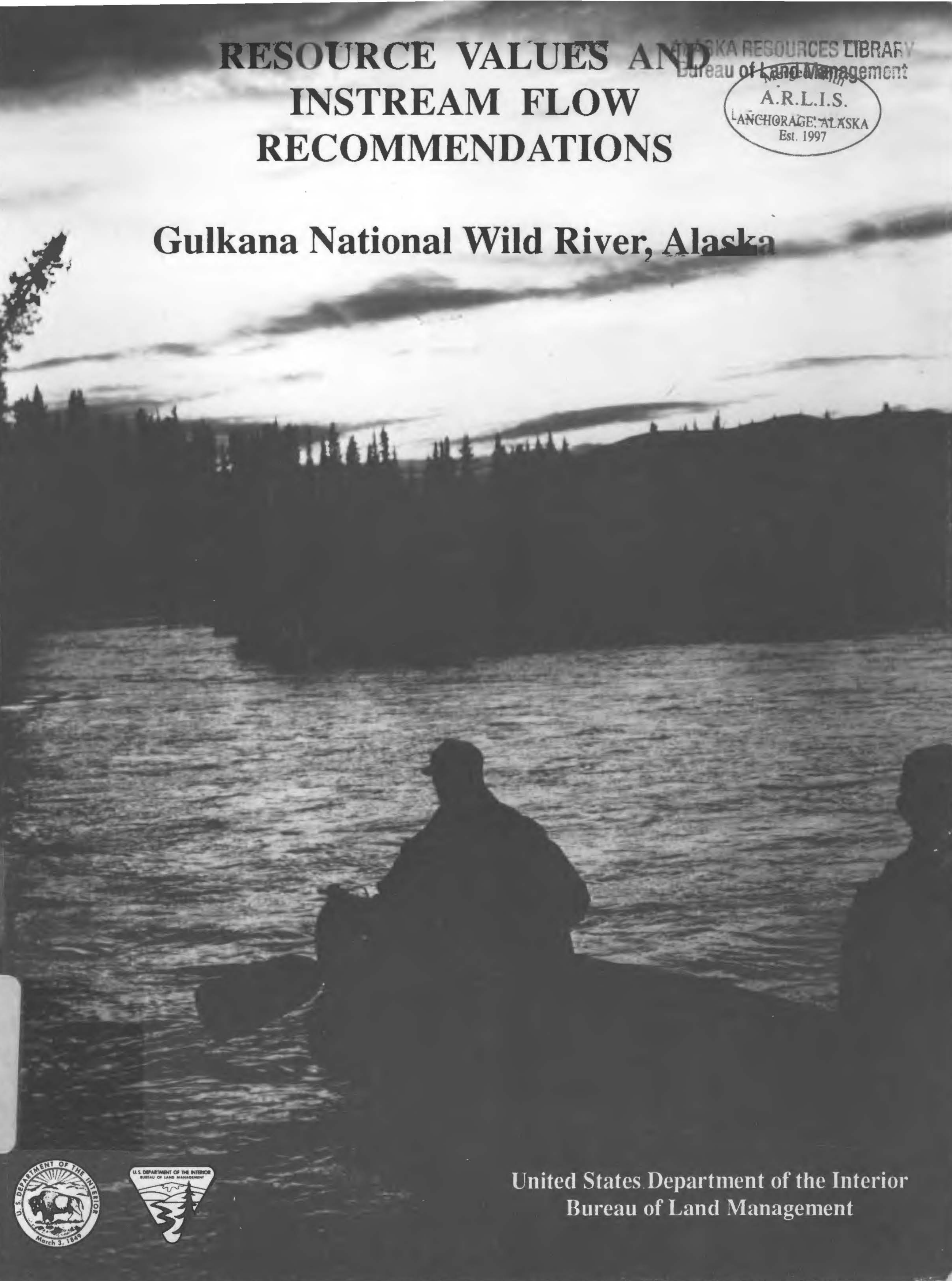
RESOURCE VALUES AND INSTREAM FLOW RECOMMENDATIONS

Gulkana National Wild River, Alaska



United States Department of the Interior
Bureau of Land Management

RESOURCE VALUES AND INSTREAM FLOW RECOMMENDATIONS

Gulkana National Wild River, Alaska

by

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". . . one more river. May there always be one more."

— Edward Abbey, 1982
Down the River - E.P. Dutton, Inc.
New York

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EXECUTIVE SUMMARY

Bald eagle, Gulkana National Wild River

The Gulkana River, a clear-water tributary to the Copper River in south-central Alaska, was designated a National Wild River by Congress on December 2, 1980. Inclusion into the Wild and Scenic Rivers System was based partially on its location in a wilderness environment with a variety of wildlife, excellent water quality, excellent habitat for resident and anadromous fish, and outstanding opportunities for recreational boating.

