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FINAL REPORT

Prepared for
National Park Service
Denali National Park and Preserve

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## Abstract

*A proposed massive road building project will, if constructed, bisect the Toklat Basin area along or adjacent to the old Stampede Trail. The road and its associated gravel pits will affect hundreds of pristine waterbodies, aquatic habitat, and wetlands. At particular risk are spring-fed gravel-bed streams which act as salmon spawning, rearing, and overwintering areas. A basic and severe lack of knowledge of the water resources along this corridor seriously threatens the NPS's ability to analyze, manage, and protect this area, and subsequently mitigate impacts if this road construction occurs. As a result, a comprehensive study was initiated to determine baseline water quality and physical hydrology information in the Toklat Basin. This report describes the preliminary investigations of water chemistry, watershed hydrology, and channel morphology for fiver drainages in the Toklat Basin, including the Sushana River, the East Fork River, Wigand Creek, the Toklat River, and the Clearwater Fork.*

*To assist with the assessment of watershed hydrology for the five major drainages, USGS predictive regional regression equations techniques were used to develop estimations of the magnitude and frequency of peak streamflows, as well as selected high-flow and low-flow duration statistics. Water quality was characterized using historic data as well as new data from samples taken specifically for this study. The remoteness of these watersheds, their location in a national park and preserve, and the limited access to these areas for humans to date, have combined to limit environmental degradation of these freshwater resources. Based on the results from cross-section surveys, a numerical hydraulic computer analysis, and field observations, approximate flood-prone areas in the vicinity of the old Stampede Trail were delineated for both the East Fork and Toklat Rivers. As part of this project, an aerial survey and brief ground visit of the Toklat Springs was conducted in March 2005 in an effort to map the extent of the springs.*

## Introduction

A single 85-mile gravel road through the old Mt. McKinley Park wilderness currently serves as the main park transportation corridor. However, construction of a new north access to the interior of Denali National Park has been under consideration by the State of Alaska and others for a number of years. The primary focus of this route is a ninety-mile road or railroad from the Parks Highway near the town of Healy to the Wonder Lake area of the park. The proposed route runs along the North side of the Alaska range, approximately 12 to 25 miles north of the existing Denali Park road. This proposed route generally follows the alignment that is commonly known as the Stampede Trail. The route would traverse state lands as well as ANILCA additions to Denali National Park that were included to ensure protection of wilderness recreation and ecosystem values.

Opening the north access corridor to visitor traffic would disturb pristine habitat and segment the park with an additional transportation corridor, bounding the Wyoming Hills range on the north and south with human development. Impacts from the proposed northern access corridor would include: influences of imported material containing non-native biota, disturbance to wet tundra and riparian habitat, and effects to hydrology, water quality and aquatic habitat of five major river corridors. These river corridors include the Sushana River, the East Fork River, the Toklat River, Wigand Creek, and the Clearwater Fork.

The National Park Service requires assistance with assessing the stream water quality, hydrology, and hydraulic geometry of the five major watersheds along the proposed North Access route, west of the Teklanika River (Figure 1). Additionally, the National Park Service is interested in obtaining baseline information on the area known as the 'Toklat springs.' One of the least understood, yet most productive, aquatic systems within the park is the salmon spawning and rearing areas created by warm springs on these north-flowing rivers. In fact, the springs provide over-wintering habitat for juvenile salmon. However, the number of springs, their precise locations, the amount of flow they contribute to each river, and their sources are unknown.

The construction of a travel corridor will require the extraction of extremely large quantities of gravel in and adjacent to these aquatic systems. Such actions could pose an immediate and significant threat to these rare springs. Addition impacts from road construction and maintenance could result in significant water quality degradation, including such parameters as turbidity, suspended solids, and heavy metals contamination. This project will utilize existing data from previous studies, along with newly acquired field information, to provide baseline information of the hydrologic resources in this area.

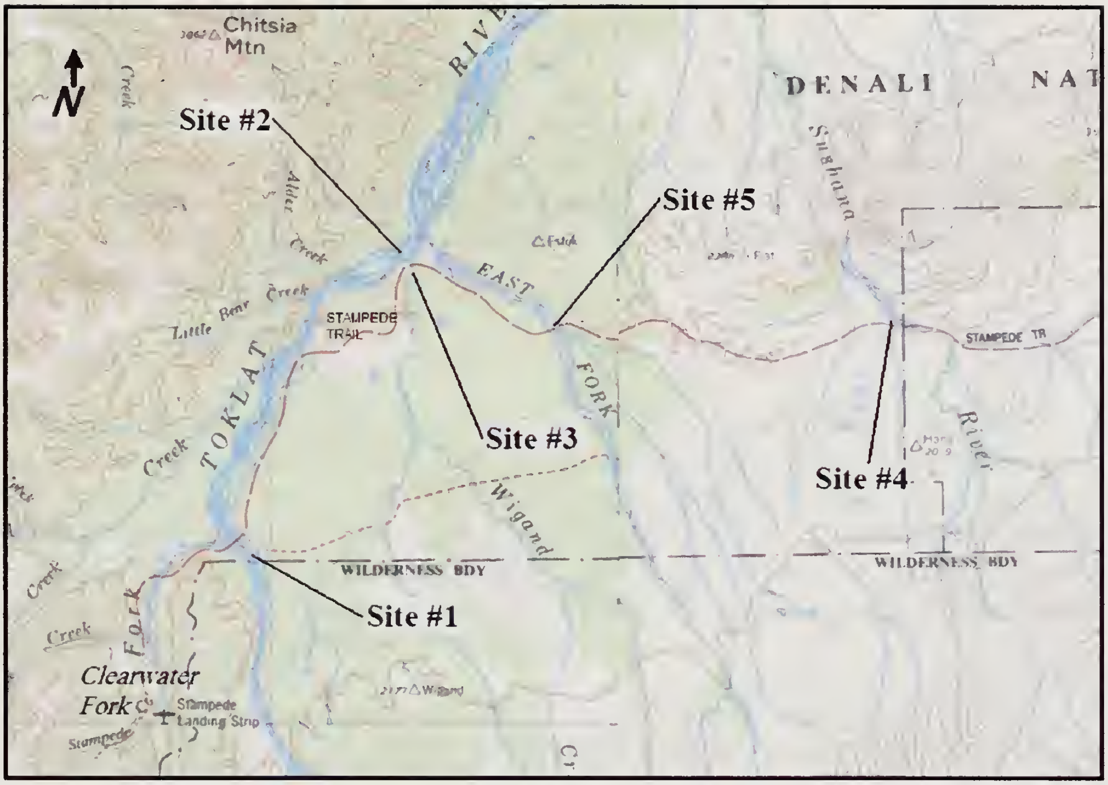
The National Park Service established a contract with Hydraulic Mapping and Modeling to provide an overview of the water quality and physical hydrology of the water resources along the Stampede Trail/North Access route. The specific tasks to be accomplished in the first phase of this project are:

- Hydrologic inventory of the five major watersheds
- Flood-flow statistics, including magnitude and flow duration and magnitude
- Water Quality analysis and STORET entry
- Aerial survey of the Toklat Springs
- Channel geometry analysis of the Toklat River
- Air photo analysis of flood-prone areas on the Toklat and East Fork Rivers

For the purposes of this study, the 5 watersheds are defined as the area above a specific point on the stream from which water drains toward that stream (Figure 2). Those downstream catchment points are essentially located at or near the intersection of the Stampede Trail and the river or stream. These points also served as the locations for conducting much of the field work, including water chemistry and cross-section surveys. The determination of the statistical hydrology was based on watershed area defined by these points.

There are two companion products to this report. The first is an MS Access database file. This file contains all field data obtained to this point, including water chemistry, discharge, cross-section surveys, pebble counts, and flood magnitude estimations. Many of the graphs included in the Appendices of this report are embedded in the Access database. Additionally, the database contains several photographs from each of the study sites.

The second product is a GIS (ArcGIS 9) file. This file contains the geodatabase used to delineate and display the five study watersheds. The projection of all the data is Albers Equal Area Alaska, NAD27.




| Field Work Site | Location (latitude, longitude) | Field Work Conducted |
|---|---|---|
| 1. Toklat River | 63° 48’ 03.6”<br>150° 15’ 51.7” | Cross-sections, pebble count, discharge |
| 2. Toklat River | 63° 53’ 47.7”<br>150° 09’ 18.4” | Water quality |
| 3. Wigand Creek | 63° 53’ 47.7”<br>150° 09’ 18.4” | Water quality, discharge |
| 4. Sushana River | 63° 52’ 38.0”<br>149° 48’ 52.0” | Water quality, discharge |
| 5. East Fork River | 63° 52’ 52.5”<br>150° 03’ 52.0” | Cross-sections, pebble count, discharge |

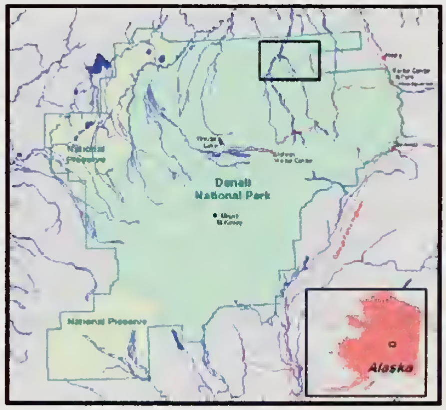



**Figure 1. Study location map, and project field work sites.**

## Hydrologic Inventory

The first step in conducting a hydrologic inventory is to compile all existing information on the study watersheds. To accomplish this, peer-reviewed and gray literature describing water-related studies within Denali National Park and Preserve were reviewed for pertinent information. The following information provides an overview and links to available water quality information for watersheds that intersect or are adjacent to the North Access corridor.

### *Water Quality*

The U.S. Environmental Protection Agency maintains the world's largest repository of ambient water quality data. STORET data available on the Internet is divided into two separate databases, according to when it was originally supplied to EPA, and to which of the two STORET databases it was originally archived (EPA, n.d.). The older database is referred to as the STORET Legacy Data Center. The Legacy Data Center contains data of undocumented quality. Further, these data are static. The Legacy Data Center does not permit updates, and data here will not change over time.

More recently acquired data are stored in the current Modernized STORET. All data supplied to EPA since January 1, 1999 have been placed in the Modernized STORET System.

Both the Legacy Data Center and the modernized STORET databases were queried to determine what types of data from the study watersheds are stored. No sites or data were found in the modernized STORET database. In the Legacy Data Center, the following watersheds are included in the database: Clearwater Fork, Moonlight Creek, Stampede Creek (above and below mine), Myrtle Creek. These stations contain water quality data; sampling of these sites occurred in the early 1980s, and was in response to extensive placer mining operations taking place on a number of streams in the Kantishna Hills mining district. Reported data include pH, discharge, major ions, and metals. These data are found in a project PDF file (storetdata.pdf).

Edwards and Tranel (1998) conducted a parkwide study to characterize water quality baseline conditions. Clear water and glacier-fed streams were sampled, both on the north side and south side of the park. They noted significant differences in mean pH, alkalinity, and conductivity values when comparing north and south side samples. Comparisons were also made between glacier-fed and clear water streams on the North side. For example, mean concentrations of most ions were relatively comparable for those two types of streams on the North side. Flow was correlated only weakly to suspended sediment and turbidity for both glacier-fed and clear water streams.

Correlation matrices were developed between chemical constituents to identify ion pairings in order to interpret possible mineralogical characteristics; those results are applicable to the watersheds flowing through the North Access corridor. For example, ion concentrations were not correlated strongly to instantaneous discharge; this finding

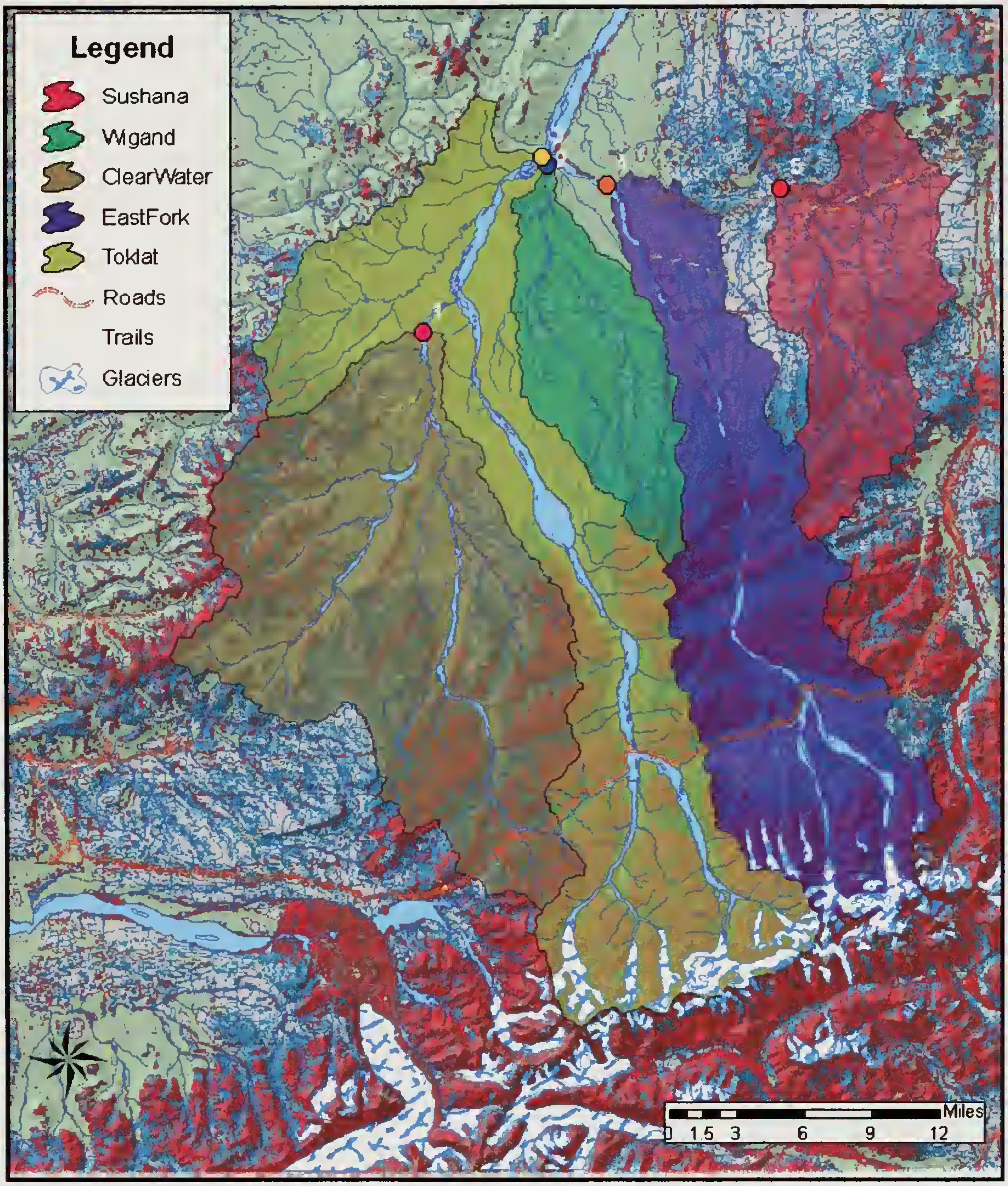


**Figure 2. Watershed map developed from GIS data.**

indicates that neither concentration nor dilution processes are prevalent with stream flow increases. High correlations for Denali Park streams were noted between sulfate and calcium and between sulfate and magnesium. Edwards and Tranel concluded that calcium sulfate and magnesium sulfate are the dominant ion pairs present in most streams in Denali National Park and Preserve.

A significant difference was noted in turbidity values between clear water streams and glacier-fed streams on the North side. The mean value of turbidity for clear water streams was 3.7 NTUs; for glacier streams (including the East Fork River), the mean

value was 363 NTUs. Flow was correlated only weakly to turbidity (and sediment) for both glacier-fed and clear water streams.

In addition to general water quality characterizations, the Edwards and Tranel report included water quality from the East Fork River and from the Clearwater Fork. These two rivers were sampled four times each between 1994 and 1996. Some of the results are described in Table 1.

***Toklat River Studies***

The hydraulic, hydrologic, and geologic conditions associated with floodplain delineation and bank erosion predictions are not well understood for large, braided river systems. Schalk et al. (2001) researched methods to delineate floodplains and assess erosion potential on large braided river systems in Denali. Field data collected for this project include surveyed cross-sections and discharge measurements for both the Toklat and East Fork Rivers. These cross-section data from the Toklat and Teklanika Rivers were used to construct hydraulic computer models to estimate flood depths, degree of inundation and water surface profiles. These are classic techniques used to delineate floodplains on other rivers. The authors note, however, that banks on the Toklat and Teklanika Rivers have been subject to large rates of lateral erosion during periods of discharge less than bankfull, and that the use of classic techniques is ineffective for predicting the location of banks subject to erosion and capture.

In addition to areas of inundation, the authors determined that the associated threat of streambank erosion associated with a particular flood event also needed to be considered when assessing the risks of flooding on wide braided rivers such as the Toklat. By using a number of physical and hydrologic parameters to assess the potential for lateral streambank erosion in an inundated area, and defining a level of consequence severity, a two-dimensional risk analysis matrix was developed to assess the risks of flooding in a braided river flood hazard zone. The authors noted that due to the high rates of hydrologic activity associated with large, braided rivers, and the presence of highly erodible banks that are found on this stream type, accurate bank erosion predictions are difficult to determine.

Included in this report is a literature review. Topics reviews include: braided rivers, causes of the braided pattern, sediment transport, floodplain delineation techniques, and bank erosion.

In response to the need for a replenishable source of gravel, the National Park Service conducted a study to provide a comprehensive analysis of the fluvial processes that occur near and in an alluvial floodplain gravel removal site (Karle, 1989). The report identified the hydraulic characteristics unique to braided rivers, which include several dividing and uniting, wide and shallow channels, with unstable and poorly defined banks and coarse bed material. Karle cites Drage (1977), who concluded in an earlier report that the primary causes of braiding are an abundant sediment load, large and sudden discharge variations, erodible banks, and a steep gradient. Karle describes the hydrology of the

Toklat River basin from the Park road corridor upstream as two subbasins roughly equal in size. In addition to snowmelt and rainfall, the Toklat is fed by glaciers, which cover two percent of the basin area (from the Park road). Karle describes the methods used for this study, which included computer modeling of the Toklat River floodplain, and experimental physical manipulations of the floodplain system. In a related document, Karle describes the techniques developed by the National Park Service that were used to excavate gravel while insuring adequate replenishment rates and self-healing of heavy equipment impacts (Karle, 1990).

