Resource Conservation District. The Mat-Su Resource Conservation District is part of the United States Department of Agriculture Natural Resources Conservation Service (NRCS). The mission of the NRCS is to provide leadership in a partnership effort to help people conserve, maintain, and improve natural resources and the environment.[2] This mission provides broad authorities for Resource Conservation Districts to reach out to various sectors of Alaska to help them plan and implement needed conservation measures.

The Natural Resources Conservation Service Mat-Su field office, which is administering the contract for this erosion study, serves the entire Mat-Su Borough- 15 million acres. This area is the fastest growing area of Alaska, doubling its population to 60,000 residents over the last 20 years.[3] Population growth and development are focused in the cities of Palmer and Wasilla, the "Core Area" between them, developing communities (such as Butte). The borough boundaries encompass the Palmer, Wasilla, and Upper Susitna Soil and Water Conservation Districts. The Mat-Su Conservation Service field office includes land holdings by not only the borough and state, but the Cook Inlet Region Incorporated and Ahtna Regional Alaska Native corporations, village tribal councils, individual Alaska Native landowners, and other private landowners. The Mat-Su RC & D assists incorporated towns such as Palmer and Wasilla, small communities, and active community councils (e.g. Butte) in their resource and land use planning**.**

In another part of the state, the Natural Resources Conservation Service recently partnered with the Fairbanks North Star Borough to purchase homes and property in an area chronically flooded by the Tanana River.4 The USDA-NRCS is preparing to implement a voluntary Floodplain Easement Program to restore and enhance the floodplain's functions and values while helping landowners relocate to avoid future damages.

The Pile Driver Slough area, located in the Fairbanks North Star Borough, approximately 30 miles south of Fairbanks, Alaska, experiences annual flooding associated with the Tanana River. The area contains approximately 162 properties consisting of permanent dwellings, seasonal cabins, and other associated structures that are affected by the annual flood events. Residents of the area are seeking

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[2] United States Department of Agriculture, Natural Resources Conservation Service, *2002 Alaska Report.*

[3] United States department of Agriculture, Natural Resources Conservation Service. *2002 Alaska Report.*

[4] Anchorage Daily News, "Borough, Feds May Buty Homes in Flood Plain of Tanana River", October 21. 2004.

financial and technical assistance from the USDA-Natural Resources Conservation Service (NRCS) to alleviate damages associated with the Tanana River flooding.

## 4.2 Matanuska Susitna Borough Coastal Management Program

The Alaska Legislature passed the Alaska Coastal Management Program (ACMP) in 1977. The ACMP is implemented through coastal districts, which include boroughs; unified home rule municipalities; home-rule, first class, and some second class cities; and Coastal Resource Service Areas for areas within the unorganized borough.[5] Statewide regulatory standards can be found in 6 AAC 80. The Matanuska-Susitna Borough approved its coastal management plan in 1984. Coastal management plans are conventionally implemented through zoning and platting. Other implementation strategies include capital improvement programs, land acquisition, sales, or trades; transportation planning; annexation; easements; eminent domain; and local review of state and federal permitting actions.

The Matanuska-Susitna Borough Coastal Management Program was adopted February 1984. The Mat-Su Coastal District boundaries encompasses the creeks and rivers- including the Matanuska River- and where lands intersect these bodies of water the management boundary extends to the 1000-foot contour level. Communities within the Mat-Su Coastal Management district include Palmer, Wasilla, and several other communities, but not Butte.

The Mat-Su Borough as a second class borough and a coastal management district could-if it so chose- invoke the adopted coastal development policy to limit development in erosion prone areas. The Mat-Su Borough Coastal Management Program includes enforceable and administrative policies related to coastal development.

For instance, Coastal Development Policy #6 specifies that the type and density of development in an area shall be determined by the physical constraints and opportunities.5

> "Physical conditions such as soil characteristics, slopes, geological features, surface and sub-surface drainage, water tables, floodplains and shore forms shall be taken into consideration when planning development in an area." 5

In addition to general policies for coastal development (see above), the Mat-Su Coastal Management Plan addresses residential coastal development. Policy #1 states that " …… scattered development needlessly degrades rivers….., and coastline open space….. causes extra public costs for public services." Due to the higher costs of extending public services to development along shorelines, the Mat-Su Coastal Management Plan goes on to say that new development should be consolidated, or aggregated, so that shoreline impacts are minimized.

Coastal management policies are implemented through comprehensive plans, plat review, land use review, technical review, planning review, subdivision review, variances, and zoning.

In the absence of a recently adopted comprehensive plan and a zoning ordinance to implement it, the Mat-Su Borough has fewer planning tools for effective guidance of development in the coastal zone and erosion prone areas.

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[5] Office of the Governor/Division of Governmental Coordination: Alaska Coastal Management Program. *Planning Alaska's Public Lands*: *The Alaska Planning Directory* . www.nrm.alrm.uaf.edu/~stodd/AlaskaPlanningDirectory/CoastalMgmt.html.

## 4.3 State of Alaska Erosion Management Policy

The Alaska Department of Commerce, Community and Economic Development/division of Community Advocacy oversees the floodplain management program for the State. The purpose of the Floodplain Management Program is to reduce public and private sector losses and damage from flooding and erosion by providing coordination, funding, and technical assistance to National Flood Insurance Program communities.

### 4.3.1 Flood Hazard Insurance Rate Map

The Federal Emergency Management Agency (FEMA) establishes the flood hazard mapping. For property located within the 100 year flood, FEMA requires all structures to obtain Flood Hazard Insurance.

### 4.3.2 Erosion Management Policy

The State of Alaska has instituted an erosion management policy that pertains to state-funded and state pass-through funded construction. [6] The erosion management policy encourages other Alaska entities to consider the following siting, design and construction policy guidelines. Some of these guidelines refer to the role of local comprehensive plans, ordinances, and subdivision approvals in addressing erosion's effects.

- The cause of the erosion problem and factors accelerating erosion should be identified before alternative solutions are proposed
- Prior to constructing erosion control measures, state agencies should analyze nonstructural alternatives, such as relocating threatened structures, and if legally consistent, proceed with the option with the greatest benefit for the least cost
- New structures should be located so that erosion control is not likely to be needed within the structure's design life. If such structures are at risk of erosion damage, the cost of erosion safeguards should be considered
- Erosion control structures should not be built to protect minimally used or vacant land
- Communities with structural erosion control measures, or erosion-prone areas, should be encouraged to incorporate appropriate flood risk and erosion mitigation planning considerations into local comprehensive plans, ordinances, and subdivision approvals.
- Communities which receive state funds for erosion protection should be encouraged to prepare an erosion (or flood) mitigation plan, and land use regulations to prevent losses and to guide development in high-risk erosion and flood-prone areas.
- If the state finds building, platting, land use regulations within an affected jurisdiction are inadequate and have added to the magnitude of a state declared disaster, public recovery assistance should be limited to a disaster loan until essential changes in the building and land use regulations are adopted
- Erosion control projects should be sited and designed using appropriate engineering principles-

[6] State of Alaska, Department of Commerce, Community and Economic Development, Division of Community Advocacy. www.commerce.state.ak.us/dca/nfip/nfip.htm

- Design life of a project according to a specified level or event (e.g. 1% flood, base flood elevation, 30-year/60-year project design life, piling depth to withstand scour)
- Analysis to determine rate of erosion, then avoid building in area that would erode in life of the building

#### 4.3.2.1 Administrative Order No. 175

In 1998, former Governor Tony Knowles issued Administrative Order No. 175 regarding state-owned and state-financed construction projects and the potential for flood and erosion damage. In this order it was stated that FEMA is responsible for the National Flood Insurance Program and through regulations has developed flood plain management criteria for flood-prone and erosion-prone areas. The administrative order goes on to say that it is in the state's best interest to site and construct state-owned and state-financed projects using the portions of those regulations pertaining to construction standards as a guide.