**Table 1. Water quality data from Tranel and Edwards (1998) for East Fork and Clearwater Fork.**

| Stream | Clearwater Fork | | | | East Fork R. | | | |
|---|---|---|---|---|---|---|---|---|
| Date | 8/16/ 1994 | 6/29/ 1995 | 7/7/ 1995 | 8/9/ 1995 | 9/12/ 1995 | 7/1/ 1996 | 8/20/ 1996 | 9/25/ 1996 |
| Flow (cfs) | . | 21.3 | 204.5 | 184.5 | . | . | . | . |
| Field pH | 8.2 | 8.03 | 7.82 | 8.22 | 8.46 | 8.22 | 8.16 | 8 |
| Field Cond (uS/cm) | 376 | 709 | 336 | 389 | 350 | 409 | 348 | 426 |
| Water Temp degC | 16.3 | 6.8 | 10.7 | 9.1 | 5.8 | 8.9 | 5.7 | 2.4 |
| TDS (mg/L) | 188 | 354 | 167 | 194 | 175 | 204 | 173 | 213 |
| Dissolved Oxy (mg/L) | . | 12.1 | 11.4 | 11.4 | 12.3 | 11.3 | 11.8 | 12.2 |
| Air Temp degC | . | 12.4 | 19 | 17.6 | 10.8 | 15.6 | 9.1 | 3.3 |
| Lab Conductivity (uS/cm) | 434 | 758 | 308 | 365 | 362 | 430 | 359 | 438 |
| Turbidity (NTU) | 4.9 | 6.1 | 0.6 | 1 | 133 | 41 | 208 | 11 |
| Alkalinity (mg CaCO3/L) | 116.2 | 109.1 | 83.5 | 92.3 | 144.9 | 117.2 | 100.4 | 124.6 |
| Cl (mg/L) | 0.35 | 0.25 | 0.3 | 0.29 | . | . | 15.8 | 25.9 |
| NO3-N (mg/L) | 0.14 | 0.08 | 0.19 | 0.18 | 0.27 | 0.13 | 0.09 | 0.12 |
| SO4 (mg/L) | 99.5 | 301.2 | 71.5 | 90.6 | 44.9 | 48.1 | 41.4 | 64.1 |
| NH3-N (mg/L) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ca (mg/L) | 54.3 | 69.56 | 46.46 | 57.73 | 31.25 | 51.87 | 43.65 | 51.84 |
| Mg (mg/L) | 20.3 | 62.63 | 15.22 | 19.41 | 10.57 | 9.68 | 9.71 | 12.43 |
| Na (mg/L) | 3.53 | 10.67 | 3.64 | 1.54 | 12.08 | 19.21 | 12.87 | 16.92 |
| K (mg/L) | 1.21 | 0.75 | 0.93 | 1 | 2.47 | 3.85 | 2.82 | 3.28 |
| DOC (mg C/L) | 1.88 | 10.54 | 2.71 | 3.61 | 7.84 | 0.68 | 7.29 | 6.05 |

In a companion study, the U.S. Geological Survey monitored the movement of bed material in the Toklat River (Emmett et al., 1996). Bedload sediment was sampled and measured using a handheld bedload sampler; median bedload size was about 8 millimeters, and transport rates ranged from less than 10 to nearly 3000 megagrams per day. As transport rates increased, mean and maximum sizes of bedload tended to increase. Additionally, the authors used radio transmitters placed inside coarse sediment cobbles to track the rate of downstream movement of bedload in the Toklat River (Emmett et al., 1996; Chaco et al., 1989). Radio-tagged particles moved distances between about 5000 and 2,000 meters during a 6- to 8-week period of high flow. The authors reported that most particle movement occurred during the first few days of submersion in water; after that, the particles tended to get abandoned on the floodplain or deposited and buried underneath other bedload.

*Fish Studies*

A survey of fishery resources and water quality was conducted in Denali National Park and Preserve in 1981 (Miller, 1981). The presence of fish was established by electroshocking in 26 streams. Streams within the five study watersheds that were sampled included a tributary to the East Fork River, Color Creek (tributary to the east branch of Toklat River), Toklat River, and three tributaries to the Clearwate Fork (Stony Creek, Betty's Brook, and Little Stony Creek). Arctic grayling (*Thymallus arcticus*) were the only species noted in these streams. Water quality parameters were recorded using field instruments; parameters included water temperature, conductivity, pH, hardness, alkalinity, dissolved oxygen, turbidity, and discharge.

A 1982 study by the NPS investigated the fish resources and aquatic habitat of the Kantishna Hills, including a few tributaries of the Toklat River (Meyer and Kavanaugh, 1982). Only five fish species were observed, with Arctic grayling and slimy sculpin the most abundant and widespread. The draft report also includes some water quality data. No final report for this 1982 draft is available.

The Toklat River and its tributaries, provide important chinook, chum, and coho salmon spawning habitat (Holder and Fair, 2002). Of special note is the Toklat Springs spawning area, which is an extremely productive fall chum salmon spawning area. The Alaska Department of Fish and Game began estimating Toklat River fall chum salmon spawning abundance and distribution in 1974, using both aerial and ground surveys conducted during periods of anticipated peak spawning (Barton 1984). Annual surveys using a variety of techniques are ongoing. The Toklat River escapement database with annual estimates of total spawning abundance is compiled and updated annually (ADF&G, 2005).

## Flood Flow Statistics

Extreme events in water hydrology are of interest to managers because of their importance both ecologically and economically. For example, extreme events affect the populations and distributions of aquatic organisms. The design of bridges, culverts and other hydraulic conveyance structures requires an understanding of expected flood characteristics (Gordon et al., 1992). Hydrologists develop estimations of such events using statistical and probabalistic methods; such methods are described below.

To assist with the assessment of watershed hydrology for the five major drainages, an estimation of the magnitude and frequency of peak streamflows is required. As these drainages are all ungaged, flood magnitudes are computed by using predictive regional regression equations. The USGS recently completed a project to update the peak-streamflow frequency statistics for streamflow-gaging stations in Alaska, and to update the regression equations for estimation of peak-streamflow frequency at ungaged sites (Curran et al., 2003). This new report supercedes previous reports describing peak-flow frequency statistics. These equations, which require the determination and use of physical and climatic drainage basin characteristics, provide estimations of the 2-, 5-, 10-,

25-, 50-, 100-, 200-, and 500-year recurrence interval flood magnitude. Statistically significant basin characteristics that vary by region throughout the State include basin area size, mean basin elevation, mean annual precipitation, mean minimum January temperature, and percentage of basin covered by forest or covered by lakes and ponds. Regression equations are provided for seven hydrologically distinct streamflow analysis regions in Alaska and conterminous basins of Canada.

The Toklat basin study watersheds fall within Streamflow Region 6 (Curran et al., 2003). The input values for the physical characteristics of each catchment for regression equations were derived in ArcView using digital data acquired from the USGS. These included 60 m resolution digital elevation models (DEM) and 1:63,000 scale hydrography for streams and lakes. Polygons for each catchment were intersected with the DEM and the lakes coverage to allow calculation of mean basin elevation, and percent of basin in: lakes and ponds, glaciers, and forest. Basin characteristics for the five watersheds are found in Table 2.

**Table 2. Basin characteristics for Toklat basin study watersheds.**

| Basin Characteristics | Clearwater Fork | East Fork River | Sushana River | Toklat River | Wigand Creek |
|---|---|---|---|---|---|
| Drainage Area ($mi^2$) | 253.0 | 203.6 | 91.6 | 264.4 | 78.5 |
| Mean Basin Elevation (ft) | 3198 | 3626 | 2321 | 3474 | 2211 |
| Area of Lakes and Ponds ($mi^2$) | 0.78 | 2.82 | 1.45 | 8.67 | 0.1 |
| Area of Forest ($mi^2$) | 86.4 | 9.0 | 2.4 | 89.4 | 45.0 |
| Area of Glaciers ($mi^2$) | 0 | 2.74 | 0 | 8.43 | 0 |

The average standard error of prediction for this method roughly ranges from plus 80% to minus 32% for flood frequency Region 6. Estimations for flood magnitudes for the 5 drainages are found in Table 3.

**Table 3. Flood frequency estimations for Toklat basin study watersheds.**

| Flood Frequency Estimate | Clearwater Fork (cfs) | East Fork River (cfs) | Sushana River (cfs) | Toklat River (cfs) | Wigand Creek (cfs) |
|---|---|---|---|---|---|
| 2-year flood | 2300 | 2870 | 1990 | 1740 | 724 |
| 5-year flood | 3490 | 4070 | 2860 | 2660 | 1180 |
| 10-year flood | 4360 | 4920 | 3480 | 3330 | 1530 |
| 25-year flood | 5520 | 6030 | 4320 | 4200 | 2010 |
| 50-year flood | 6420 | 6870 | 4960 | 4880 | 2390 |
| 100-year flood | 7350 | 7740 | 5620 | 5570 | 2790 |
| 200-year flood | 8310 | 8610 | 6300 | 6280 | 3210 |
| 500-year flood | 9630 | 9800 | 7230 | 7250 | 3790 |

It is also important to note the accuracy and limitations of using such regression equations to estimate flood magnitudes on ungaged rivers. The updated USGS method

provides values for the standard error of prediction, which is a measure of the accuracy of a streamflow statistic for an ungaged site estimated from the regression equations. For example, the standard error of prediction for the Region 6 $Q_2$ estimate ranges from -33% to +49%. The USGS method also provides estimations of the 5% and 95% confidence limits for each discharge estimation. All errors of prediction and confidence limits for the estimations of flood magnitudes are found in Appendix B.

The flood flow frequency analysis is a method to assign probabilities to events of a given size. In Table 2 above, the probability is expressed as a "N-year flood" and represents a 1-in-N-year chance. This recurrence interval describes the average length of time between two floods of a given size or larger. The probability of such a flood being equalled or exceeded in any one year is the reciprocal of the recurrence interval. For example, a 100-year flood event has a 1% probability of being equalled or exceeded in any given year. The annual exceedence probabilities are plotted on log-normal probability axis to provide a graphical flood frequency analysis. The annual exceedence graph for the Sushana River is plotted in Figure 3. Graphs for all five watersheds are found in Appendix C.

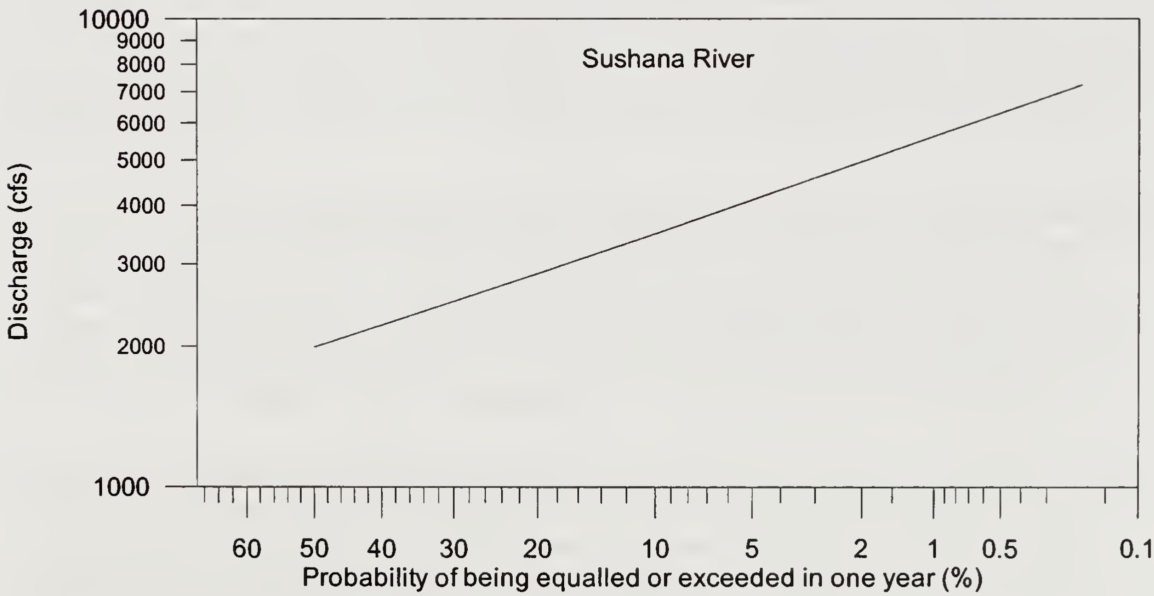



**Figure 3. Annual exceedance probability and flood magnitudes for Sushana River watershed.**

The graphical flood frequency analysis may be used to used to provide estimations of the bankfull discharge at a site. The bankfull discharge is an important flow parameter to determine when assessing the hydrology of a watershed because of the concept that river channels are shaped by, and accommodate, a dominant discharge, and that this discharge occurs with some frequency. Though the gross form of a channel may be shaped by rarer (large) flows, the maintenance of the channel form, and features such as gravel bars, bank vegetation, and others are more closely related to more frequent discharges. The bankfull discharge, or that discharge which just fills the channel to its bank, is often assumed to be

the dominant discharge (Gordon et al, 1992). Many investigators assign a recurrence interval of 1.5 years to the bankfull discharge.

In addition to using field techniques to determine bankfull discharge, it may be estimated from the graphical flood frequency analyses. By extraploting the straight line of the annual exceedence probabilities, the 1.5 year recurrence interval, with a probability of 0.67% is used to find the bankfull discharge. Estimated bankfull discharges for the five major rivers are found in Table 4.

**Table 4. Estimates of bankfull discharge for the 5 Toklat basin study sites.**

| | Clearwater Fork | East Fork River | Sushana River | Toklat River | Wigand Creek |
|---|---|---|---|---|---|
| Bankfull discharge (cfs) | 1850 | 2360 | 1630 | 1400 | 560 |

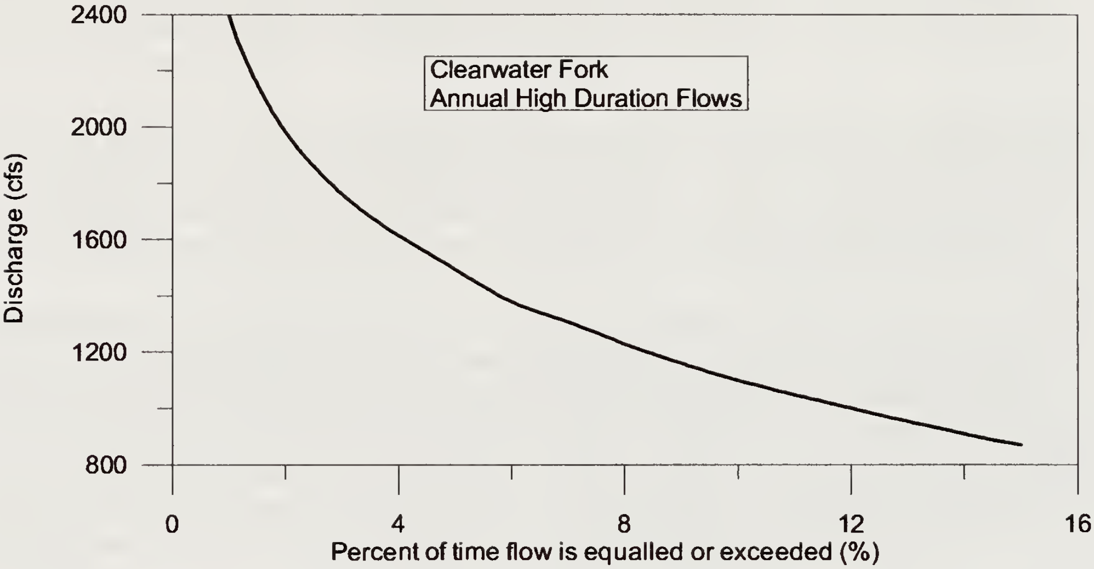
Another aspect of a watershed hydrologic analysis is the development of a flow-duration curve. These curves, developed from streamflow data, are used to display the relationship between streamflow and the percentage of time it is exceeded. For example, the 98-percent duration flow is considered a low flow, because it is equalled or exceeded 98 percent of the time. Conversely, the 2-percent flow is considered a high flow, as it is only equalled or exceeded 2 percent of the time. The development and evaluation of flow-duration curves can provide specific answers for resources concerns, such as what percentage of time the daily flow on a stream with fish spawning habitat is at or above some critical level.

The USGS recently developed methods for estimating daily mean flow-duration statistics for seven regions in Alaska (Wiley and Curran, 2003). This report includes equations to estimate the 15-, 10-, 9-, 8-, 7-, 6-, 5-, 4-, 3-, 2-, and 1-percent duration flows for the October-through-September water year for 7 regions in Alaska and conterminous basins in Canada. Additionally, The 98-, 95-, 90-, 85-, 80-, 70-, 60-, and 50-percent duration flows may be estimated for the individual months of July, August, and September.

Regression equations for estimating the selected high-flow and low-flow statistics for the selected months and seasons for ungaged sites were developed from an ordinary-least-squares regression model using basin characteristics as independent variables. Basin characteristics included drainage area and precipitation for high flow estimation, and drainage area, precipitation, mean basin elevation, and area of glaciers for low flow estimation. These estimating equations can be used at ungaged sites in Alaska where streamflow regulation, streamflow diversion, urbanization, and natural damming and releasing of water do not affect the streamflow data for the given month or season (Wiley and Curran, 2003).

The Toklat Basin falls within the Region 6 flood frequency area. For Region 6, standard errors of estimate ranged from 27 to 33 percent for high-duration flow statistics, and 34 to 78 percent for monthly low-duration flow statistics.

Figure 4 contains the graphs for both the high-flow and low-flow duration statistics for the Clearwater Fork. Graphs for all the study watersheds are found in Appendix D.



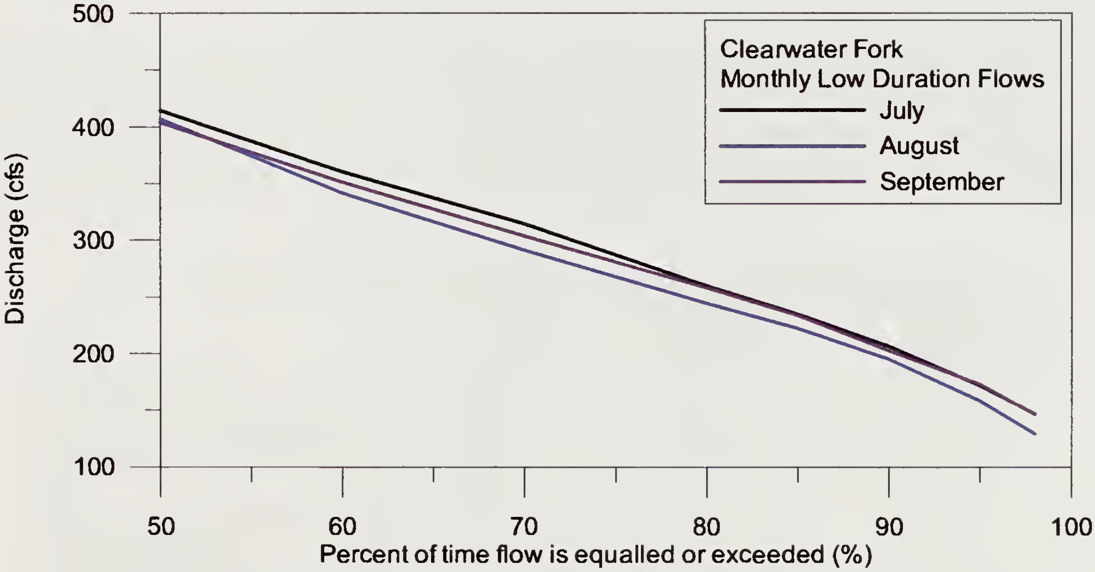




**Figure 4. High flow and low flow duration statistics for the Clearwater Fork.**

## Water Quality

Because of its importance to the biota which drink or transpire or live in the water flowing through rivers, water quality has long been regarded as an important characteristic in the assessment and description of watersheds both remote and urban (Gordon et al., 1992). As described previously some water quality information is already

available for the East Fork River and Clearwater Fork from the Edwards and Tranel report (1998). For the remaining watersheds without not included in that baseline survey (Sushana, Toklat, Wigand), water quality information was obtained by field visits to the sites in August 2004, using a variety of field techniques (Table 5). Some parameters were measured in the field, while laboratory analyses of collected water samples were used for other parameters.

At each sampling site, stream temperature, pH and dissolved oxyen were measured in the field. Temperature and dissolved oxygen were measured with a YSI DO 200 Dissolved Oxygen/Temperature Meter, and pH was measured with a Oakton hand-held wand-type pH meter. Turbidity was measured with a Hach Model 16800 Portalab TurbidiMeter.

Temperature and dissolved oxygen were determined by immersing the conductivity cell directly into the stream water near the channel's edge, but in the active current. After allowing the meter to stabilize for a few minutes, the reading for each parameter was recorded in the field notebook. Temperature was recorded in °C, and dissolved oxygen was recorded in ppm. The dissolved oxygen meter was calibrated at the beginning of the sampling effort, according to the manufacturer's instructions. Similarly, the pH wand was calibrated at the start of the sampling day according to the manufacturer's instructions.

Samples were collected and stored in new HDPE bottles for laboratory analysis. Four 250-ml samples were collected at each stream. One sample was collected for ionic chemistry analyses, one sample was collected for dissolved organic carbon, and two samples was collected for duplicates. Each sample bottle was labeled with the sampling location, date, time, and bottle number prior to collecting the samples.

**Table 5. Water quality for Sushana River, Toklat River, and Wigand Creek.**

| | Sushana River | Toklat River | Wigand Creek |
|---|---|---|---|
| Date | 08/19/2004 | 08/19/2004 | 08/19/2004 |
| Discharge (cfs) | 8.21 | na | 102.68 |
| water temperature (deg C) | 8.9 | 13.8 | 5.8 |
| dissolved oxygen (ppm) | 11.87 | 10.24 | 13.79 |
| pH | 8.28 | 8.53 | 8.45 |
| conductivity (*u*s/cm) | 274 | 310 | 541 |
| Turbidity (NTU) | 0.9 | 1020 | 2.2 |
| Total Phosphorus | <0.1 | <0.1 | <0.1 |
| Nitrate-Nitrogen | 0.1 | 0.2 | 0.1 |
| Ammonium-Nitrogen | <0.1 | <0.1 | <0.1 |
| Alkalinity | 100.0 | 118.5 | 120.0 |
| Calcium | 38 | 45.0 | 63.0 |
| Magnesium | 13 | 9.0 | 32.0 |
| Sodium | 3 | 7.0 | 9.0 |
| Potassium | <1.0 | 1.0 | 2.0 |
| Chloride | <1.0 | 6.0 | 4.0 |
| Sulfate | 14.0 | 9.0 | 66.0 |
| Dissolved Organic Carbon | 1.2 | <MRL | <MRL |

The bottles for ionic chemistry and dissolved organic carbon were filtered by hand-vacuum pumping through a 0.45-um membrane filter. The filtering apparatus (Nalgene 310) and the filter were rinsed initially with stream water, and the stream rinse water was then discarded. The sample was then filtered, and the initial filtered water was used to rinse the bottle and cap. Then the full sample was filtered and poured into the bottles. All samples were refrigerated immediately after collection and then shipped immediately to the analytical laboratories in coolers packed with ice and placed within insulated boxes. The samples for dissolved organic carbon analysis were delivered to Analytica Laboratories in Anchorage, Alaska, and all other samples were delivered to the Central Analytical Laboratory at Oregon State University in Corvallis, Oregon.

A coincident discharge measurement was taken at the time of sampling, if safe wading conditions allowed for such (Figure 5). Measurements were made at the East Fork River, Wigand Creek, and Sushana River. To measure discharge, a tape was stretched across the stream, and depth and velocity were measured at 0.6-depth levels using either a Price AA or Pygmy current meter and wading rod. Typically, the stream flow was divided into 5-percent sections, and measurements were taken in the middle of the sections. At least 20 cross-sectional measurements were collected for each transect.

**Figure 5. Discharge measurement at the East Fork River.**

The results from the water chemistry analyses of the Sushana River, the Toklat River, and Wigand Creek are similar to those for the East Fork River and Clearwater Fork, and within the ranges for North side glacier-fed and non glacier-fed rivers as described in the Edwards and Tranel report (1998). The pH values for the 3 sampled sites were contained in a narrow range from 8.28 to 8.53; all samples were considered alkaline (i.e., pH > 7.0.). A study of 62 streams in Denali found the average pH of north-side streams at 7.77, and 7.00 for the south side. Alkalinity values for the 3 sites ranged from 100.0 to 120.0 mg/L. These streams may be considered well-buffered, especially when compared

to south side streams within Denali. Generally speaking, a well-buffered system will resist quick and dramatic changes to the pH of the water from sources such as atmospheric acidic deposition.

There are two main sources of dissolved oxygen in stream water: the atmosphere and photosynthesis. Oxygen readily dissolves into cold water up to a saturation point through the actions of waves and tumbling water. Additionally, oxygen is introduced by aquatic plants and algae as a byproduct of photosynthesis. The measured values of water temperature and dissolved oxygen values are sufficient for fish growth and activity. All dissolved oxygen values were at or close to saturation values for fresh water.

Turbidity levels were well within expected ranges. Glacier fed rivers, such as the East Fork and Toklat Rivers, generally show turbidities in excess of 30 NTU during mid to late summer discharges (Milner and Oswood, 1997). Turbidity measurements for those two rivers reflect the high suspended sediment loads common in glacier fed systems (Figure 6). Likewise, the low turbidity values from the three clearwater streams (Sushana River, Wigand Creek, and Clearwater Fork) were well within the typical range for clear water rivers in Alaska, which generally have turbidities of less than 10 NTU (Milner and Oswood, 1997).

The general water quality of the five study watersheds may be described as good. The remoteness of these watersheds, their location in a national park and preserve, and the limited access to these areas for humans to date, have combined to limit environmental degradation of these freshwater resources.

### Channel Geometry Analysis

The shape of a river cross-section at a given location is a function of the flow, the quantity and size of the sediment carried by the flow, and the composition of the bed and bank materials of the river. Surveys of channel characteristics are conducted to both help describe the physical characteristics of the stream channel, and to provide a physical representation of the channel for numerical modeling purposes. Using basic cross-section survey techniques, all major features of the stream channel and floodplain for the East Fork and Toklat Rivers at the potential road corridor crossing were measured and mapped. Fieldwork was conducted during Setember 2004 during a period of low flow, to allow surveyors to safely wade the channels. The fieldwork conducted at each site includes the following:

- survey of longitudinal profile
- survey of 2 or 3 cross-sections per site
- water discharge measurements in each flowing channel, at each site
- water surface elevation data for each discharge measurement
- channel material gradation, using pebble count
- river morphology information
- photographs
- high water indicators, where available

**Figure 6. High suspended sediment load and turbidity in the Toklat River.**

All profile surveys and cross-section surveys were conducted using a Pentax PTS V3 three-second total station. Most sites were wadable, and cross-sections were surveyed by shooting to a wader carrying a reflecting prism. All discharge and velocity measurements were made using a Price AA or pygmy current meter.

The water surface slope was surveyed to be used as a surrogate for the energy slope of the channel. The slope was surveyed by surveying the horizontal location and vertical elevation of the water surface at the right edge of water at multiple locations along the main channel of each river. The slope was calculated by dividing the elevation difference between the upstream and downstream point by the total horizontal difference along the channel between the two points.

An example of a surveyed cross-section is found in Figure 7. Note that because these braided rivers are extremely wide in nature, the vertical scales are much smaller than the horizontal scale when graphing the cross-sections. For example, the verticle scale in Figure 7 is 1:160. The horizontal scale is 1:1200. All surveyed cross-sections for the East Fork and Toklat Rivers are found in Appendix E.

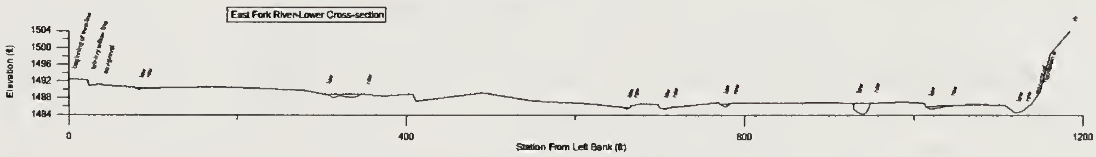



**Figure 7. Lower cross-section, East Fork River.**

Cross-section widths from bank to bank, the energy slope of the channel at low flow, the total flow measured in all significant channels at the time of the survey, and the distance between the cross-sections at their mid-points, and the energy slope of the channel at low flow are found in Table 6.

**Table 6. Results from cross-section surveys of East Fork and Toklat Rivers.**

| Site | East Fork River | | | Toklat River | |
|---|---|---|---|---|---|
| | upper | middle[1] | lower | uppper[2] | middle |
| width (ft) | 1298 | 1256 | 1117 | 2376 | 2872 |
| distance between (ft) | 643 | 1014 | - | 1865 | |
| slope (ft/ft) | 0.0098 | | | 0.0097 | |
| discharge (cfs) | 49.03 (3 channels) | | | 87.53 (4 channels) | |

1-Location of middle East Fork cross-section N63°52'52.5" W150°03'52.0"
2-Location of upper Toklat cross-section N63°48'03.6" W150°15'51.7"

To characterize the composition of the stream bed, a Wolman pebble count was conducted at each study site (Wolman, 1954). Bed particles were randomly selected via a step-toe procedure, and the intermediate axis (neither the longest nor shortest of the three mutually perpendicular sides of each particle picked up) was measured and recorded. One hundred particles were measured per count. Pebble counts were conducted between the bankfull limits of the channel, unless the section was not wadable.

Counts were conducted between the lower and upper cross-sections of each site. The sampler began at the downstream cross-section, and worked his way upstream in a zigzag fashion while continuing to sample. In addition to the in-channel pebble counts, dry banks adjacent to the channels were sampled by stretching a 100-foot tape along the ground surface and measuring each pebble at one foot increments. For both pebble counts, the particles are tallied and reported by using Wentworth size classes in which the size doubles with each class (2, 4, 8, 16, 32, etc.). Particle tallies are plotted as a cumulative total on log-normal graphs; graphs for the Toklat and East Fork Rivers are found in Figure 8, along with estimations for both the in-channel and dry bank materials of the $D_{50}$, which is the effective median particle size.

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## Morphological Description

The East Fork and Toklat Rivers are both multiple-channel, or braided systems, and consist of interconnected distributary channels formed in depositional environments. At the study stites, these channels are classified as D4 stream types in the Rosgen classification system (Rosgen, 1996). The channel bed materials are predominantly gravels, with a mixture of cobbles, silt, and occasional boulders. Typical braided channel systems such as these two rivers are characterized by high bank erosion rates, excessive deposition occurring as both longitudinal and transverse bars, and annual shifts of the bed locations (Rosgen, 1996). Bed location shifts have been noted by this author much more frequently upstream on the Toklat and East Fork rivers, often in the space of a month or less. The bed morphologies for both rivers are characterized by a closely spaced series of rapids and scour pools formed by convergence/divergence processes that are very unstable, though more pronounced in the Toklat River.

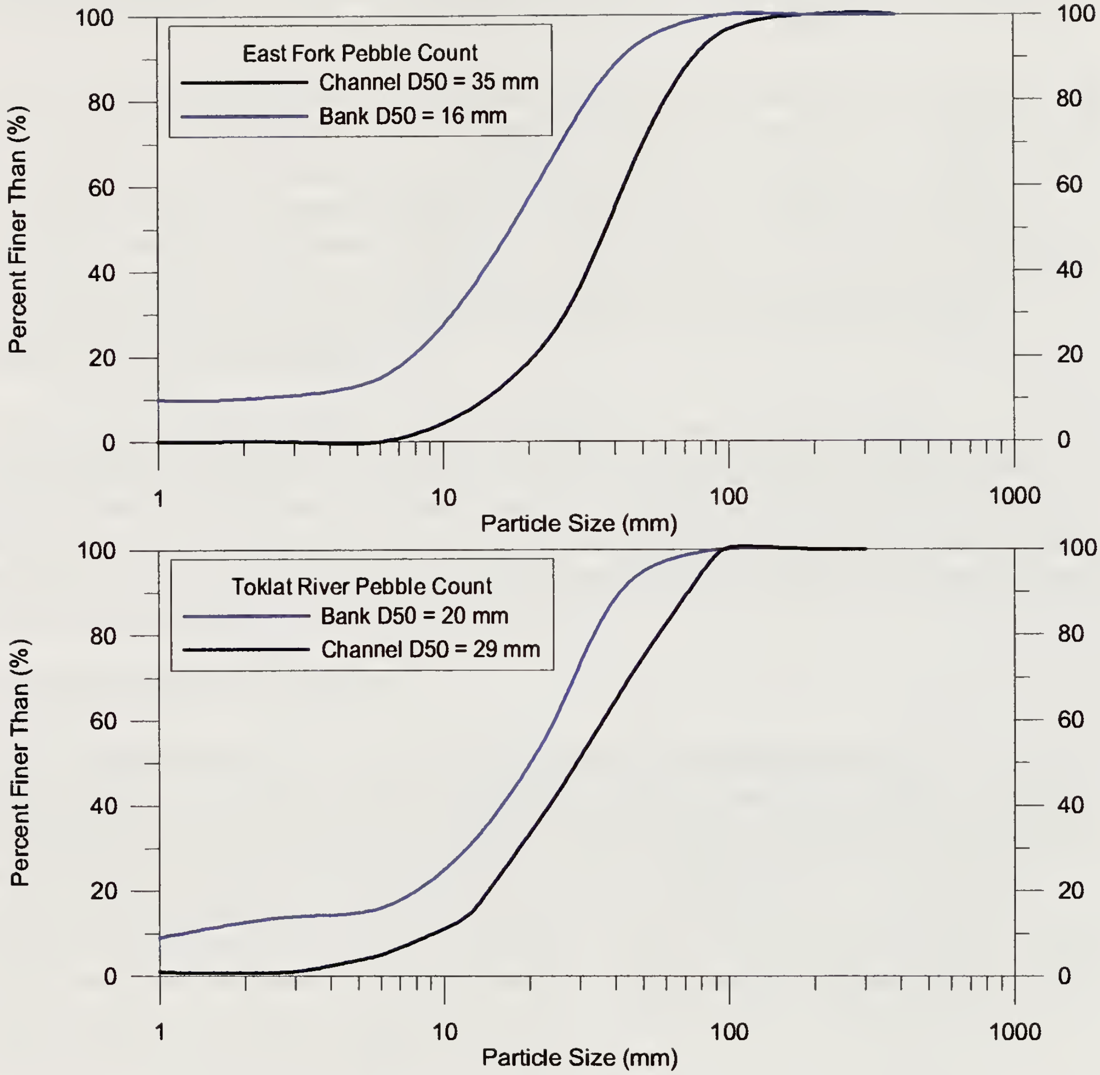


**Figure 8. Particle size distributions for the East Fork and Toklat Rivers.**

As mentioned before, the primary causes of braiding are an abundant sediment load, large and sudden discharge variations, erodible banks, and a steep gradient. Previous studies have shown that the presence of glaciers in a watershed, even in small amounts, can significantly modify the hydrograph from precipitation-dominated rivers (Anderson, 1970). The flow of glacier-fed rivers in Denali National Park and Preserve may be expected to steadily increase from early May to the middle of June, as snowmelt occurs. High flashy peaks in the hydrograph are often observed in July and August, and are due to a combination of warmer weather (glacial melt) and precipitation events (Karle, 1989).

Rosgen noted that width to depth ratios for braided rivers are very high, and may range from 40 to 400 or larger (Rosgen, 1996). Large width to depth ratios were noted for all

surveyed cross-sections for this study for these two rivers. Emmett et al. (1996) noted very high sediment supply yields for both the East Fork and Toklat Rivers.