Included in the administrative order were guidelines for state agencies responsible for 1)construction of buildings, structures, roads or other facilities;2)leasing or disposal of lands or properties, and 3) programs affecting land use planning.

1. For construction of and loans for buildings, roads, and other facilities consideration shall be given to setbacks, flood proofing, building elevation, and erosion control measures in flood and erosion- prone areas.
2. For leasing or disposal of lands or properties, flood and erosion hazards shall be determined and to minimize future public expenditures for protection shall consider including 100-year flood elevation data or flood risk information within all new subdivision proposals greater than 50 lots or 5 acres – whichever is less.
3. For programs affecting land use planning, shall take erosion hazards into account when evaluating plans and permits and shall encourage land use appropriate to the degree of hazard involved.

## 4.4 Alaska Statutes Title 29: Planning Authorities

Alaska statutes under Title 29 Municipal Government details the planning, platting and zoning powers conveyed to local government. First class, second class, and home rule boroughs must provide for planning, platting, and zoning regulations on an area-wide basis. The Matanuska-Susitna Borough is a second class borough, and by state statute must provide for planning, platting, and zoning regulations. By AS 29.40.010(B), a borough can delegate to a city its planning and land use regulations. The MSB has delegated to the cities of Palmer and Wasilla planning and land use powers.

A comprehensive plan is a prerequisite to instituting zoning. The Matanuska-Susitna Borough Assembly in 1986 passed Resolution No. 86-7, which established policy guidelines for development of comprehensive plans. The policy stipulates that comprehensive planning will be conducted on a community by community basis, not area-wide.

### 4.4.1 Comprehensive Plan

The MSB Assembly, by Title 15.24.030, has been vested with the responsibility to prepare a comprehensive borough-wide plan of development designed to:

- secure safety from fire, flood, pollution and other dangers
- provide for orderly development in harmony with the ability to provide services efficiently
- preserve natural resources,
- preserve property values
- Facilitate adequate provision for transportation and traffic safety; water, wastewater; schools, recreation and other public requirements.

The comprehensive plan consists of several elements: Matanuska-Susitna Borough Comprehensive Development Plan, MSB Coastal Management Plan, City of Palmer Comprehensive Plan, City of Wasilla Comprehensive Plan, City of Houston Comprehensive Plan, MSB Core Area Comprehensive Plan, Long Range Transportation Plan, MSB Recreational Trails Plan (2000), comprehensive plans for Chickaloon, Chase, Glacier View, Big Lake, Knik-Fairview, Lake Louise and Sutton; and 25 lake management plans.

If elements of the comprehensive plan conflict, the element most recently adopted shall govern.

The Matanuska-Susitna Borough Comprehensive Development Plan was adopted in 1970 but has been amended many times, the most recent 2002.

The most current adopted comprehensive plan for the MSB is the Matanuska-Susitna Borough Comprehensive Development Plan (1970). This pre-dates the several Matanuska River Erosion Task Force Reports, including the one dated 1992. Having an adopted comprehensive plan, although in need of update, does provide the basis for a zoning ordinance to limit or prohibit development in certain flood hazard zones.

#### 4.4.1.1 Matanuska-Susitna Borough Core Area Comprehensive Plan

The core area is the residential area between the cities of Palmer and Wasilla. It is one of the most populated areas in Alaska but has no official name and is not a city on its own. The *Matanuska-Susitna Borough Core Area Comprehensive Plan* was adopted in1997. The core area plan extends to the western edge of the Matanuska River but does not include the river or the land area on the other side.

The *Core Area Comprehensive Plan* follows the adopted 1970 *Borough Comprehensive Plan*. It describes the land use issues, goals, areas of future probable growth, and recommendations for implementation of goals. In addition, background research was done on the physical, historic, and socioeconomic characteristics as well analysis of land use patterns and characteristics, community facilities, and transportation systems.

Unlike the City of Palmer and City of Wasilla plans, the core area plan includes few recommendations for new regulatory provisions to implement the plan. The regulatory provisions in the core area plan provide for protection of the public health, safety, and welfare of the core area by regulating land uses with a negative impact on residential neighborhoods. Such land uses include adult oriented businesses, group homes, or half-way houses for criminal rehabilitation, race tracks, commercial waste incinerators, and uses which result in extremely high levels of noise.

There exist some environmental concerns with drainage that intensify as development pressures increase and may affect how and where development occurs. Sensitive habitat and valuable natural resources can be viewed as a constraint. The borough's coastal management plan establishes policies regarding development in sensitive habitat areas. The coastal management plan policies overlay the core area planning process.

The core area plan has broken down the core area by physiographic area by the suitability of geology and soils for different kinds of development. As contrasted with the Soil Conservation Service classification system, this system takes into account engineering properties of soils. The physiographic Unit 6 Modern Floodplain and Wetland areas and Unit 7 Modern Floodplains of the Matanuska and Knik Rivers relate to the erosion prone areas resulting from the hydro geological forces in the Mat-Su Erosion Assessment study. Unit 6 is represented by the modern floodplain of the little Susitna River in the north and by by the abandoned floodplain of the Matanuska river in the south. Both have extensive flooded areas either year-round or seasonally. The unit comprises approximately 16% of the core area.

Unit 7 Modern Floodplains of the Matanuska and Knik Rivers are subject to powerful and regular erosion and flooding forces. Areas bordering these landforms are subject to these hazards. The plan recommends that dangers not be dismissed simply because events happen only once in a long while at any given location. "Recent loss of houses along the landform clearly underscores this."1 Lake George outburst flooding at one time flooded down the Upper Knik River, regularly destroying the approaches to the Knik River bridge near the Butte. Only small glacial advances would be required to establish the once yearly extreme flooding event. This physiographic unit comprises approximately 6% of the core area.

#### 4.4.1.2 Asset Management Plan for Borough Owned Land in the Butte

Some of the land and property affected by erosion lie within the Butte area. The Butte area lies at the furthest eastern edge of the Matanuska-Susitna Valley tucked against the Chugach Range. It is separated from the rest of the valley by the Matanuska River to the north and the Knik River to the south. The Butte Area is unincorporated and is located south of Palmer in the MSB, between mile 9 and mile 16 of the Old Glenn Highway. The community lies at the foot of Bodenburg Butte, east of the Matanuska River, 42 miles north of Anchorage. The 2002 Census estimates the population of the Butte Area to be 2,931 and is a largely rural settlement of over 960 homes.

The MSB's Community Development Department, since 2003, has been in the process of working with Butte residents, the Butte Community Council, and a consultant team on a management plan for borough-owned lands in the Butte area.[7] Input was also provided by Alaska State Troopers, Eklutna Native Corporation, Palmer Soil and Water Conservation District, and State Department of Natural Resources. Comments were due in October 24, 2003 and, once received, the draft plan was scheduled to go first to the Ag and Forestry Advisory Board and the Parks Recreation and Trails Advisory Board, and then on to the Planning Commission and Assembly. The Butte Asset Management Plan has not yet been adopted.