In the vicinity of the surveyed cross-sections, the right bank (looking downstream) of the East Fork River is approximately 6-7 feet high. Overhanging black spruce trees and a thick organic layer are collapsing into an active channel, indicating recent erosion. The left bank is much lower, approximately 1 foot hight, with low willows, no obvious organic mat, and scalloped areas of erosion noted occasionally. In the center of the wide braided gravel drainage course, willow 6-10 feet high was noted in some areas. Large uprooted spruce tree boles were also noted scattered across the drainage course, indicating recent flood activity.

In the vicinity of the Toklat River surveyed cross-sections, the right bank is approximately 1-2 feet high. The bank appears stable, and the adjoining floodplain supports mature white spruce and aspen trees 30 feet high or more, and thick willow 6 feet or higher. A heavy deposit of silt is observed on the floodplain floor. The low left bank adjoins a terrace consisting of willow, alder, and grasses, which is backed by a steep bank of mixed connifer, birch, and aspen trees.

## Hydraulic Modeling Analysis

Because of the difficulty in obtaining hydraulic measurements during high river stage, computer numerical analysis software is often used to estimate water surface elevations and water velocities during high flood flows. For example, a commonly used program is the HEC-RAS hydraulic modeling system (USACE, 1998), which is a water-surface profile computational model for one- dimensional, gradually varied flow. The basic computational procedure is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction(Manning's equation) and contraction/expansion. The momentum equation is utilized in situations where the water surface profile is rapidly varied, such as at bridges (USACE, 1998).

Numeric models of study sites are created using stream geometric data. Once the models are constructed and calibrated, estimations of channel velocities and stage are calculated for each cross-section for a range of discharges.

The cross-section conditions present at a typical braided river site present many unique computational problems for numerical modeling efforts. At low and intermediate flows, the occurrence of flowing water in any of the many channels spaced across the wide braided drainage course appears often as a randomized process. In fact, channels with a higher thalweg elevation may contain significant flow while lower channels on the same section are often dry. Such an effect can be noted in the cross-section surveys for the East Fork and Toklat Rivers for this survey.

Such conditions cannot be replicated in a numerical model, where hydraulic calculations assume flowing water initiates at the lowest point in a cross-section. This results in a situation where a numerical model cannot be properly calibrated at low flow, even using

observed discharges and water surface elevations in numerous channels across the section. Additionally, modeling at high flood flows may also not result in accurate predictions of which channels or areas of the wide cross-section are inundated. Results from such modeling efforts should be used with extreme caution.

Numerical models of the Toklat and East Fork Rivers were constructed in HEC-RAS, using the surveyed cross-sections. Techniques were employed to increase the functional stability of the hydraulic analysis process; this is accomplished by increasing the number of cross-sections in the model by replicating surveyed cross-sections and adjusting the elevation of the points, based on the surveyed slope. Estimates of the Mannning's n roughness value were obtained by using the field discharge measurements to back-calculate a value. Estimates of the areas of inundation were made by modeling 4 diferent flood flows: the 2-year, 50-year, 100-year, and 200-year flood. An example of the output from HEC-RAS for the 200-year flow in the Toklat upper cross-section is found in Figure 9. Graphs from both rivers and all cross-sections are found in Appendix F.

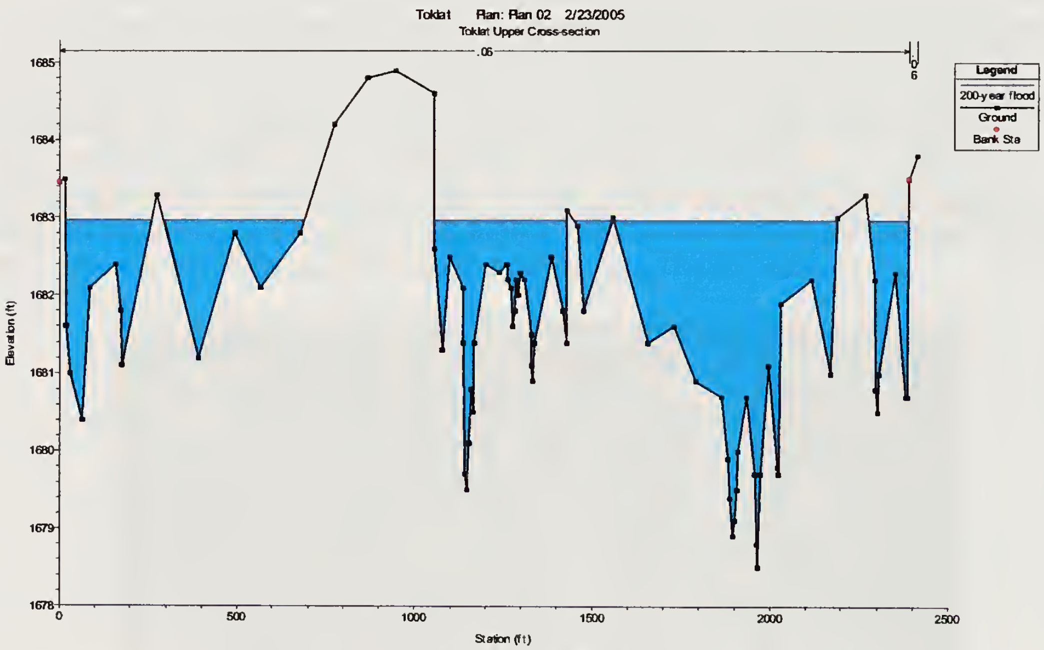


**Figure 9. HEC-RAS estimate for the 200-year flood for the Toklat River.**

## Flood-Prone Area Delineation

Based on the results from the cross-section surveys, HEC-RAS analysis, and field observations, approximate flood-prone areas in the vicinity of the old Stampede Trail were delineated using 1:6000 true color aerial photographs from 1987. The results are found in Figures 10 (East Fork River) and Figure 11 (Toklat River).

A floodplain may be defined as a level area near a river channel, constructed by the river in the present climate and overflowed during moderate flow events (Leopold, 1994). For a typical meandering single channel river, the flood-prone area is generally found in a

vegetated zone between the top of the channel bank and higher terraces. For braided rivers such as the Toklat and East Fork Rivers, the flood-prone areas generally occur between the two banks, on the non- or lightly-vegetated gravel drainage course.

As noted earlier in this report, the delineation of floodplains and predicted areas of bank erosion is difficult on large braided rivers. For example, even though the HEC-RAS analysis for the three cross-sections of the East Fork show the 100-year flood flow contained within 900 to 1,000 feet center to right in the 1400-foot cross-sections, field evidence shows obvious flow channels in the 'non-flood' sections. Though some areas of the braided gravel cross-section are higher in elevation than others by 3 to 5 feet and appear as 'islands' in the HEC-RAS analysis, this does not exclude those areas from being subject to occasional flow inundation. Because of this, the flood prone areas in Figures 10 and 11 were delineated largely by using the existing permanent vegetation line, along with field observations.

Though banks on these large braided rivers can be subject to large rates of lateral erosion, even at lower flows, it appears large floods generally do not readily inundate the higher vegetated banks, but are contained within the banks, even as they erode. Older, non-active side channels that have revegetated exist in some areas, such as the inside point bar bisected by the old Stampede Trail on the left bank of the East Fork River (Figure 10). Some of these channels may be the result of winter icing conditions, which can leave a thick layer of ice covering the entire gravel bar long into the spring and early summer. Such aufeis often forces water flowing from spring melt out of the main channel and over the banks into the lower vegetated areas until the gravel course melts out.


**Figure 10. Approximate flood-prone area for the East Fork River.**

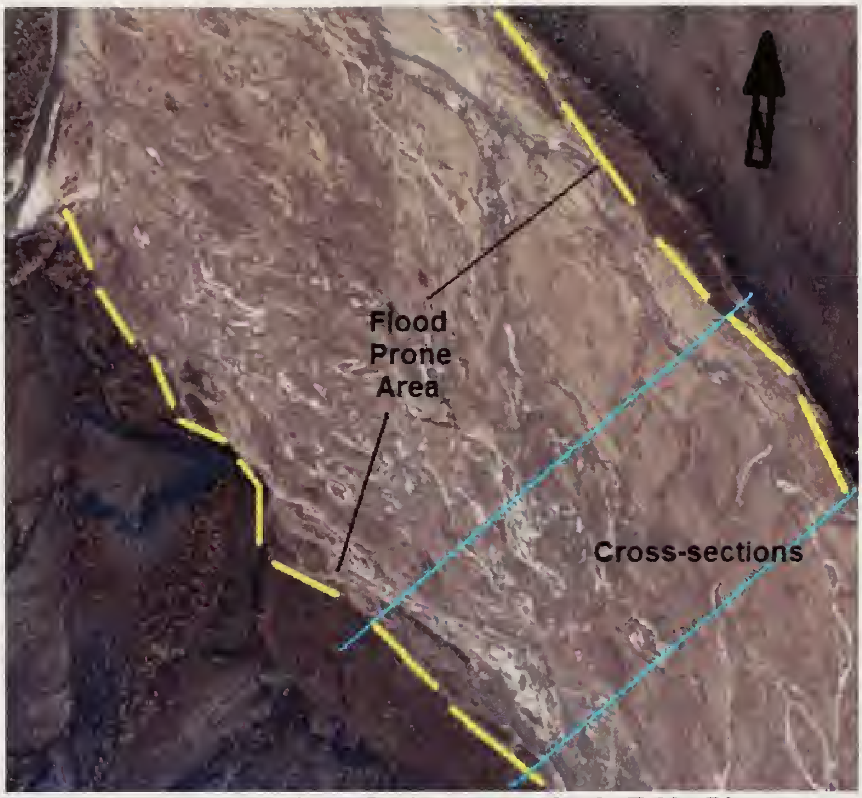

**Figure 11. Approximate flood-prone area for the Toklat River.**

## Toklat Springs

The Toklat Springs is a an extremely productive fall chum salmon spawning area that is very important to the subsistence and commercial fisheries along the Tanana and Yukon rivers (ADF&G, 2005). This feature's existence is due in part or whole to an upwelling of water through the riverbed gravels, and is notable for its reach of open water all winter long. The springs are located at the confluence of the Sushana River and the Toklat River, approximately 18.5 miles north of the confluence of the East Fork River, Toklat River, and the Stampede Trail (Figure 12). The springs are described in several documents, including Sheldon (1930) and Valkenburg (1974).

Sheldon described the open water as 6 to 8 kilometers in length, though he did not delineate the fractions of length on the Sushana or Toklat Rivers. On several field visits in Februrary and March of 1973 and 1974, Valkenburg noted that the springs originate from water bubbling up through the dry channel bed of the Sushana River, starting at about 0.75 km upstream from its confluence with the Toklat. At that time, the total extent of the open water was estimated at 4 km, and water depths were estimated to be from a few centimeters to 2 meters in some larger pools. Valkenburg also noted that it is possible that the spring is just a re-emergence of the waters of the Sushana River (1974).

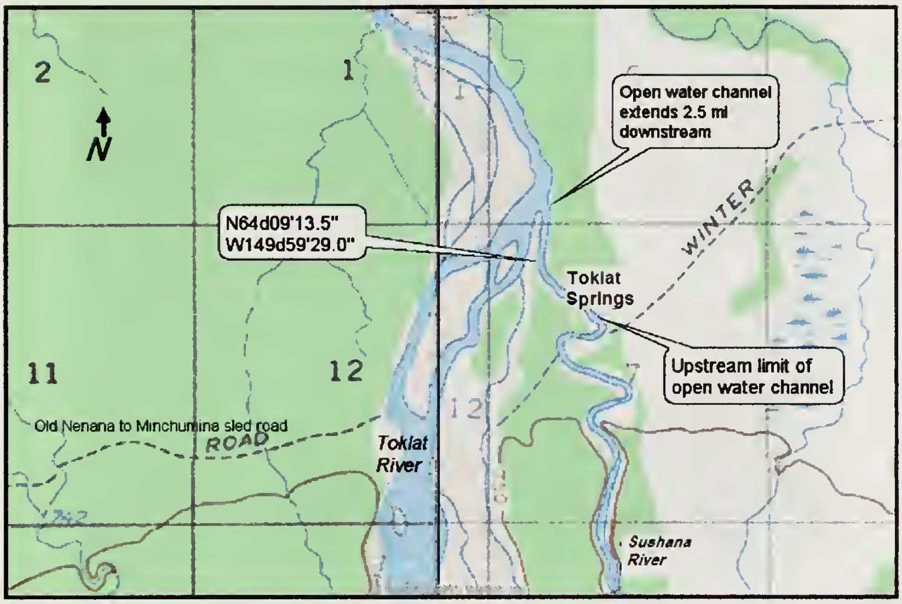


**Figure 12. Location of the Toklat Springs, and extent of open water during a March 2005 site visit.**

Valkenburg obtained several water temperature reading on a visit to the springs on March 18, 1974. He noted that the water temperature ranged from 4° C at the head of the springs to 2° C 1.5 km downstream (Valkenburg, 1974).

As part of this project, an aerial survey and brief ground visit of the Toklat Springs was conducted in an effort to map the extent of the springs. The visit was conducted using a chartered ski-equipped SuperCub fixed wing aircraft. The site was flown on March 24, 2005. After observing the springs from the air, the aircraft landed on the Toklat River bar adjacent to the springs so that on-the-ground observations could be made.

Location readings were taken on the ground using a handheld GPS unit to delineate the extent of open water on the Sushana River. Open water was noted for approximately 2500 feet upstream of the confluence with the Toklat River (Figure 13). From the confluence with the Toklat River, this channel remained open downstream for a distance of approximately 2.5 miles, where a large area of aufeis was noted (Figure 14). Observers note that the extent and discharge of the springs varies somewhat annually, depending on seasonal precipitation patterns and influx from side channels of the Toklat River (Bonnie Borba, ADF&G, personal communication, 2005).

Water ranged in depth from a tenth of a foot to approximately 3 feet deep in one pool in the downstream section. Water temperatures were measured with a handheld thermometer. Temperatures ranged from +1° C at the upstream end of the open water to 2° C at the lower end. Though not measured, visible discharge was noted to double from the upstream end to the lower end; total discharge was estimated not to exceed a few cubic feet per second.

Figure 13. Upper end of open water channel at Toklat springs.

In addition to the Toklat springs, open water channels were noted in several other locations nearby. For example, smaller open water channels were located on several streams approximately 1 and 2 miles to the east and several miles north of the Toklat River. These channels remained open for several miles before closing back up with an ice cover, or connecting to the Toklat River channel. One open channel was also noted flowing into the west side of the Toklat River, several miles downstream from the Toklat springs.


Figure 14. Open water channel extending downstream from Toklat Springs.

In their descriptions of the springs, both Sheldon and Valkenburg noted extensive evidence of wildlife utilizing the spring area. During the March 2005 visit for this study, a wolf was observed at the site during the initial flyover; it subsequently left the site

during our visit. Six ducks were also noted at the site, though the species was not noted. Additionally, there were numerous salmon heads and carcasses that had been recently deposited on the banks along the channel; again, the species was not noted. (Figure 15).

**Figure 15. Salmon head at Toklat Springs.**

## Recommendations

Additional studies are needed to continue the evaluation of the water resources of the north access corridor. Given the likelihood of the continued interest in developing a transportation corridor in that area, the following suggested research topics are outlined below:

- Estimates of the quantity of gravel required to build the north access route should be developed. Potential sites for gravel borrow pits should be identified. Impacts to local hydrologic conditions from gravel mining should be identified.

- River crossings should be identified, and a discussion of the impacts from bridges and culverts should be developed. Impacts from floodplain restriction should be identified.

- In addition to the Toklat River, occasional fish spawning and rearing areas should be identified on other streams, including the East Fork River and Wigand Creek.

- Other potential threats to the park aquatic resources should be identified and quantified.

- In the event of imminent development of a transportation corridor, long-term monitoring of the water quality in these watersheds should be initiated. Water

quality parameters to be monitored should be carefully selected with the goal of being able to quickly and accurately ascertain potential impacts to the aquatic habitat of these watersheds.

## Companion Products

A number of products developed for this study were not included in this report, due to space limitations and the desire for a manageable document for park managers to use. Instead, these products are included on a companion CD, available on the sleeve of this report. Those products include:

- All digital project photographs to date, organized by river.
- GIS (ArcGIS 9) file. This file contains the geodatabase used to delineate and display the five study watersheds. The projection of all the data is Albers Equal Area Alaska, NAD27.
- EPA STORET water quality files.
- MS Access database file, which contains all field data obtained to this point, including water chemistry, discharge, cross-section surveys, pebble counts, and flood magnitude estimations. Many of the graphs included in the Appendices of this report are embedded in the Access database. .

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## Appendix A. Flood magnitudes, estimates of error, and confidence limits

This program computes estimates of N-year floods for ungaged sites in Alaska based on the report "Estimating the Magnitude and Frequency of Peak Streamflows for Ungaged Sites on Streams in Alaska and Conterminous Basins in Canada", WRIR 03-4188. See the above publication for equations. VERSION 10/04/03 . In addition to the standard error of prediction (SE), the average equivalent years of record (EQ. YEARS) value is an overall measure of predictive ability; it relates the predictive ability of the regression equations to that obtained by flood-frequency analysis of number of years of peak-discharge data collected at the site.