The Asset Management Plan is for over 6,000 acres of Borough-owned land within the Butte area. The community is named for the Bodenburg Butte, a prominent rock outcropping and landmark, Butte features views of Pioneer Peak and the Chugach Mountains, It is characterized by historic farm settings and access to recreational areas contained by glacial rivers, mountain trails, and the Knik Glacier.

An asset management plan or land use plan can lay out an integrated land use planning model that balances the natural characteristics of the land with those needs and desires of the people residing in the Butte area. Such an approach links the distinct set of natural resources and unique natural features with appropriate land uses. Unique natural features such as underlying bedrock may render certain

[7] Land Design North, Northern Economics, Inc., Agnew::Beck. *Asset Management Plan for Borough Owned Land in the Butte Area (Draft).* May 2004. Prepared for Matanuska-Susitna Borough.

parcels resistant to the effects of river erosion. However, other parcels may be especially prone to flooding or erosion. In the latter instance, common sense suggests that a Special Land Use Designation or land use/zoning designation would be a more cost effective method of mitigating the effects of river erosion versus dredging, trenching, and gravel extraction.

In the Draft Asset Management Plan for Borough-Owned Lands in the Butte/Chapter 3 Natural & Cultural Resources, there is an explanation of the hydrology.

> "One of the most powerful forces at work in shaping the land is the hydrological system, including glaciers, rivers and rain." The implications for development are that "residential development must be carefully located out of the floodplain and drainage area to preserve life and property."

The Draft Asset Management Plan contains a map depicting the development suitability of land in the Butte area. Parcels west of Bodenburg Butte are in the floodplain, of very low development suitability, low suitability, or moderate development suitability. Though the maps depict patterns of the landscape and predict suitability for development opportunities, they are not intended to be used as basis for zoning. However, they provide a basis for consideration of appropriate land use measures for anticipating the effects of erosion.

### 4.4.2 Flood Plain Development in the Mat-Su Borough

This section explains the MSB's requirement for development permits and elevation certificates for development within the federally designated flood hazard areas.

#### 4.4.2.1 Existing Borough Requirements for Flood Damage Prevention

Prior to any development within a federally designated flood hazard, flood plain development permit and elevation certificates are required. The flood plain development permit consists of two parts- the MSB flood hazard development permit and the elevation certificate. (A sample copy of a Floodplain Development Permit Application can be found in Appendix A of this technical memorandum.) The Development Permit requires certification by a registered Architect or Engineer. The elevation certificate requires certification by a registered engineer or surveyor.

To determine if a development project is within a designated flood hazard area, a flood hazard determination can be obtained from the Mat-Su Borough Code Compliance. Provision of the street address, subdivision name, lot and block, or township, range, section, and parcel number will be checked against the flood hazard maps. The flood hazard maps pertinent to the Mat-Su Borough and project area are: Panel 9725 of 9855, Panel 9730 of 9855, and 9740 of 9855. These maps are available from the Borough Code Compliance Office in the Planning Department.

Eligibility for flood hazard insurance requires that the development conform to the minimum standards of development as described in MSB 17.29 Flood Damage Prevention excerpted in the following section of this memorandum.

#### 4.4.2.2 Elevation certificate

The National Flood Insurance Program requires local governments to obtain elevation certificates for all new construction and substantial improvements in the flood plain. Elevation certificates are used to record the elevation of the lowest floor of new construction in the floodplain and to determine the proper flood insurance rate for floodplain structures. The MSB, as the local jurisdiction, must ensure that the elevation certificates are completed correctly. Required information includes:

- Location of structure (tax parcel number and legal description)
- Use of building
- Flood Insurance Map panel number and date, community name and source of flood elevation

#### 4.4.2.3 MSB Title 17 Zoning

Section 29 of the Mat-Su Borough's Chapter 17 Zoning Regulations addresses flood damage prevention. The Findings of Fact of this section acknowledge that the Mat-Su Borough is subject to periodic inundation, resulting in loss of life and property, health and safety hazards, disruption of commerce and governmental services, extraordinary public expenditures for flood protection and relief, and impairment of the tax base. Given the flood hazard, the purpose of the flood damage prevention measures are to minimize public expenditures on costly flood control projects, minimize damage to public facilities and utilities ( including roads), maintain a stable tax base by providing for sound development of special flood hazard areas, ensure potential buyers are notified property is in area of special flood hazard, and to ensure residents of special flood hazard assume responsibility for their actions.

Through Title 17, the Borough has established an area of special flood hazard. This area has been established based on Federal Emergency Management Agency's scientific and engineering report entitled "The Flood Insurance Study, Matanuska-Susitna Borough". These flood insurance rate maps are available from the Borough planning office. Before construction or development begins within any area of special flood hazard, both a development permit and elevation certificate is required. The application for a development permit requires plans drawn to scale

General standards for flood hazard reduction are included in the Mat-Su Boroughs municipal code-Title 17. Zoning. A building safety service area does not exist within the core area of the Borough. Commercial and industrial building plans are reviewed by the State Fire Marshal, who serves as engineering plan review. The following section was excerpted from the MSB code Title 17.

**17.29.160 GENERAL STANDARDS FOR FLOOD HAZARD REDUCTION.**

(A) In all areas of special flood hazards, the following standards are required:
(1) Anchoring.
(a) All new construction and substantial improvements shall be anchored to prevent flotation, collapse, or lateral movement of the structure.
(b) All manufactured homes must like-wise be anchored to prevent flotation, collapse or lateral movement and shall be installed using methods and practices that minimize flood damage. Anchoring methods may include, but are not limited to, use of over-the-top or frame ties to ground anchors and other techniques set out in "Manufactured Home Installation in Flood Hazard Areas," a guidebook published by the Federal Emergency Management Administration.
(2) Construction materials and methods.
(a) All new construction and substantial improvements shall be constructed with materials and utility equipment resistant to flood damage.
(b) All new construction and substantial improvements shall be constructed using methods and

practices that minimize flood damage.
(c) Electrical, heating, ventilation, plumbing and air-conditioning equipment and other service facilities shall be designed and/or otherwise elevated or located so as to prevent water from entering or accumulating within the components during conditions of flooding.
(3) Utilities.
(a) All new and replacement water supply systems shall be designed to minimize or eliminate infiltration of flood waters into the system;
(b) New and replacement sanitary sewage systems shall be designed to minimize or eliminate infiltration of flood waters into the systems and discharge from the systems into floodwaters;
(c) On-site water disposal systems shall be located to avoid impairment to them or con-tamination from them during flooding;
(4) Subdivision proposals.
(a) All subdivision proposals shall be consistent with the need to minimize flood damage;
(b) All subdivision proposals shall have public utilities and facilities such as sewer gas, electrical, and water systems located and constructed to minimize flood damage;
(c) All subdivision proposals shall have adequate drainage provided to reduce exposure to flood damage;
(d) Where base flood elevation data has not been provided or is not available from another authoritative source, it shall be generated for sub-division proposals and other proposed developments which contain at least 50 lots or five acres, whichever is less.
(5) Review of development permits. Where elevation data is not available either through the Flood Insurance Study or from another authoritative source pursuant to MSB 17.29.130(A)(4), applications for development permits shall be reviewed to assure that proposed construction will be reasonably safe from flooding. The test of reasonableness is a local judgment and includes use of historical data, high water marks, photographs of past flooding, and the like, where available. Failure to elevate at least two feet above grade in these zones may result in higher insurance rates.
(Ord. 87-52, § 2 (part), 1987)

Review of development permits.[8] Where elevation data is not available either through the Flood Insurance Study or from another authoritative source pursuant to MSB 17.29.130(A)(4), applications for development permits shall be reviewed to assure that proposed construction will be reasonably safe from flooding. The test of reasonableness is a local judgment and includes use of historical data, high water marks, photographs of past flooding, and the like, where available. Failure to elevate at least two feet above grade in these zones may result in higher insurance rates.
(Ord. 87-52, § 2 (part), 1987)

In all areas of special flood hazards where base flood elevation data has been provided as set out in MSB 17.29.060 or 17.29.130(A)(4), the following provisions are required:
(1) Residential construction.
(a) New construction and substantial improvement of any residential structure shall have the lowest floor, including basement, elevated to or above base flood elevation.
(b) Fully enclosed areas below the lowest floor that are subject to flooding are prohibited, or shall be designed to automatically equalize hydrostatic flood forces on exterior walls by allowing for the entry and exit of floodwaters. Designs for meeting this requirement must either be certified by a registered professional engineer or architect or must meet or exceed the following minimum criteria:
(i) A minimum of two openings have a total net area of not less than one square inch for every square foot of enclosed area subject to flooding shall be provided.
(ii) The bottom of all openings shall be no higher than one foot above grade.
(iii) Openings may be equipped with screens, louvers, or other coverings or devices, provided

[8] Matanuska-Susitna Borough municipal code. *Title 17. Zoning.*

they permit the automatic entry and exit of floodwaters.
(2) Nonresidential construction. New construction and substantial improvement of any commercial, industrial or other nonresidential structure shall either have the lowest floor, including basement, elevated to the level of the base flood elevation; or, together with attendant utility and sanitary facilities, shall:
(a) Be floodproofed so that below the base flood level the structure is watertight with walls substantially impermeable to the passage of water;
(b) Have structural components capable of resisting hydrostatic and hydrodynamic loads and effects of buoyancy;
(c) Be certified by a registered professional engineer or architect that the design and methods of construction are in accordance with accepted standards of practice for meeting provisions of this subsection based on their development and/or review of the structural design, specifications and plans. Such certifications shall be provided to the official as set forth in MSB 17.29.130(A)(6);
(d) Nonresidential structures that are elevated, not floodproofed, must meet the same standards for space below the lowest floor as described in MSB 17.29.170(A)(2);
(e) Applicants floodproofing non-residential buildings shall be notified that flood insurance premiums will be based on rates that are one foot below the floodproofed level (for example, a building constructed to the base flood level will be rated as one foot below that level).
(3) Manufactured homes. All manufactured homes to be placed or substantially improved within Zones A1-30, AH, and AE shall be elevated on a permanent foundation such that the lowest floor of the manufactured home is at or above the base flood elevation and shall be securely anchored to an adequately anchored foundation system in accordance with the provisions of MSB 17.29.160(A)(1)(b). (Ord. 87-52, § 2 (part), 1987)

## 4.5 Potential MSB Ordinance Revisions to Address Reduction of Erosion Hazards

According to the State Department of Commerce, Community and Economic Development, which coordinates the state's flood insurance program,[9] the first line of defense against erosion should be to advise people not to build in erosion-prone areas. Damage due to erosion statewide has required mitigation and relief expenditures by federal, state and local government. Ac cording to information from the MSB Planning Department/Code Compliance, in August 2004, Circle View Subdivision off Bodenburg Butte Road lost more than 100 feet landward-perpendicular to the shore- to erosion. The erosion threatened a home under construction and a nearby power line. Several borough built finger dikes had been keeping the river at bay until the advent of a 50-year flood event summer 2004.

The State has issued an administration order preventing construction and funding of public infrastructure and facilities in areas prone to erosion. Local land use regulations could be utilized to help reduce costs to the public for damage caused by erosion and to require property owners to assume responsibility for wise development in areas with potential for damage from erosion. Measures such as limiting the number of lots affected, lowering the density of development along hazardous areas, and lowering the intensity of development in those areas can reduce the potential for damage caused by erosion.

### 4.5.1 Flood Hazard Mitigation Plan

Under the National Flood Insurance Reform Act of 1994, Congress authorized establishment of a federal grant program to provide financial assistance to states and communities for flood mitigation planning and activities. Though floodplain data are not always useful in predicting erosion hazards,

[9] Hollander, Zaz. "Borough May Dig Channel". *Anchorage Daily News.* September 26, 2004.

the two are related. This memorandum recommends that the MSB prepare an updated Flood Mitigation Plan and incorporate recent information on erosion patterns.. Such an updated plan would enable the borough or other entities to qualify for Flood Mitigation Assistance grants. Eligible activities under flood mitigation assistance grants include elevation of structures, relocation of flood-threatened (erosion-prone) insurable structures, and acquisition**.** Monies are available through a state administered, cost-share program for grants that can cover planning for flood mitigation, technical assistance, and mitigation projects.

In addition, given the recurring and cyclical interest in erosion hazards along the Matanuska River and with the availability of scientific modeling and GIS, this memo recommends the following:

- Real estate disclosure is critical in apprising current homeowners and potential homebuyers about flood hazard risk. Disclosure of erosion hazard risk should be required in the real estate transaction
- Provide local realtors and lending institutions with GIS copies of the Flood Insurance Rate Maps
- Utilize GIS and other technologies (e.g. modeling) to analyze erosion risk
- MSB should consider seeking public input on utilizing property acquisition as a technique for willing sellers to sell flood-prone property
- Identify properties appropriate for protection because of flood risks. Depending on public input, MSB should pursue acquisition, conservation easements, or flood hazard protection regulations.

### 4.5.2 Erosion Overlay Zone

An overlay zone is a land use planning tool that perhaps could be utilized to guide development in erosion-prone areas along the Matanuska River in the MSB. The overlay zone would be based on data, information, and maps such as the Alaska District Corps of Engineers map of erosion patterns from 1916 to 1995 (December 1995), GIS information from the MSB, erosion studies, and the recent MIKE-21 model of the Matanuska River as part of the MWH *Matanuska River Erosion Assessment Study*. The following subsections of this memorandum describe elements that might go into an erosion overlay zone.

#### 4.5.2.1 Minimum Lot Size

Land within an erosion hazard zone may not be platted to lots less than five acres in area. Land determined to be within the 30 year erosion rate hazard zone shall not be platted to lots less than 40 acres in area.

#### 4.5.2.2 Length to width ratio

Lots within erosion hazard zones shall be configured to minimize frontage along the water course and to maximize the length of the lot perpendicular to the water course to provide developable area as far as possible away from the shore.

#### 4.5.2.3 Infrastructure

Primary subdivision access, collector streets, and major utilities, collector and distribution facilities shall be constructed outside the erosion hazard zones so as to reduce the number of lots affected by damage due to erosion. The borough shall not assume maintenance responsibilities for subdivision roads within erosion hazard zones.

Likewise, the borough will not assume maintenance or operation responsibilities for utility systems within erosion hazard zones as part of private subdivision construction or other private development.