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Flood frequency estimates for
Site: Clearwater River
Region 6
Drainage area,in square miles: 253.00
Percent of area in lakes and ponds: 0.3
Forest cover, in percent: 34.0

| N | DISCHARGE (cfs) | SE (+%) | SE(-%) | CONFIDENCE LIMITS 5% | 95% | EQ. YEARS |
|---|---|---|---|---|---|---|
| 2 | 2300. | 47.8 | -32.3 | 1200. | 4420. | 1.3 |
| 5 | 3490. | 49.0 | -32.9 | 1790. | 6800. | 1.8 |
| 10 | 4360. | 52.0 | -34.2 | 2170. | 8760. | 2.2 |
| 25 | 5520. | 56.8 | -36.2 | 2600. | 11700. | 2.7 |
| 50 | 6420. | 61.0 | -37.9 | 2900. | 14200. | 3.0 |
| 100 | 7350. | 65.5 | -39.6 | 3170. | 17000. | 3.3 |
| 200 | 8310. | 70.2 | -41.2 | 3420. | 20200. | 3.5 |
| 500 | 9630. | 76.8 | -43.4 | 3720. | 24900. | 3.6 |

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Flood frequency estimates for
Site: Toklat River
Region 6
Drainage area,in square miles: 264.38
Percent of area in lakes and ponds: 3.3
Forest cover, in percent: 34.0

| N | DISCHARGE (cfs) | SE (+%) | SE(-%) | CONFIDENCE LIMITS 5% | 95% | EQ. YEARS |
|---|---|---|---|---|---|---|
| 2 | 1740. | 48.1 | -32.5 | 905. | 3360. | 1.2 |
| 5 | 2660. | 49.4 | -33.1 | 1360. | 5210. | 1.7 |
| 10 | 3330. | 52.4 | -34.4 | 1650. | 6720. | 2.2 |
| 25 | 4200. | 57.3 | -36.4 | 1970. | 8960. | 2.7 |
| 50 | 4880. | 61.5 | -38.1 | 2190. | 10900. | 3.0 |
| 100 | 5570. | 66.1 | -39.8 | 2390. | 13000. | 3.2 |
| 200 | 6280. | 70.9 | -41.5 | 2570. | 15400. | 3.4 |
| 500 | 7250. | 77.6 | -43.7 | 2780. | 18900. | 3.5 |

Flood frequency estimates for
Site: Wigand Creek
Region 6
Drainage area,in square miles: 78.46
Percent of area in lakes and ponds: 0.1
Forest cover, in percent: 57.3

| N | DISCHARGE (cfs) | SE (+%) | SE(-%) | CONFIDENCE LIMITS 5% | 95% | EQ. YEARS |
|---|---|---|---|---|---|---|
| 2 | 724. | 47.9 | -32.4 | 377. | 1390. | 1.6 |
| 5 | 1180. | 49.2 | -33.0 | 605. | 2300. | 2.3 |
| 10 | 1530. | 52.1 | -34.3 | 758. | 3080. | 2.9 |
| 25 | 2010. | 57.0 | -36.3 | 945. | 4270. | 3.6 |
| 50 | 2390. | 61.2 | -38.0 | 1080. | 5300. | 3.9 |
| 100 | 2790. | 65.7 | -39.6 | 1200. | 6480. | 4.2 |
| 200 | 3210. | 70.4 | -41.3 | 1320. | 7820. | 4.5 |
| 500 | 3790. | 77.1 | -43.5 | 1460. | 9850. | 4.7 |

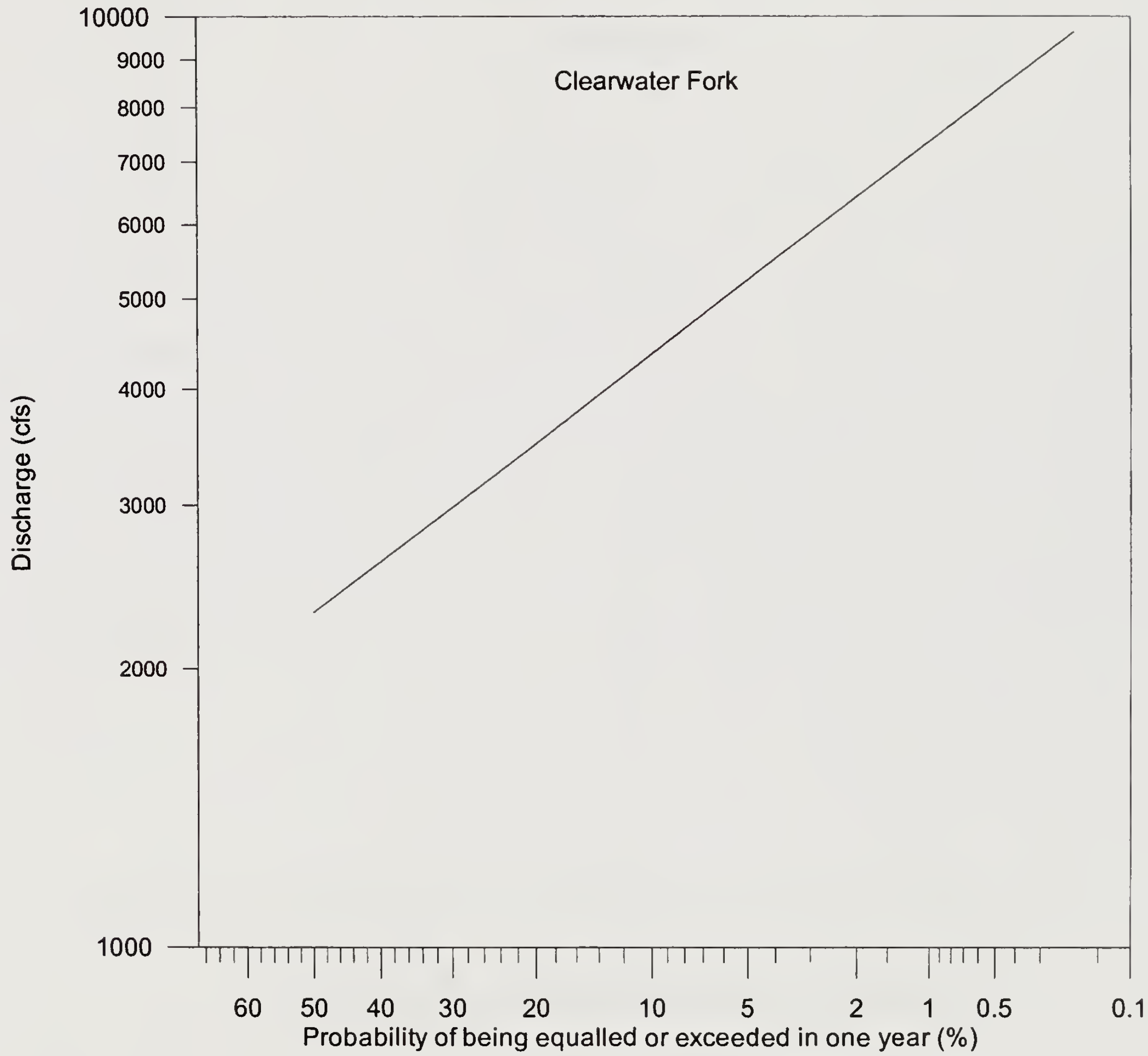
Flood frequency estimates for
Site: East Fork River
Region 6
Drainage area,in square miles: 203.60
Percent of area in lakes and ponds: 1.4
Forest cover, in percent: 4.4

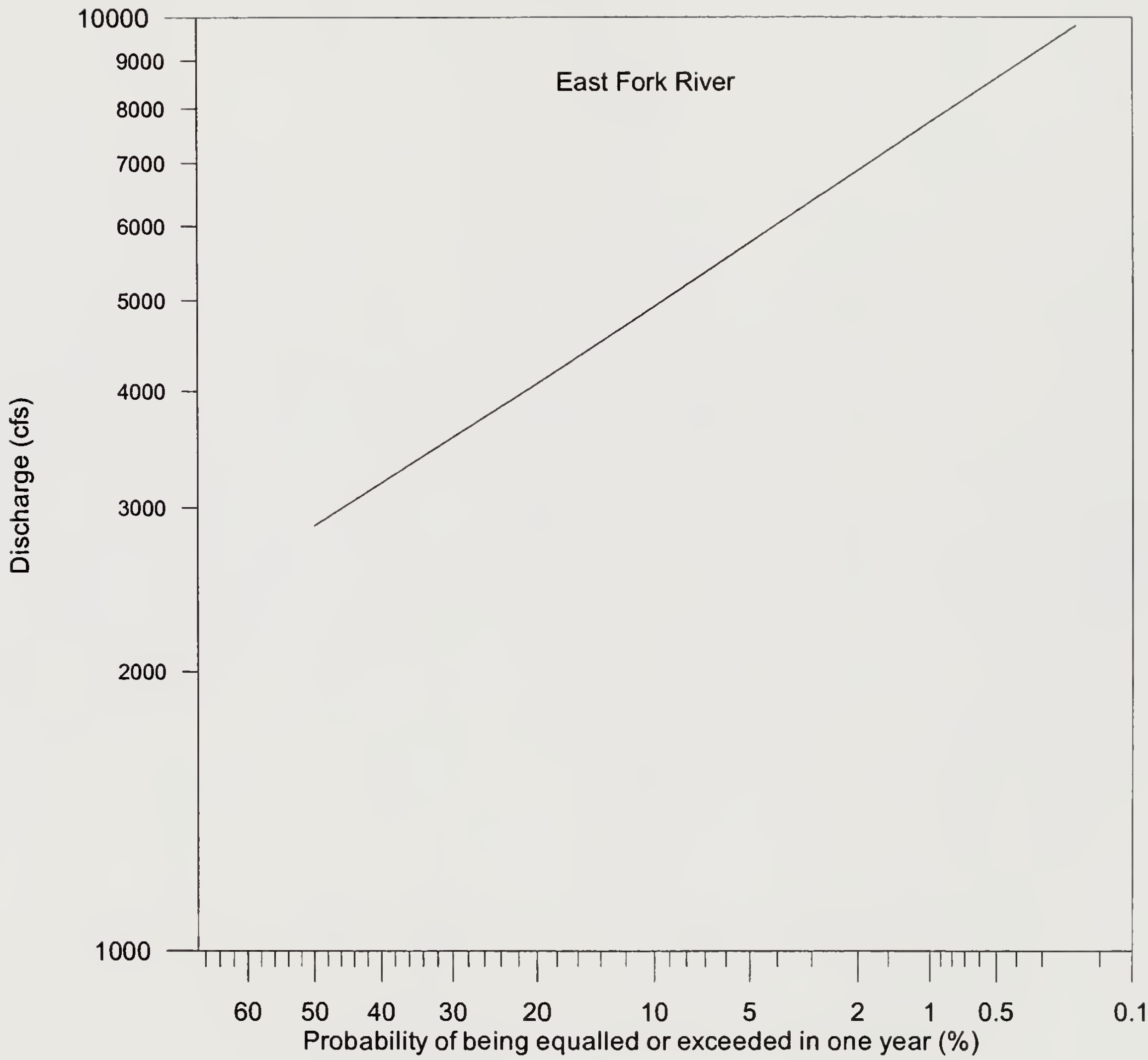
| N | DISCHARGE (cfs) | SE (+%) | SE(-%) | CONFIDENCE LIMITS 5% | 95% | EQ. YEARS |
|---|---|---|---|---|---|---|
| 2 | 2870. | 48.3 | -32.6 | 1490. | 5540. | 1.3 |
| 5 | 4070. | 49.6 | -33.2 | 2080. | 7980. | 1.8 |
| 10 | 4920. | 52.7 | -34.5 | 2430. | 9970. | 2.3 |
| 25 | 6030. | 57.7 | -36.6 | 2820. | 12900. | 2.8 |
| 50 | 6870. | 61.9 | -38.3 | 3070. | 15400. | 3.1 |
| 100 | 7740. | 66.5 | -40.0 | 3300. | 18100. | 3.4 |
| 200 | 8610. | 71.4 | -41.6 | 3500. | 21200. | 3.5 |
| 500 | 9800. | 78.2 | -43.9 | 3730. | 25700. | 3.7 |

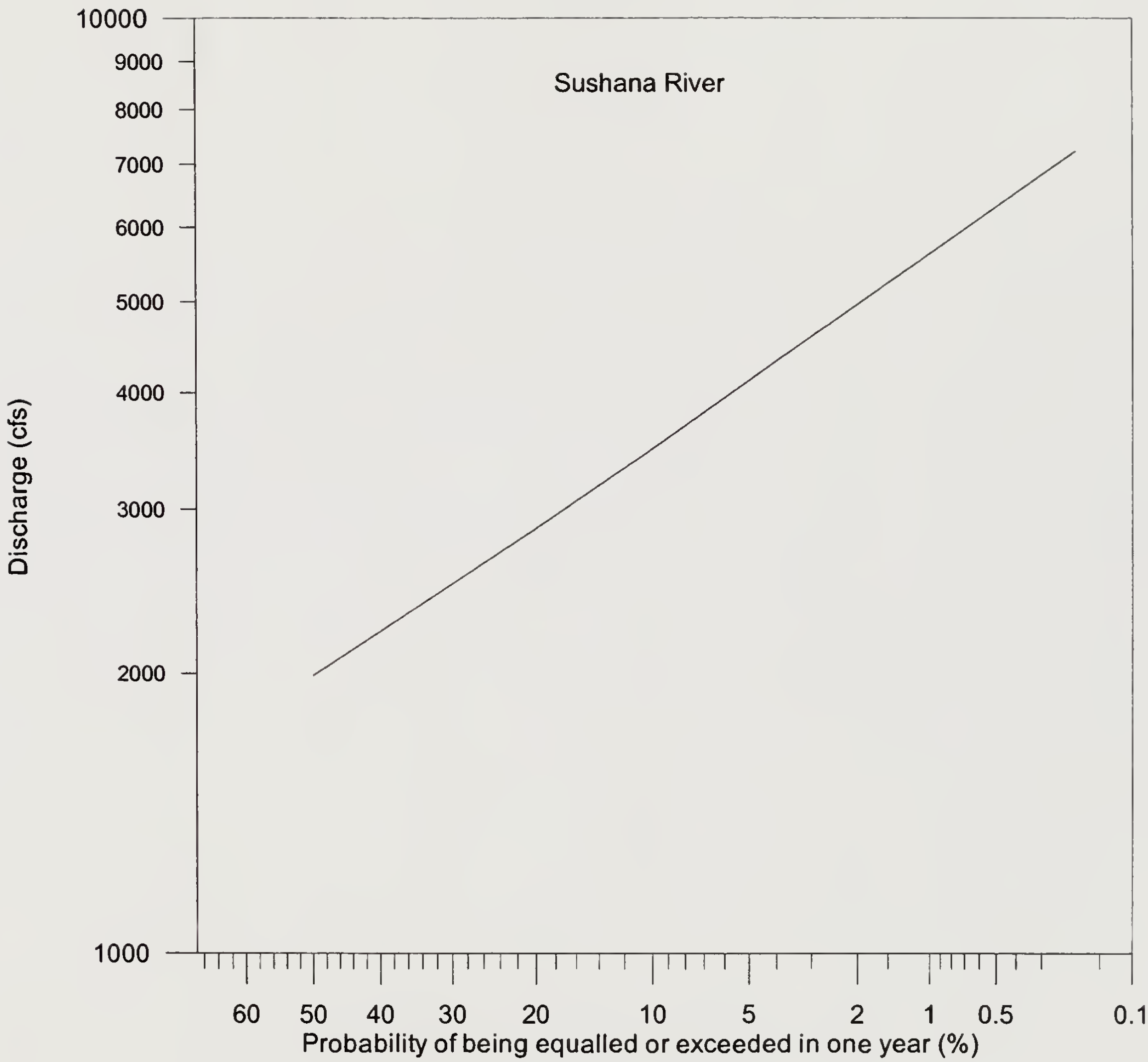
Flood frequency estimates for
Site: Sushana River
Region 6
Drainage area,in square miles: 91.60
Percent of area in lakes and ponds: 0.0
Forest cover, in percent: 2.6

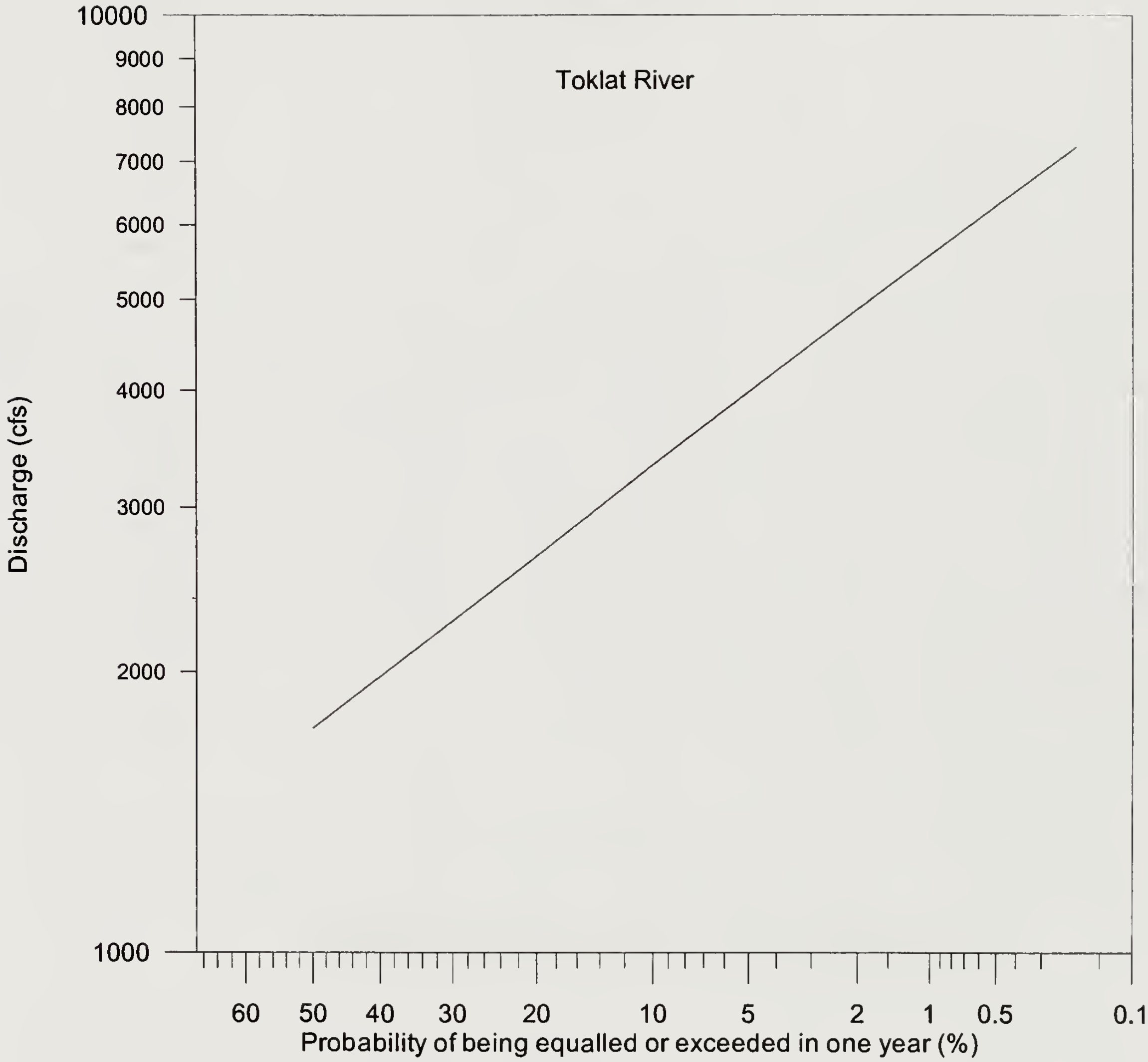
| N | DISCHARGE (cfs) | SE (+%) | SE(-%) | CONFIDENCE LIMITS 5% | 95% | EQ. YEARS |
|---|---|---|---|---|---|---|
| 2 | 1990. | 49.3 | -33.0 | 1020. | 3890. | 1.5 |
| 5 | 2860. | 50.7 | -33.7 | 1440. | 5680. | 2.1 |
| 10 | 3480. | 53.9 | -35.0 | 1700. | 7160. | 2.6 |
| 25 | 4320. | 59.1 | -37.2 | 1990. | 9380. | 3.2 |
| 50 | 4960. | 63.6 | -38.9 | 2180. | 11300. | 3.6 |
| 100 | 5620. | 68.3 | -40.6 | 2360. | 13400. | 3.9 |
| 200 | 6300. | 73.3 | -42.3 | 2510. | 15800. | 4.1 |
| 500 | 7230. | 80.4 | -44.6 | 2700. | 19400. | 4.2 |