#### 4.5.2.4 Designation of Erosion Hazard Zone

All land within 500 feet landward of the mean ordinary highwater line of any water course listed in this section is designated as being within the 60 year rate erosion hazard zone and is subject to applicable borough erosion hazard mitigation standards.

Within this Erosion Hazard Zone, the following uses and structures would be prohibited. Within the 60 year erosion hazard zone, no more than three dwelling units would be allowed. Within the 30 year erosion hazard rate zone, no more than two dwelling units per lot would be permitted. Uses and structures prohibited in both the 60 year and 30 year erosion hazard zones would be: structures containing habitable floors for which the lowest horizontal support is less than two feet above average pre-existing grade, commercial or industrial buildings, basements, underground storage tanks, junkyards, landfills, utility substations, and commercial storage of hazardous material.

# 5 Erosion Control- Property Acquisition and Development Prohibitions

Trenching in the river or building a series of dikes are current approaches under consideration for addressing the effects of river erosion. These engineering alternatives focus on altering the forces of the river- a physical constraint- rather than guiding or preventing various land uses in the vicinity of the erosion-prone area. A recent example of another approach can be seen in another second class borough, the Fairbanks North Star Borough. In response to the cost of responding to recurring flooding and erosion along the Tanana River, the Fairbanks North Star Borough (FNSB) has partnered with NRCS. In order to restore the floodplain's functions and values, FNSB and NRCS are extending applications to property owners to sell their property at fair market value and relocate out of the floodplain. This may well be a more cost effective than repeated and recurring efforts to control flooding and erosion by dredging or trenching.

Land ownership maps from the Matanuska-Susitna Borough 2004 GIS data files illustrate that land along the east bank of the river within the project study area is in either borough or private ownership. Some of the most erosion-prone areas are in private ownership. The impetus for the Butte Area Plan (described in a previous section of the memorandum) was the need to discern the best alternatives for managing borough-owned land assets. For lands of high resource or recreational value- or those in environmentally sensitive areas, it was recommended these lands either remain in borough ownership or, alternatively, be acquired.

For the purposes of discussion, if one focuses on the area most prone to erosion (see Map of Matanuska River/Matanuska River at Bodenburg Butte, Erosions Patterns from 1916 to 1995, Alaska District Corps of Engineers), several observations can be made. This information plus parcel information and property appraisals for tax purposes from the tax parcel layer of the Matanuska-Susitna Borough 2004 GIS data files are used in the succeeding, screening level assessment. Of 44 parcels selected (and selection was somewhat arbitrary except for proximity to the east side of the Matanuska River and within project area), average assessed valuation is $9553/acre. Among the 44 parcels, parcel size ranged from .92 acres to 4.98 acres. Assessed valuation ranged from $12,000 to $32,800 per tax parcel. These figures perhaps start to provide a basis for contrasting the costs and benefits for erosion control alternatives

## 5.1 Public Education

The Alaska Department of Commerce, Community, and Economic Development is a resource for floodplain management. Supported by funding by FEMA and the Alaska Coastal Management Program, DCCED has published a QuickGuide for Floodplain Management in Alaska (2003). Topics include flood insurance, community responsibilities, understanding the riverine floodplain, the flood insurance rate map, What is the Elevation Certificate and How is it Used?

This QuickGuide provides a user friendly informational handbook that could be utilized in MSB to lay the groundwork for understanding land use regulations to mitigate erosion.

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# Market Analysis of Matanuska Valley Gravel Materials

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**October 2004**

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# Summary of Findings

This technical memorandum presents findings of a market analysis conducted for gravel materials mined from the Matanuska River as part of a potential erosion control project. The market analysis considers current and future supply and demand of local aggregates, as well as the pricing of raw gravel, within a ten-year study period.

The primary markets for gravels mined from the Matanuska River are in Palmer, Wasilla, and Anchorage. Palmer and Wasilla have abundant sand and gravel resources, and local supply is able to accommodate demand for anticipated residential and commercial development over time.

Anchorage has a demand for approximately 4 million tons of sand and gravel each year, and does not have a local supply. Over the next ten years, the quantity demanded is expected to drop significantly due to a decline in residential and large-scale construction.

Potential development of the Knik Arm Bridge, an expansion of the Port of Anchorage, and other major construction would create additional demand on either side of the Arm, though gravel produced through erosion control dredging would be at a price disadvantage for these bridge and port projects due to the significant transportation costs.

Existing markets for Matanuska River gravels will absorb the proposed annual production of up to 500,000 tons (333, 000 cubic yards) with minimal pricing impacts. The current resource value for these gravels ranges from $1.00 to $1.25 per cubic yard in-situ, in the Palmer and Wasilla areas. This corresponds to about $0.67 to $0.83 per ton.

Market rates for extracted, stockpiled, and loaded gravel averages $2.00 per ton in the Palmer and Wasilla areas, and $5.50 to $6.00 per ton in Anchorage. The difference between retail resource values and market prices reflects the cost of transportation and other value-added activities.

The probable range of resource values for pit-run gravel in the Palmer and Wasilla areas is $0.84 to $1.04 per ton in 2014. With today's level of consumption, production of 500,000 tons would represent 12.5 percent of the Anchorage market share and 2 to 3 percent of the Southcentral Alaska market share, as defined by the Department of Natural Resources. Additional costs for extraction, stock-piling, and loading suggest prices of $2.00 per ton ($3.00 per cubic yard) for typical quantities, at the source.

Annual production of 500,000 tons would produce roughly $1 million in revenues, assuming the gravel is sold at the pit, FOB truck, at approximately $2.00 per ton ($3.00 per cubic yard). For efficiency, any mined gravels not used in the erosion control process should be offered for sale to a distributor serving the Palmer, Wasilla, or Anchorage markets.

The following sections provide more information on local gravel resources, present and future market conditions, and the market potential for gravel mined from the Matanuska River.

# Local Gravel Resources

Sand and gravel resources are prevalent throughout Alaska, due to heavy glaciation. These resources are limited only in the Yukon and Kuskokwim basins, in the western arctic, and in certain areas near Homer, on the Kenai Peninsula. The primary consumer of sand, gravel, and other construction aggregates is the construction industry, which uses them for local construction projects. Due to their high densities, these resources are rarely transported long distances, and quarry sites are generally located close to end-users and product markets in order to limit transportation costs (Northern Economics, Inc., 2002).

Like most of Alaska, the Southcentral region has abundant gravel resources. In 2002, the Department of Natural Resources (DNR) received 22 responses to a questionnaire sent to sand and gravel producers operating in the region about activities and production. The Southcentral region is defined as a large area that reaches to the northern edge of the Matanuska-Susitna Borough (MSB), the southern tip of the Kenai Peninsula, the west side of Cook Inlet, and the Canadian border and Yakutat to the east. There are many more mining operations than these 22 reported to the DNR, however, and the MSB alone probably has around 100 of them (Lovs, 2004).

Gravel is especially abundant throughout the MSB, and is found is varying quantities and qualities throughout the Borough. Quality depends primarily on the size of the gravels available. Larger gravels are considered to be of higher quality because the stones may be crushed to whatever size is needed. Finer materials are considered to be of lower quality, since they cannot be enlarged as needed (Crafford, 2004). Additionally, silt is an impediment to construction gravel use, since it holds moisture and increases frost susceptibility.