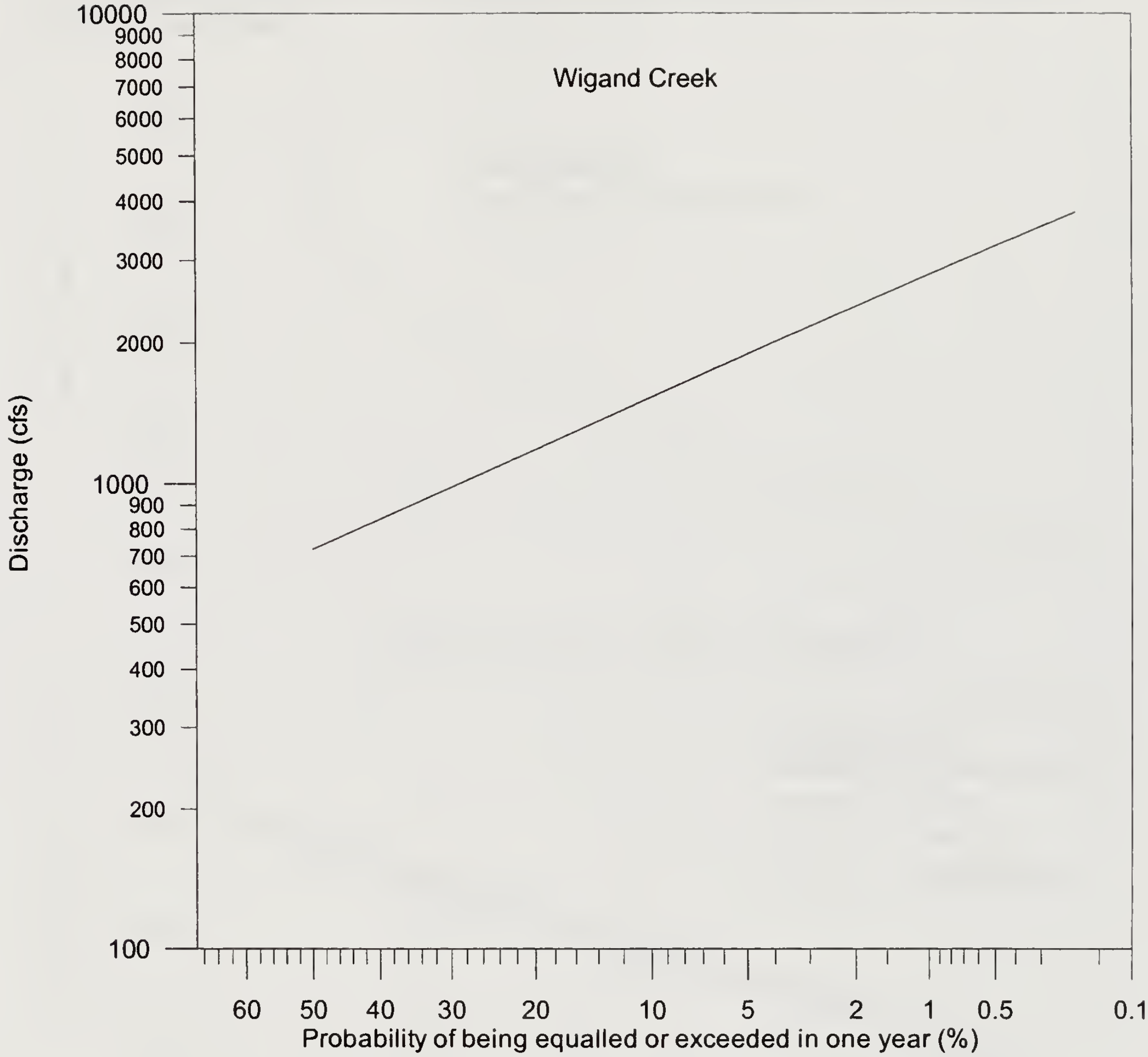
## Appendix B. Annual exceedance probability graphs



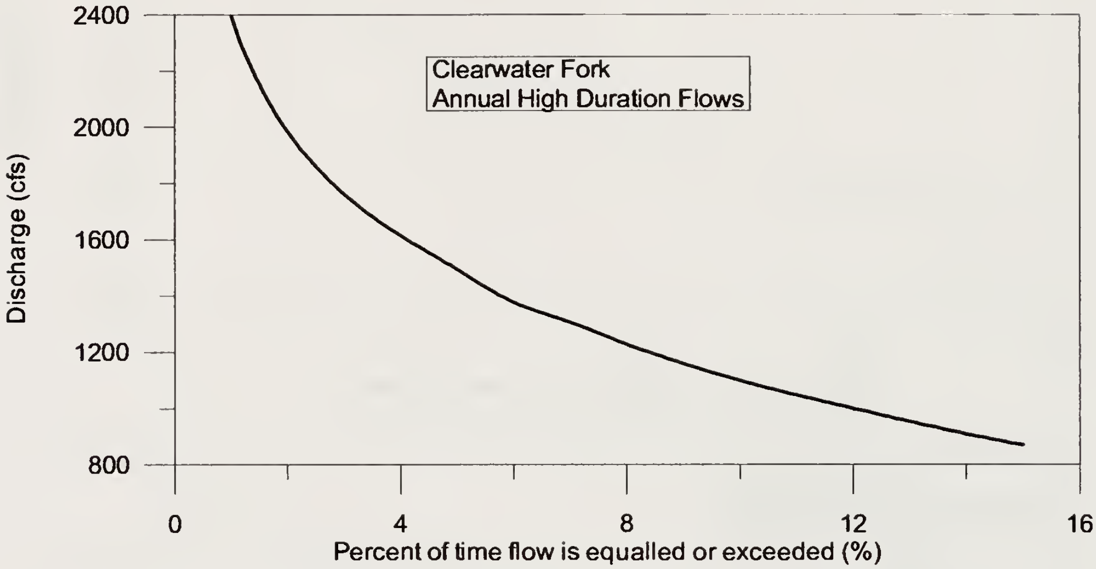

East Fork River
Discharge (cfs)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
60
50
40
30
20
10
5
2
1
0.5
0.1
Probability of being equalled or exceeded in one year (%)

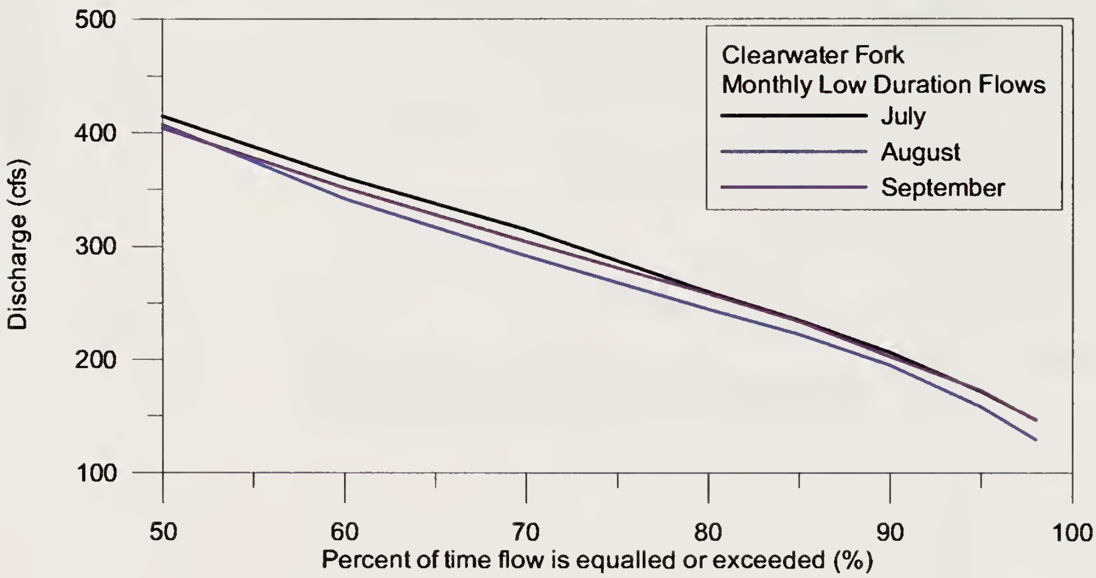

Sushana River
Discharge (cfs)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
60
50
40
30
20
10
5
2
1
0.5
0.1
Probability of being equalled or exceeded in one year (%)

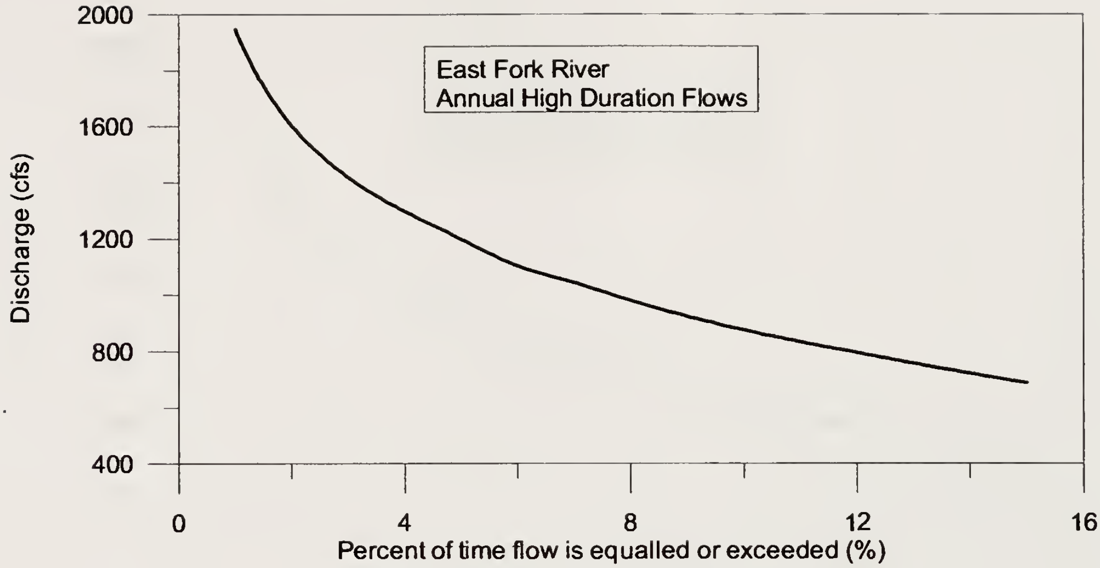

Toklat River
Discharge (cfs)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
60
50
40
30
20
10
5
2
1
0.5
0.1
Probability of being equalled or exceeded in one year (%)

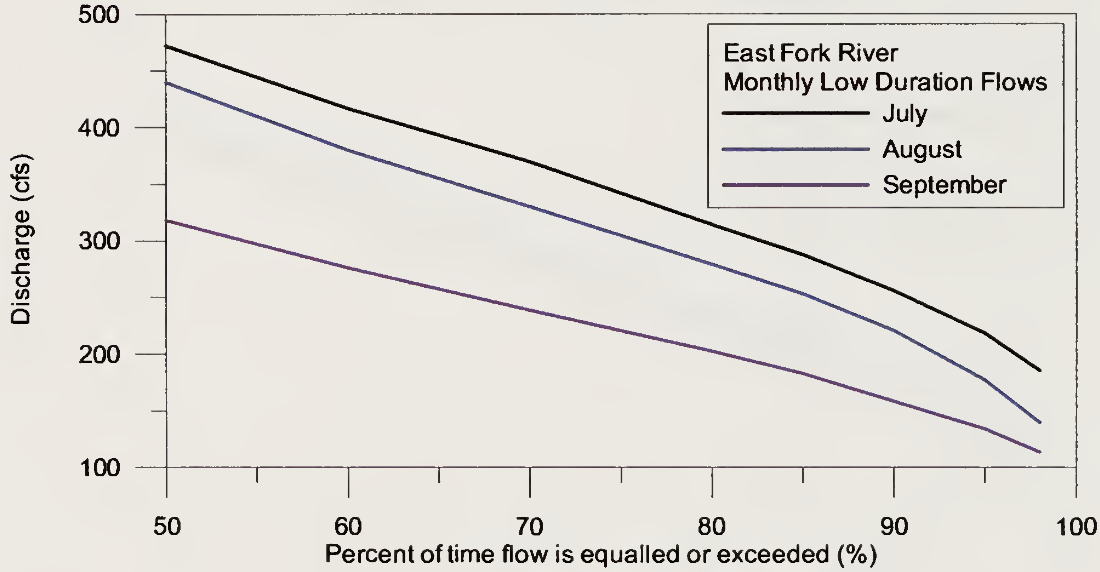

Wigand Creek
Discharge (cfs)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
60
50
40
30
20
10
5
2
1
0.5
0.1
Probability of being equalled or exceeded in one year (%)

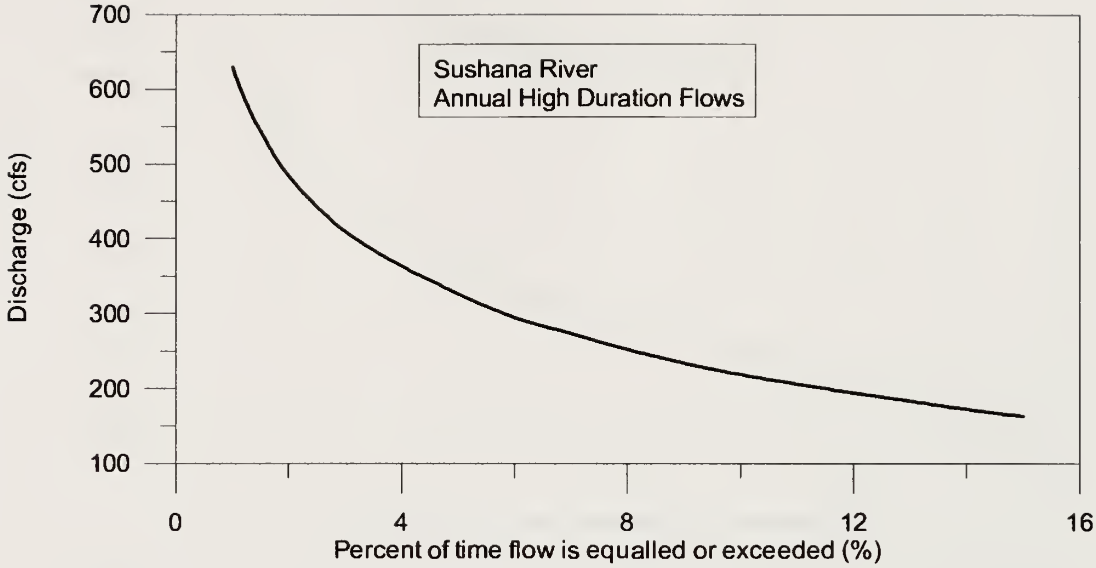
## Appendix C. High flow and low flow duration statistics for Toklat basin study watersheds