The three main gravel resource owners in the MSB are Cook Inlet Region, Inc., the State of Alaska (including pits designated for use by the Department of Transportation and Public Facilities), and the MSB itself. Other operations, including mining on private land for specific projects, may take place in the Borough, although most of these operations are temporary, for private use, and of limited quantity. The Alaska Economic Information System indicates four major gravel pits are active in the MSB, near Palmer. Annual production from these pits is about 2 million tons (1.3 million cubic yards) of aggregates, all of which is shipped to Anchorage via rail (DCED, 2004).

Attempts were made to obtain additional information about other long-term gravel operations in the MSB, since mining operations conducted as part of erosion control might use existing distribution channels. However, the Borough does not maintain current records of gravel pit operations, nor does it require special permitting that might be used to identify them (Hudson, 2004). Therefore, information on area mining activities comes from secondary sources. The MSB is working on an asset management plan for its gravel resources, though this work is ongoing and the results are not yet available.

# Local Gravel Market, Present

In 2002, DNR reported production of 10.0 million tons of sand and gravel in Southcentral Alaska, half of which was used in road construction on the Kenai Peninsula. Emergency road repair on the Kenai Peninsula late in the year was responsible for the consumption of1.6 million tons in 2002. The annual production had an estimated value of $52.2 million worth of sand and gravel, based on a value of $5.20 per ton (DGGS, 2002).

Sand and gravel is typically produced on an as-needed basis. For this reason, gravel consumption and production are typically located very close to each other. While residential and commercial users may purchase gravel from centralized locations, road construction and maintenance projects rely on gravels available near a project. About 4 million tons of gravel is used annually in the Anchorage area, which reflects 40 percent of the total Southcentral production and consumption as reported by DNR in 2002, and about 18 percent of the statewide production as reported by DNR.

Gravel production in the Southcentral region is shown for a seven-year period in Figure 1, based on published information from the DNR (DGGS SR51-57, 2004). The solid line indicates the tons produced each year, which has varied from year to year but stayed between 3 and 10 million tons.

The dashed line shows the total value of production, based on DNR estimates of the cost per ton. Production changes have accounted for most of this total change in value.

**Figure 1. Production Quantity and Value of Construction Sand and Gravel in Southcentral Alaska, 1996-2002**

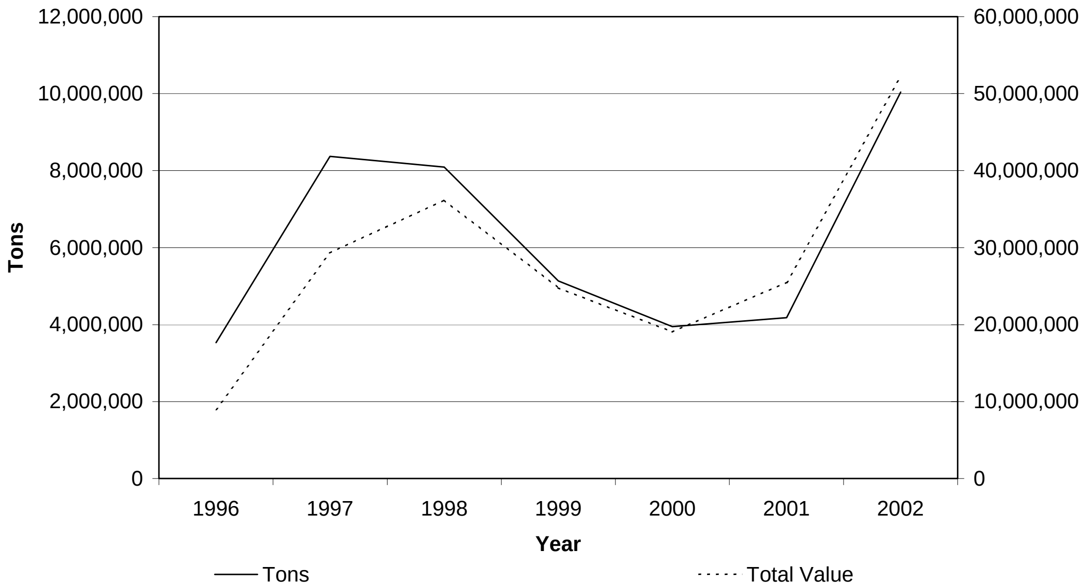
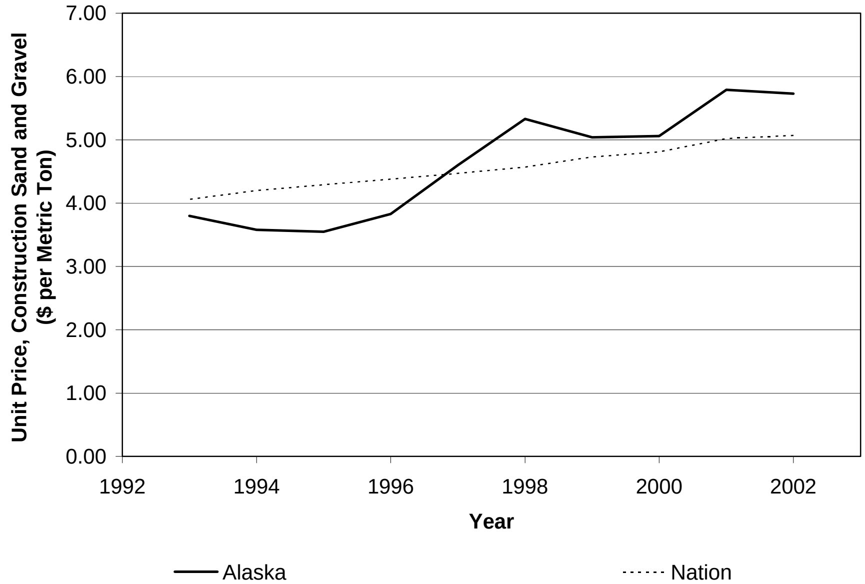



Figure 2 shows unit prices for construction sand and gravel in Alaska for 1993 to 2002, based on information published by USGS. For comparison, the figure also shows the price at the national level. Over time, the price of gravel has increased, although in Alaska the fluctuations from year to year are significantly larger than for the rest of the nation. In 2002, average gravel prices in Alaska were around $5.75 per ton. This is essentially the same price for Anchorage, but it is higher than market rates in the MSB due to the abundant gravel resources in the area.

**Figure 2. Unit Price for Construction Sand and Gravel, Alaska, 1993 to 2002**




Source: USGS, 1994-2002 and 1997-2004

## Local Gravel Market, Future

A prior study on sand, gravel, and aggregate demand in Southcentral Alaska provided several conclusions about demand for these materials in the future (Northern Economics, Inc., 2002). Some of the study's key conclusions are:

- Demand for construction sand and gravel in Anchorage will drop significantly within 10 years, due to a reduction in the amount of developable land. However, development in the Matanuska-Susitna Borough and other communities in the Municipality of Anchorage (such as Eagle River) will help to maintain the market for aggregates in the region. Potential redevelopment of areas will also provide demand for aggregates.
- Sand and gravel extraction at existing operations in the Palmer area will last for another 25 to 35 years. An operation was underway in Knik, although it is currently halted. Identified gravel deposits in the Point MacKenzie area might be feasible in the future. While these and other operations are taking place in Southcentral Alaska, they do not preclude development of an additional gravel source, and any new developments may actually extend the useful lives of other operations.

These findings are applicable to this study. The proximity of the proposed Matanuska river mining site to railroad infrastructure makes rail transportation to Anchorage an attractive means of selling gravel.