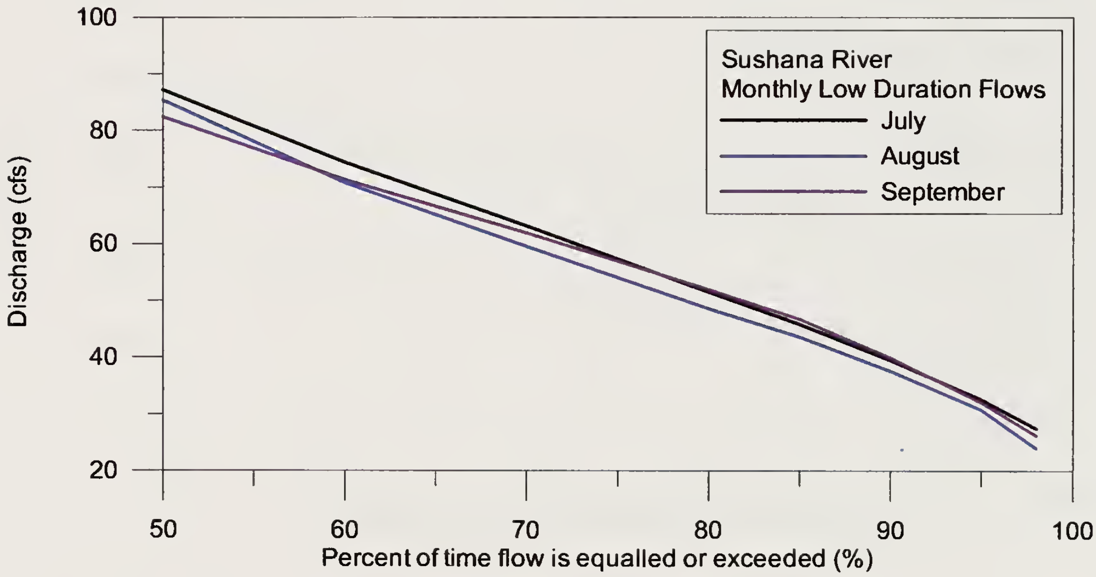


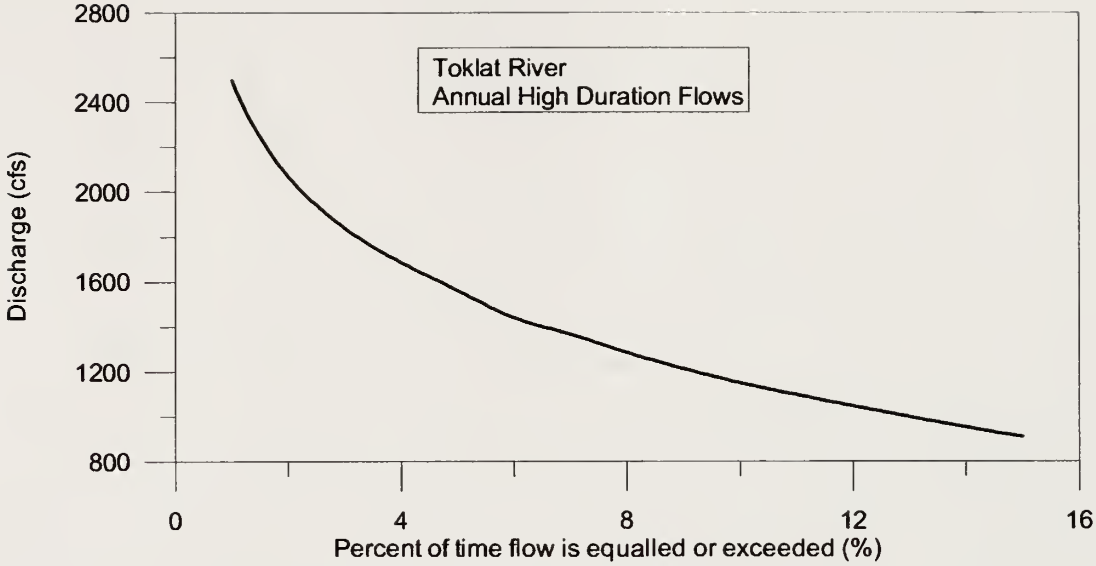



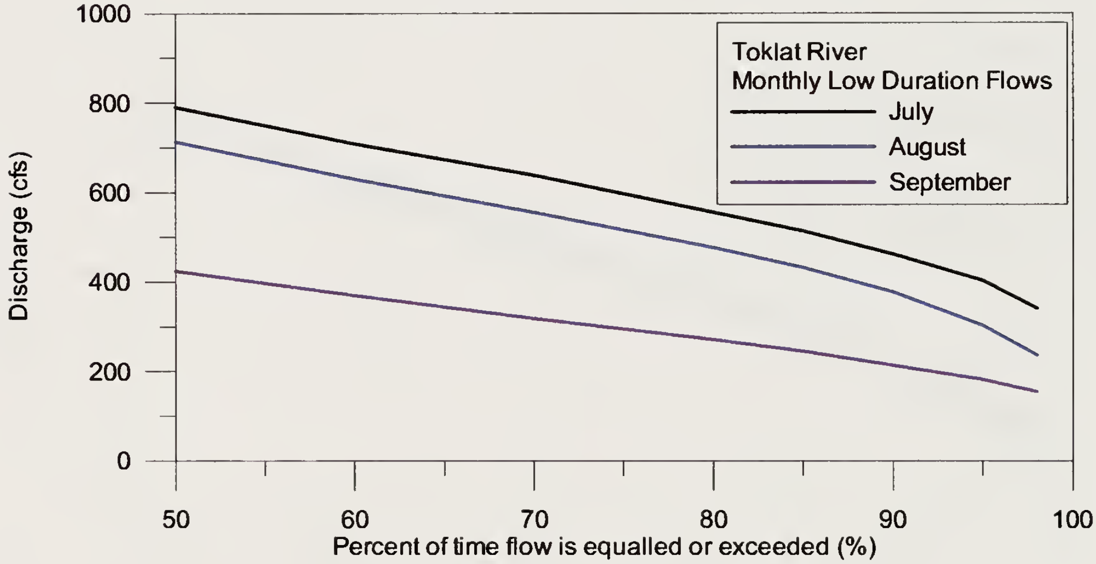

East Fork River
Annual High Duration Flows
Discharge (cfs)
2000
1600
1200
800
400
0
4
8
12
16
Percent of time flow is equalled or exceeded (%)

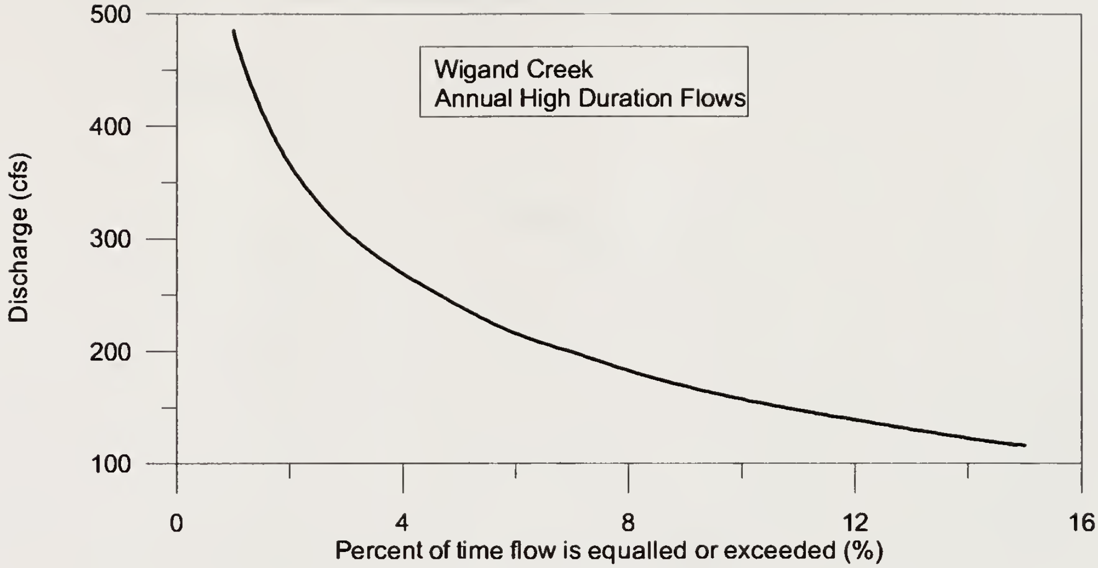

East Fork River
Monthly Low Duration Flows
July
August
September
Discharge (cfs)
500
400
300
200
100
50
60
70
80
90
100
Percent of time flow is equalled or exceeded (%)

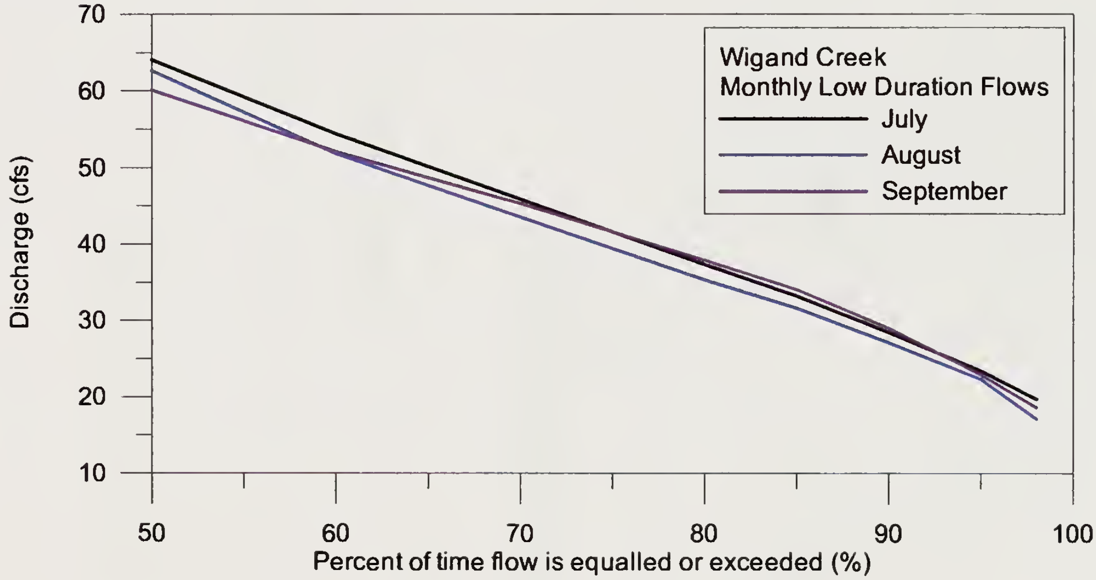

Sushana River
Annual High Duration Flows
Discharge (cfs)
Percent of time flow is equalled or exceeded (%)
700
600
500
400
300
200
100
0
4
8
12
16


Sushana River
Monthly Low Duration Flows
July
August
September
Discharge (cfs)
Percent of time flow is equalled or exceeded (%)
100
80
60
40
20
50
60
70
80
90
100

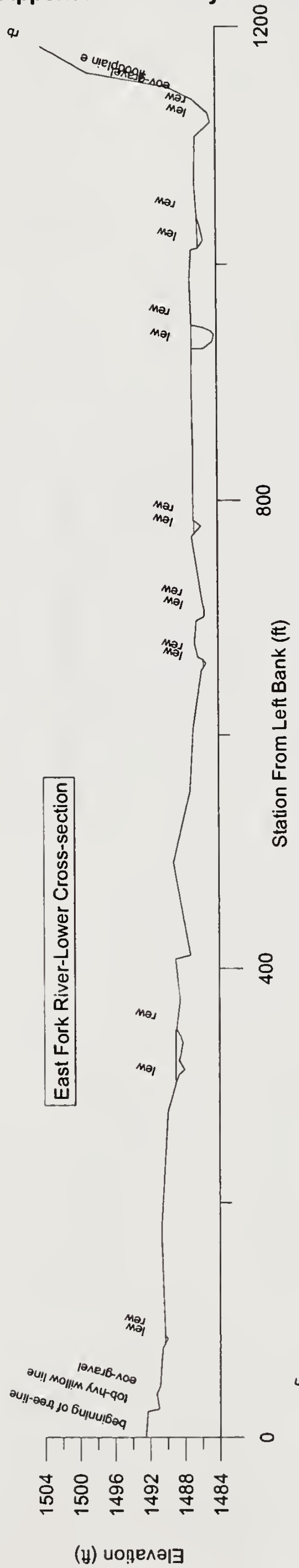

Toklat River
Annual High Duration Flows
Discharge (cfs)
2800
2400
2000
1600
1200
800
0
4
8
12
16
Percent of time flow is equalled or exceeded (%)

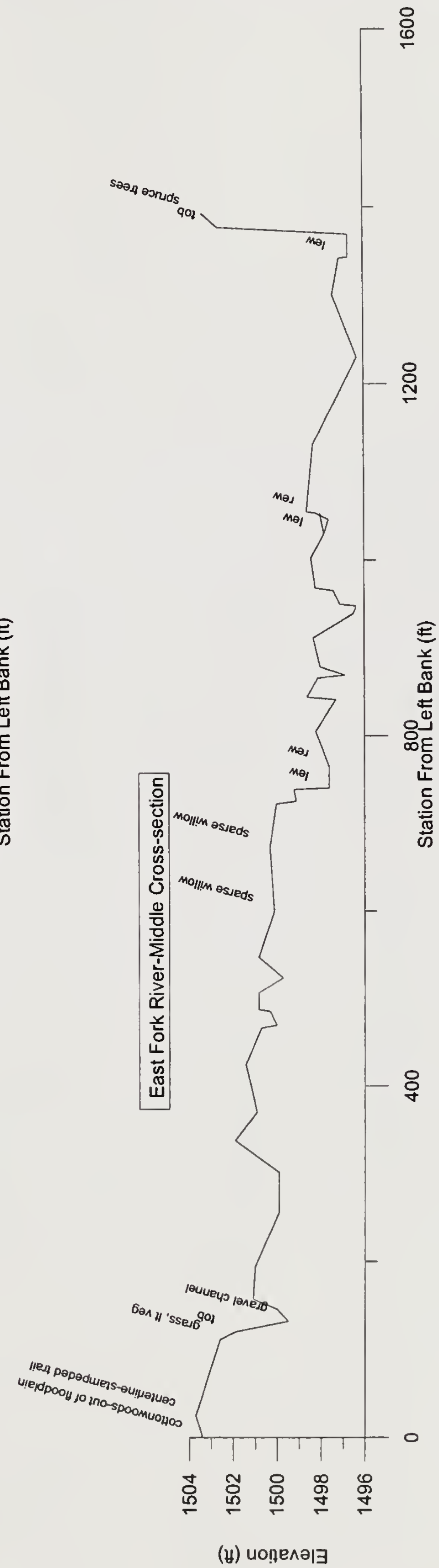

Toklat River
Monthly Low Duration Flows
July
August
September
Discharge (cfs)
1000
800
600
400
200
0
50
60
70
80
90
100
Percent of time flow is equalled or exceeded (%)

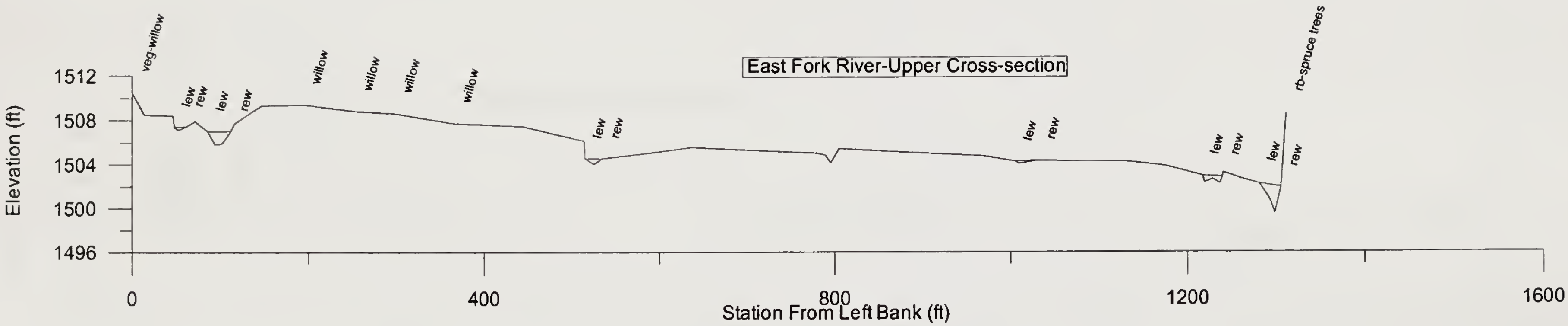

Wigand Creek
Annual High Duration Flows
Discharge (cfs)
500
400
300
200
100
0
4
8
12
16
Percent of time flow is equalled or exceeded (%)

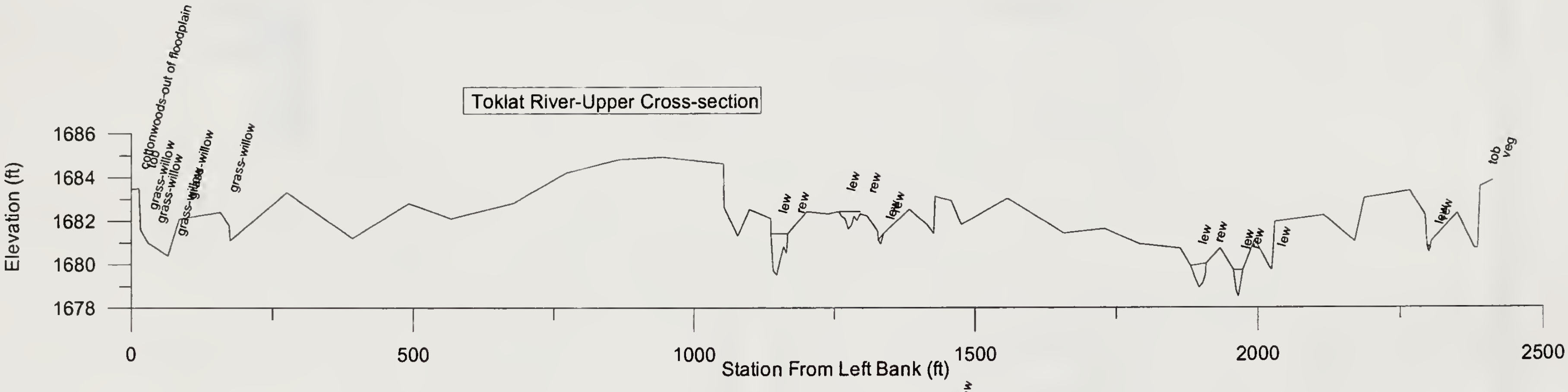

Wigand Creek
Monthly Low Duration Flows
July
August
September
Discharge (cfs)
70
60
50
40
30
20
10
50
60
70
80
90
100
Percent of time flow is equalled or exceeded (%)

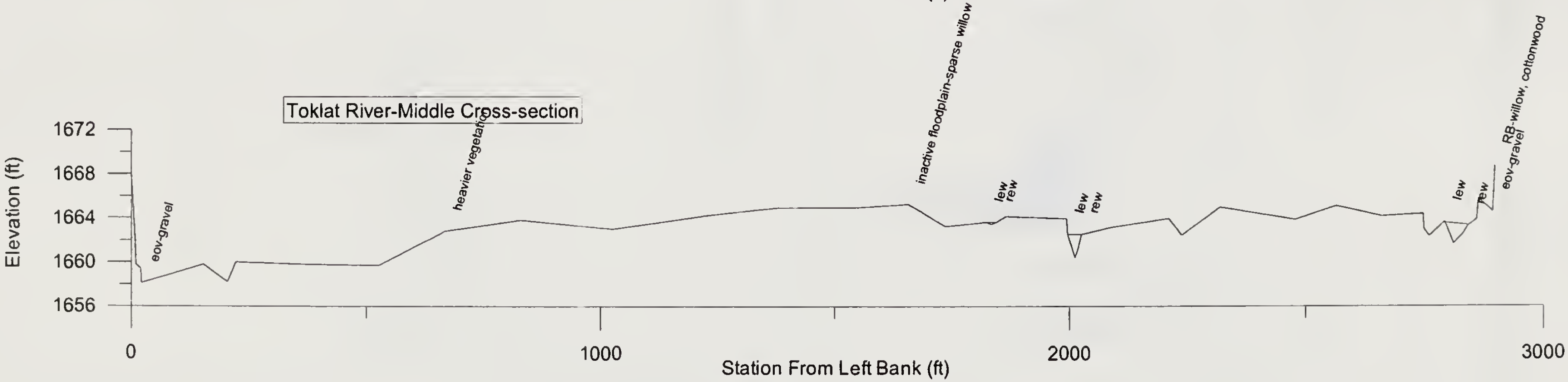
## Appendix D. Surveyed cross-sections for the East Fork and Toklat Rivers