The proposed Knik Arm Bridge and Port of Anchorage expansion projects, each of which would require enormous quantities of gravel during their construction phases. Gravel resources located at Point MacKenzie have been identified as a potential source for the port expansion project. The MSB Port Director indicated that as much as 50 million tons of gravel could be mined from sites within 1.5 miles of the Port MacKenzie dock (Northern Economics, Inc., 2002).

Future demand for gravel will be significantly lower in the Anchorage area than it is today. This will reduce the quantity of gravel that is sent by rail from Palmer and Wasilla. Demand in the MSB will be higher due to the rapid population growth the area has experienced, which will likely continue. However, abundant gravel resources in the MSB will be adequate to cover future demand for residential and commercial development in the area. Overall, the demand for dredged material in the MSB and Anchorage will remain stable or grow over time.

Gravel prices should maintain their steady rise over the next decade, though subject to some year-to-year volatility. These increases will be due to inflation, rather than major changes in the supply and demand for gravels. As long as supply exceeds demand, as it has in the past and is expected to do over the next decade, prices will not increase significantly.

Potential markets and channels of distribution are discussed further in the next section.

# Market Potential, Matanuska River Gravels

Gravels mined from the Matanuska River will likely be sandy gravel to gravelly sand (MWH, 2004). This type of material would be acceptable for gravel markets in Palmer, Wasilla, Anchorage, and surrounding areas. These markets could easily utilize the quantity of gravel expected to be produced from the riverbed each year as long as it is offered at a competitive price.

## Quantity of Gravel

Gravels are naturally replaced annually at a rate of up to 500,000 tons in the Matanuska River, although the actual replacement rate from year to year could vary significantly (Jokela, 2004). This level of production is small compared with larger stand-alone gravel pit operations, but may make sense because of the social and economic benefits from erosion control. Initial dredging in the river to establish channels is expected to produce as much as 9.5 million tons of gravel.

In general, a mining operation producing less than 1 million tons annually is not economical (Lovs, 2004). Attempting to sell gravel on site or set up an ongoing operation somewhere in the MSB would require a significantly greater supply of gravel, sufficient to last at least 7 or 8 years.

## Quality of Gravel

Steve Lovs of Anchorage Sand & Gravel reviewed project sampling reports and indicated that the gravels seemed acceptable. He noted that silts and other fine particles (below #200 sieve mesh) were fairly low in most samples. The materials below #200, namely silt, are a problem when the gravels are used in road construction. Most road contracts limit silt to 6 percent due to its ability to retain water and increase frost susceptibility. The Matanuska River samples did not have an excess amount of silt, which is often a problem when mining riverbeds.

Mr. Lovs also noted that the reports did not indicate large rocks (exceeding 16″ to 20″), which can be a problem when mining and transporting gravels. In active river channels, larger rocks may be more prevalent, and should be sorted and set aside.

## Potential Markets

Potential markets for these gravels include Palmer, Wasilla, and Anchorage. The first market is in the Palmer and Wasilla area, where the gravels would be mined. The second market is Anchorage, which would require transportation by rail. Transportation by truck is not cost effective for distances over about 30 to 40 miles (Crafford, 2004).

Since these markets are currently served by numerous small pits (in the case of Palmer and Wasilla) and Anchorage Sand & Gravel and other construction contractors (in Anchorage), the most cost effective manner of disposing of these materials is selling through existing distribution channels to realize scale efficiencies.

### *Palmer and Wasilla Markets*

Due to the abundance of gravel in the MSB, supply should exceed demand for the study period. For this reason, no price changes are expected other than inflation.

The current resource value for gravels is $0.67 to $0.83 per ton in-situ. In the case of the proposed erosion control, a jurisdictional determination is necessary regarding ownership of the resource.

If the materials in the river bed are owned by the State (as expected), payment of a royalty may be required under materials sales regulations. In this case, the resource may be valued at fair market value or based on an appraisal, depending on how the operation is classified (DNR, 2004). The base rate for gravel is $1.00 per cubic yard, in the pit, unless the purchaser is a public agency in which case the rate would be half of the base, or $0.50 per cubic yard (Cox, 2004 and Sullivan, 2004). The base rate is roughly equivalent to $0.67 per ton, or $0.33 per ton for a public agency. The State's royalty rate is adjusted periodically to match local market values.

In addition to the resource value (base rate), the cost of the material will increase dramatically with each handling. Therefore, gravel should be sold to the Palmer or Wasilla market through a distributor or another producer, due to the low quantity produced and the transportation distances involved. Another option would be to directly utilize produced gravels in the erosion control project.

### *Anchorage Market*

Within the next 10 years, the quantity of gravel demanded in Anchorage will decline significantly. The current demand of 4 million tons annually is based on a high level of construction activity over the last several years. As the remaining land in the Anchorage bowl is developed, and fewer hotels and *big box* stores are built, demand for construction gravel will decline significantly. Gravels will be needed for maintenance and smaller construction projects, but not in the quantities seen recently. The planned Port of Anchorage Expansion and Knik Arm Bridge would require gravel, possibly from Point MacKenzie or the Matanuska River. These projects would greatly increase demand for sand and gravel in Anchorage during construction.

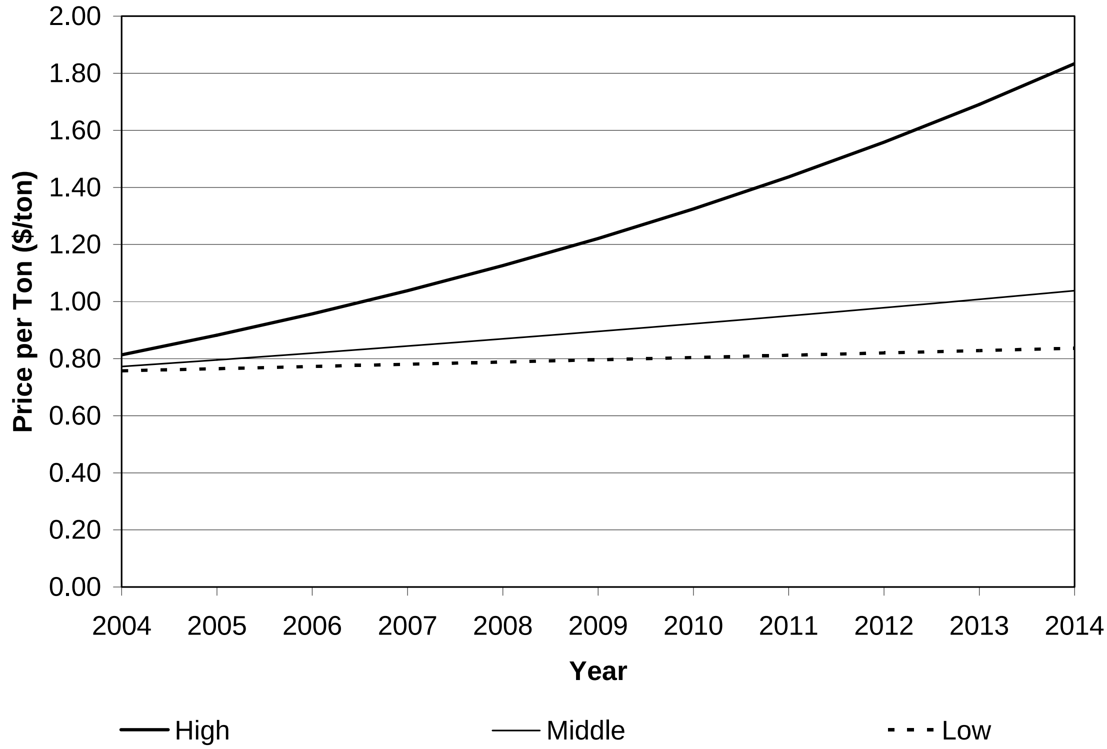
Gravel may be priced in the $5.50 to $6.00 per ton (or $8.25 to $9.00 per cubic yard) range in Anchorage, which reflects the $4.50 to $5.50 cost of transporting the material by rail from Palmer and the $0.67 to $0.83 resource value. Transportation cost is a direct function of the distance that gravels must travel. However, the availability of offloading sites and gravel deposits proximate to those sites may cause gravel prices to follow a fixed-step (stairstep) function for pricing. Gravels sold in the Anchorage market from the project should be wholesaled to a distributor.

## Anticipated Raw Material Prices

Gravel mined from the Matanuska River would likely be sold at the market rate in Palmer, which is currently about $0.67 to $0.83 per ton for in-situ gravel. This cost would apply to both Palmer and Anchorage markets, as adjusted for transportation costs.

Over the next ten years, aggregate prices will only change due to inflation. Supply will match or exceed demand, reducing upward pressures on market prices, and production of up to 500,000 tons annually will be sold at competitive market prices. The result will be flat to slightly higher prices. Figure 3 shows high, middle, and low prices for sand and gravel resources sold in Palmer from 2004 to 2014.

**Figure 3. Anticipated Price of Pit Sand and Gravel, Palmer, 2004-2014**




The figure shows anticipated prices under three levels of inflation. The high case shown represents the 8.5 percent inflation in aggregate prices seen over the past several years of DNR data for Southcentral. The middle case shows a 3 percent inflation rate, and the low case shows 1 percent inflation.

The high case shows a retail resource value for a ton of gravel at $1.83 per ton (2014) in Palmer and Wasilla, up from an average of about $0.75 per ton today. The low and middle cases give a range of values from $0.84 to $1.04 per ton in 2014, representing a modest increase over today's prices. The low and middle prices represent a probable range of retail resource values over the next decade.

At 2004 market prices in the MSB, the average retail price for pit-run gravel is about $2.00 per ton ($3.00 per cubic yard), FOB truck. At that price, the retail sale of 500,000 tons of gravel would result in revenues of approximately $1,000,000. Profits from that sale would equal that amount less any transportation and other operational costs incurred in mining the gravel from the river bed, transporting it to a point of sale, and loading it in the customers' trucks. Additional handling steps would increase both the sale price and the handling costs. Selling to another producer or distributor would result in a lower sales price and correspondingly lower handling costs. Note that these prices are for retail sales, FOB truck. It is very common for retail and wholesale sales to be priced at the pit, in the ground, with the customer paying all costs for subsequent handling. Large volume purchases typically receive a discount from the $0.67 to $0.83 per ton in-situ price. The recent Parks Highway overpass project, for instance, utilized nearby gravel resources for which the contractor paid a resource value of between $0.25 and $0.35 per ton in the ground (Polen, 2004).

Although gravel is a commodity and the price is mostly inelastic to changes in production, increasing the gravel supply may have slight impacts on the price per ton. At a production level of 500,000 tons, the price is anticipated to drop by about one cent per ton, as measured in 2002 dollars. Increasing production by 9.5 million tons, such as by attempting to sell the full quantity produced by initial dredging operations, would cause prices to decline by roughly 21 cents in 2002 dollars, if demand for such a large quantity existed. However, these adverse price effects may be mitigated or eliminated by selling to another producer, signaling to other producers so that they can make adjustments to their production levels, identifying and selling to a specific project that will need a large quantity of gravel, or spreading the sale of larger quantities of gravel over time.

## Market, Logistical, and Environmental Issues

A number of questions and factors must be considered when determining the maximum amount of gravel that may be sold:

- **Market share:** What is a reasonable level of market penetration, given that existing suppliers already provide these materials? Given market prices of approximately $2.00 per ton at the pit, FOB truck, in the Palmer and Wasilla area, would the operation be financially feasible?
- **Distribution issues:** Who currently supplies gravel from the area? What is the most effective manner in which to sell gravel? Can materials be sold through an existing distributor to minimize infrastructure costs? What other distribution channels are available? Is suitable property available near the dredging site for storage of the gravels if it is sold directly to consumers? What routes are available for accessing the river for dredging operations?
- **Processing and environmental issues:** What level of processing is required to sell to a customer or distributor? What effect would additional processing, such as washing or sorting, have on the sales price? What permits and other regulations would govern the choice to process further?

### *Market Share*

Gravels mined from the Matanuska River would represent a small share of the combined Anchorage and MSB markets. The market share would likely be on the order of 2 to 3 percent of total production in Southcentral Alaska (as defined by DNR), even as demand in the Anchorage area declines over time. Production of 500,000 tons annually would represent a 12.5 percent share of the Anchorage market. This is likely to be too large of a market share, pointing to the importance of selling to both the Anchorage and MSB markets.

### *Distribution*

The two choices for distribution are to sell aggregates to customers through a newly formed operation, or to make an arrangement with an existing distributor or producer to sell the gravels. While the details of an arrangement with a distributor or producer are not possible to determine at this stage of the analysis, potential purchasers might include Anchorage-based producer Anchorage Sand and Gravel Company, construction companies such as Wilder, State or local governments, or Palmer-based pit operators such as Central Paving Products.

Selling gravels directly to customers would be difficult due to the small scale of production. Even if mining took place annually with no foreseeable end date, variable annual production of 500,000 tons would be uneconomical. Therefore, prospective developers might consider selling the mined gravels to a distributor to avoid the logistical challenges associated with transportation, storage, and direct sales to customers.

Another option would be to use the mined gravels to aid in the erosion control project, if they are needed. Rather than selling the gravels to offset the cost of erosion control, this option would reduce the cost by using “free” materials. The larger gravels might be suitable for armor rock, and the rest could be used as fill. This depends on the course of action taken.

### *Additional Processing and Environmental Issues*

Before selling gravels to a distributor or other customer, a conveyor system or other means of transporting the materials will be needed to bring the gravels from the river to a rail or road link, or a location where customers may pick up gravel. Additional processing, such as washing or sorting, may also be needed before the gravels would be salable, although those options have not been deemed necessary based on the current analysis of the riverbed materials.

An analysis of the streambed composition indicates a relatively low level of fines. However, a producer should keep in mind the additional steps necessary to produce gravel from an area with a higher content of fines. A challenge often facing gravel producers mining from streambeds is that the gravels are often coated with fine sands and other materials that are undesirable and unusable (Crafford, 2004). In order to remove these fine coatings, washing may be needed. However, any operation that discharges contaminated water, even if the water and particulates go back to the streambed from which they were extracted, may be required to apply for a discharge permit, which could add significantly to the cost and complexity of the proposed mining operation.

Washing and screening may increase the value of the mined gravels, but any discharges will need to satisfy the regulations and permitting process surrounding such activity. Prospective developers will need to address the regulations surrounding water discharges and the expected gains relative to the cost of acquiring permits and monitoring the operation. At a low level of production, further washing and processing is likely not economical.

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