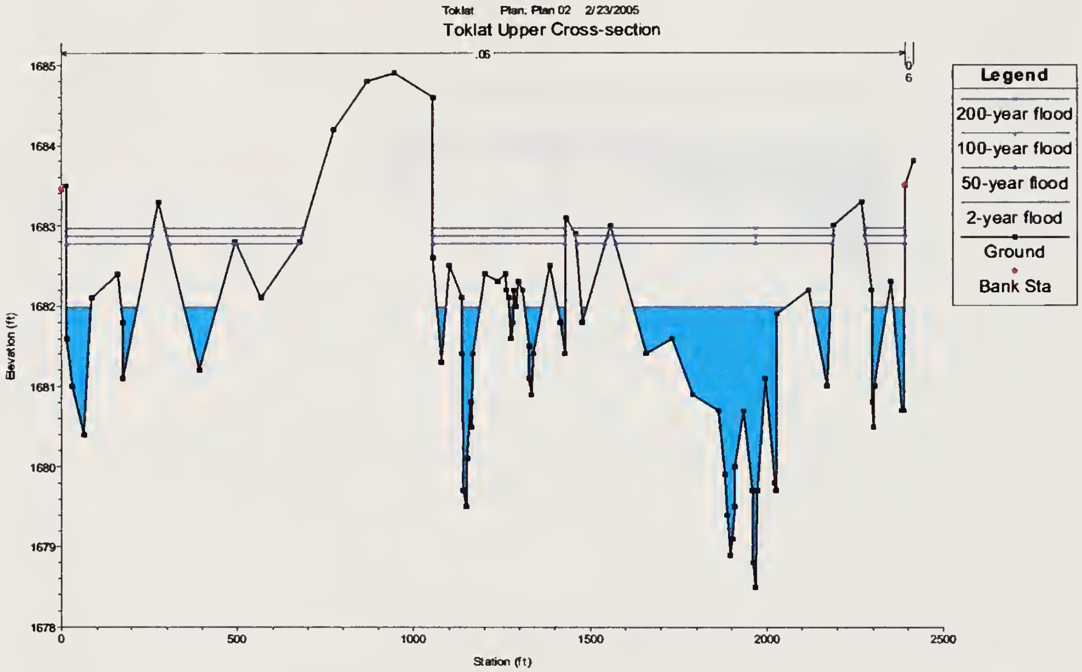



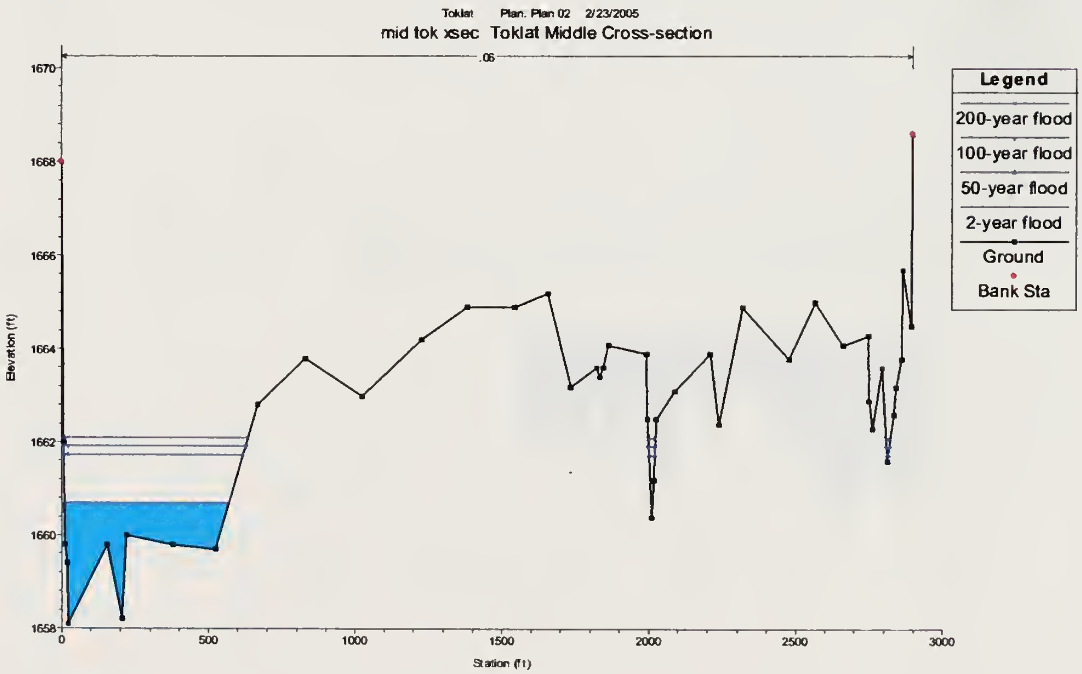

East Fork River-Upper Cross-section
Elevation (ft)
1512
1508
1504
1500
1496
0
400
800
1200
1600
Station From Left Bank (ft)
veg-willow
lew
rew
lew
rew
willow
willow
willow
willow
lew
rew
lew
rew
lew
rew
lew
rew
rb-spruce trees

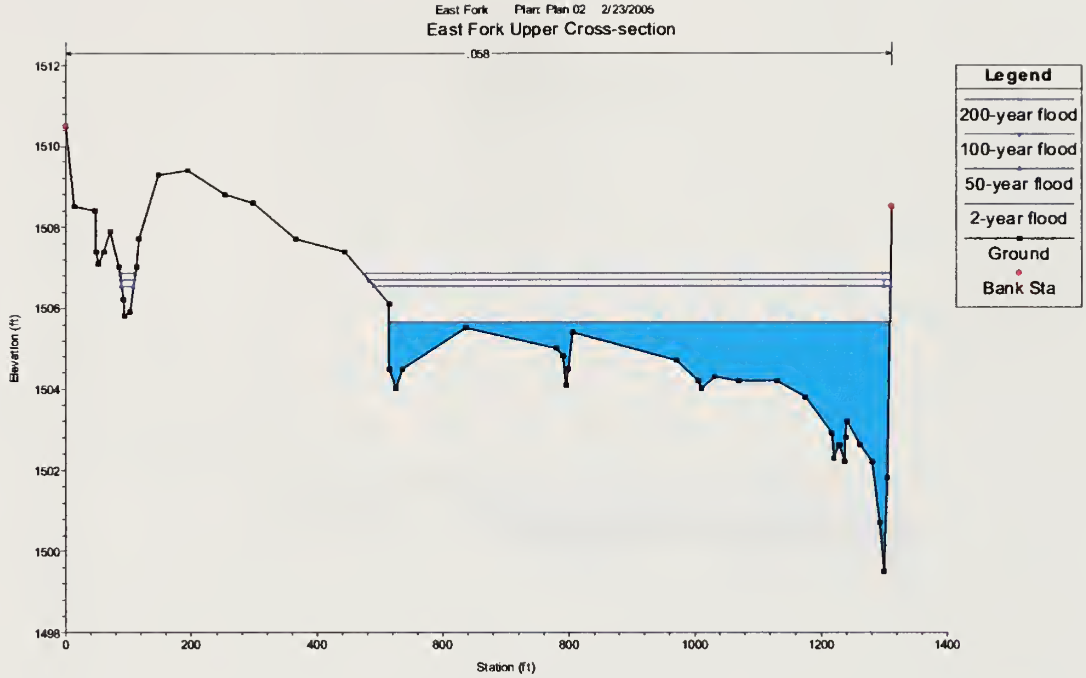

Toklat River-Upper Cross-section
Elevation (ft)
1686
1684
1682
1680
1678
0
500
1000
1500
2000
2500
Station From Left Bank (ft)
cottonwoods-out of floodplain
tob
grass-willow
grass-willow
grass-willow
grass-willow
grass-willow
lew
rew
lew
rew
lew
rew
lew
rew
lew
rew
lew
lew
rew
tob
veg

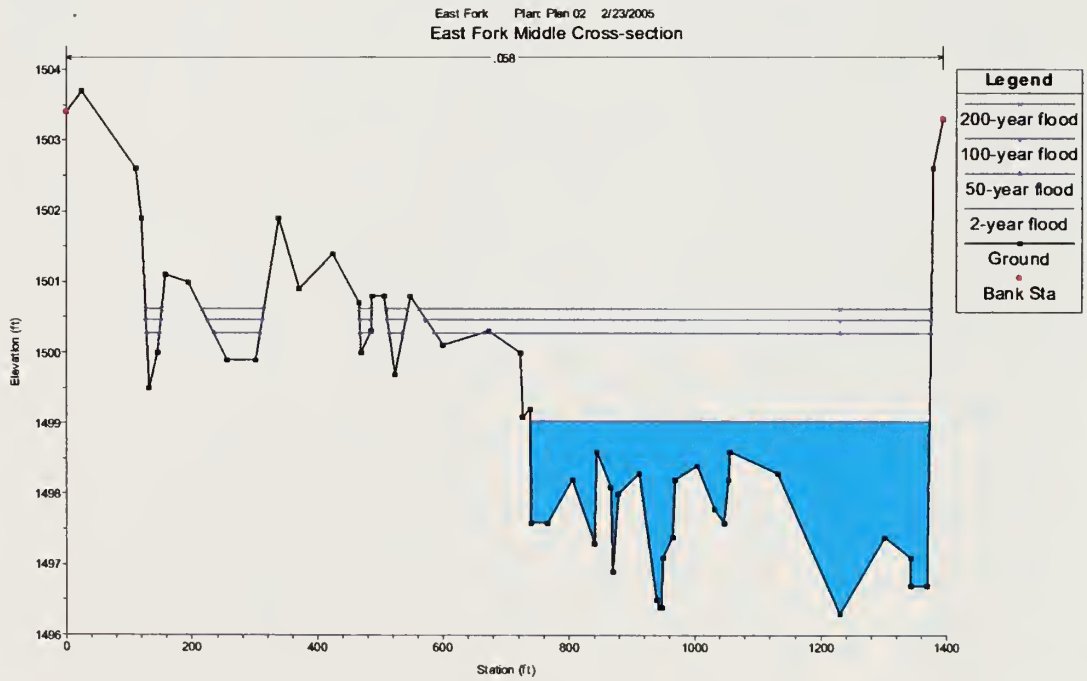

Toklat River-Middle Cross-section
Elevation (ft)
1672
1668
1664
1660
1656
0
1000
2000
3000
Station From Left Bank (ft)
eov-gravel
heavier vegetation
inactive floodplain-sparse willow
lew
rew
lew
rew
lew
rew
eov-gravel
RB-willow, cottonwood

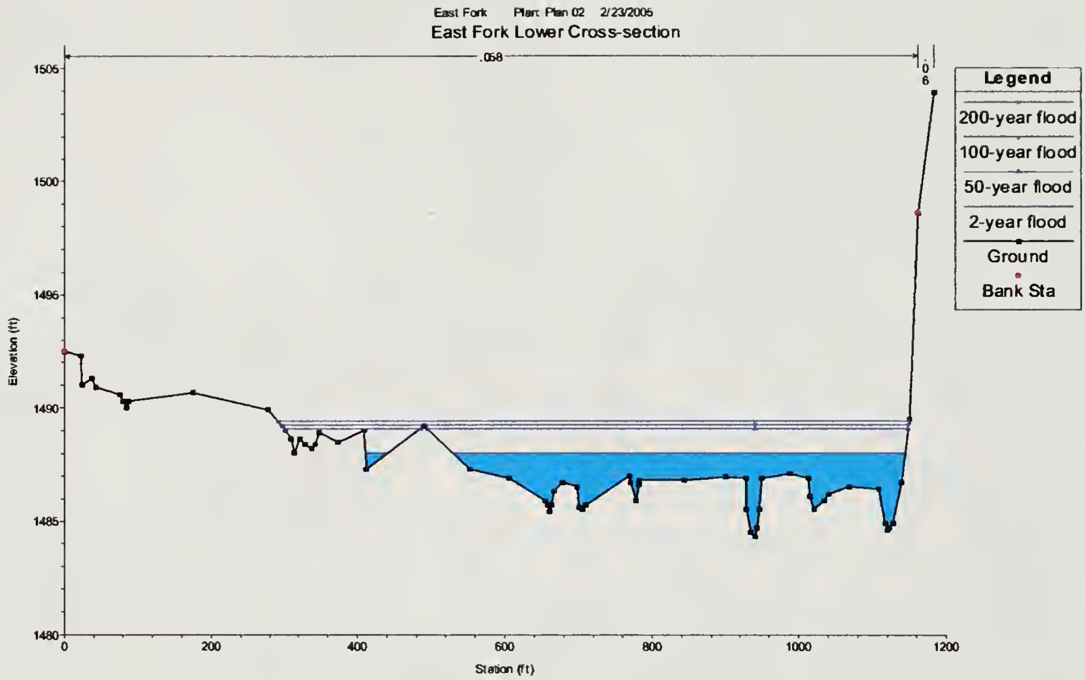
# Appendix E. HEC-RAS Modeling results for the Toklat and East Fork Rivers

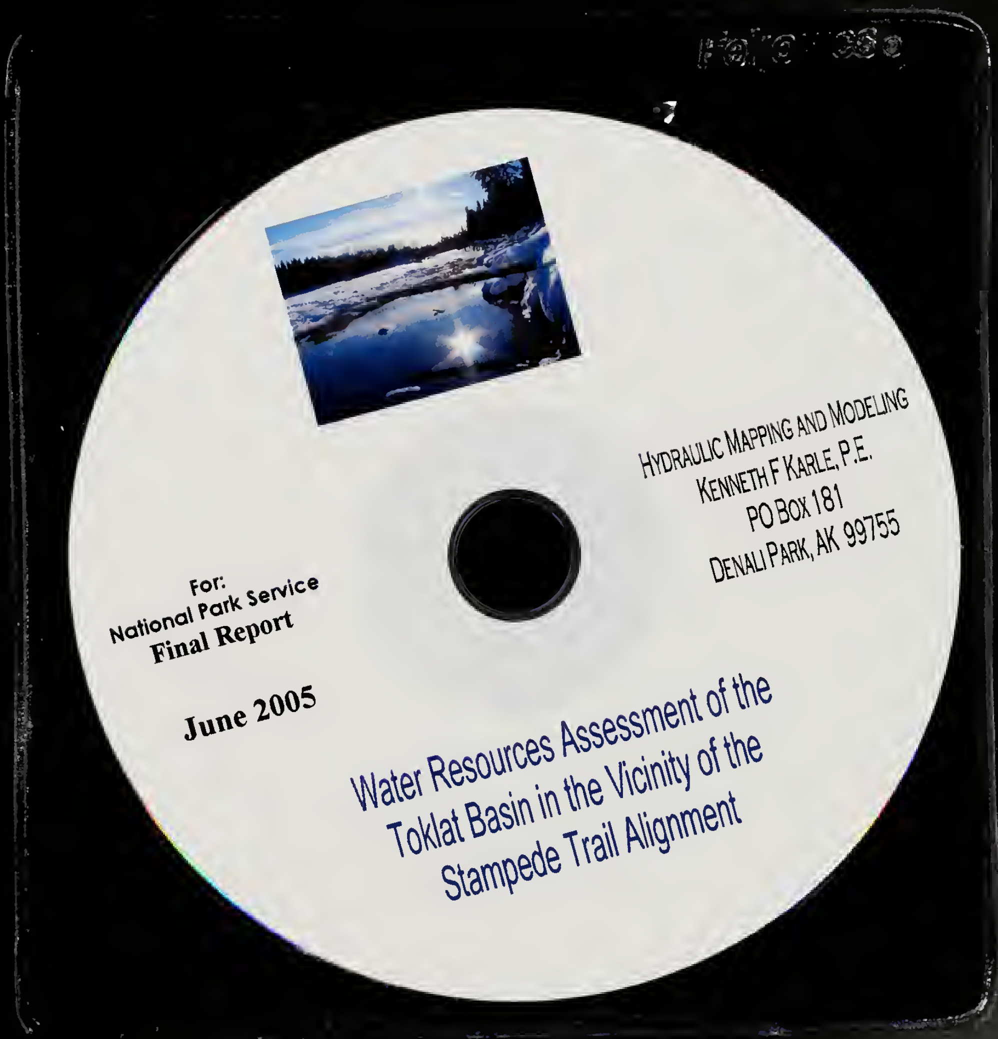



East Fork Plan: Plan 02 2/23/2005
East Fork Upper Cross-section
.058
Legend
200-year flood
100-year flood
50-year flood
2-year flood
Ground
Bank Sta
Elevation (ft)
Station (ft)


East Fork Plan: Plan 02 2/23/2005
East Fork Middle Cross-section
.058
Legend
200-year flood
100-year flood
50-year flood
2-year flood
Ground
Bank Sta
Elevation (ft)
Station (ft)


East Fork Plan: Plan 02 2/23/2005
East Fork Lower Cross-section
.058
Legend
200-year flood
100-year flood
50-year flood
2-year flood
Ground
Bank Sta
Elevation (ft)
Station (ft)
1505
1500
1495
1490
1485
1480
0
200
400
600
800
1000
1200


Hydraulic Mapping and Modeling
Kenneth F Karle, P.E.
PO Box 181
Denali Park, AK 99755
For:
National Park Service
Final Report
June 2005
Water Resources Assessment of the
Toklat Basin in the Vicinity of the
Stampede Trail Alignment