The goal of this project was to identify the amount of water necessary to preserve and protect the natural values of the Gulkana National Wild River and its immediate corridor environs and to recommend a legal mechanism through which those recommended flow regimes can be recognized and protected.

The river originates above Summit Lake (elevation around 4,000 feet), flows from tree line through a valley parallel to the Richardson Highway, and enters Paxson Lake. Three miles below the Lake outlet the river is joined by its Middle Fork and continues through forested uplands, a steep and narrow reach known as Canyon Rapids, and a glacial lakebed. For purposes of this assessment, the following Gulkana River reaches were studied specifically in order to determine intream flow amounts: Middle Fork, West Fork, and Main Stem (Paxson Lake to Middle Fork confluence, and Canyon Rapids to Sourdough).

The hydrology of the river is controlled by precipitation, basin physiography, lake storage, and the presence of permafrost. No runoff originates from glacier melt. The 2,140-mile river basin is located mostly within the Copper River Plateau and drains 1,759 miles of watershed generally flowing south to the Copper River. It consists of the Gulkana Uplands, the Lake Louise Plateau, and the Copper River Lowlands.

Results of literature reviews and field surveys were used to establish relationships between flow-dependent resource values and flow levels. Instream flow recommendations are based on a cross-comparison of flow requirements and consider season of use.

Three types of boating opportunities were analyzed for flow requirements: (1) family/novice boating, (2) "drag" boating, and (3) whitewater boating. The primary floating opportunity, family/novice, requires at least a flow level of 2,100 ft^3/s during high flow periods (June - July) and after periods of heavy rains in August. Drag boating, which involves greater boating skills with more effort to pull boats across shallow areas, occurs during lower flow periods of August and September and requires at least 1,400 ft^3/s. The Canyon Rapids section offers challenging whitewater boating opportunities at flows of 3,000 ft^3/s or greater, which are usually available from late May through June.

Flow requirements for salmon spawning are based on critical water depths and velocities. Steelhead and salmon spawning and migration generally occur from May through August. These species require 30 ft^3/s during this 4-month period in the Middle Fork below the Dickey Lake outlet. Chinook and sockeye salmon spawn and migrate from June through August in the mainstem and require a flow of 100 ft^3/s immediately below Paxson Lake. Late fall and winter flows must be sufficient to maintain pool depths and thus provide overwinter habitat for fish.

Gravel bars are used as campsites and high flows are necessary to periodically rejuvenate and maintain these. To predict effects of floodflows on gravel bar widths, relationships between bar width and 2-year peak discharge were established. Instream flows of 1,093, 3,872, and 6,887 ft^3/s are recommended as 2-year floodflows for the Middle Fork, the West Fork, and the Main Stem below West Fork confluence, respectively. Although the 2-year floodflow was emphasized as being required to maintain bars, a random series of floodflows of varying magnitude is actually required for channel maintenance. A summary of monthly instream flow requirements for eight locations is presented in the chapter, *Instream Flow Recommendations, to Protect Critical Resource Values.* Recommended flows for any given time period satisfy the flow requirements of all resource values for each location listed.

The project team recommends that a State of Alaska *Application for Reservation of Water* be submitted to the Alaska Department of Natural Resources, Division of Land and Water Management, specifying the water flow amounts as recommended in the report.

The team also recommends that an additional 15 miles of the South Branch of the West Fork be added to the wild river designation, that the U.S. Geological Survey gauge at Sourdough be reactivated, and that BLM monitor river use impacts in order to adjust river management strategies on the Gulkana National Wild River.

INTRODUCTION

The Gulkana River is a clear-water tributary to the Copper River in south-central Alaska (Figure 1). The river corridor is in close proximity to a major highway (Richardson Highway) and within a day's driving distance from both Anchorage and Fairbanks. The Gulkana is one of the most popular recreational rivers in Alaska.

The Alaska National Interest Conservation Act of December 2, 1980, (P.L. 96-487) designated the upper portion of the Gulkana River (including the lower portions of the Middle and West Forks) as a component of the National Wild and Scenic Rivers System. Approximately 181 river miles of the Gulkana River and its tributaries were classified "wild" pursuant to the Wild and Scenic Rivers Act (P.L. 90-542).

However, the National Wild River status does not necessarily protect river flows, and the language contained in the Wild and Scenic Rivers Act does not guarantee a specific flow regime. The river management plan for the Gulkana National Wild River (USDI-BLM, 1983) specifies that "a reservation of minimum water flows sufficient for public recreation, and to support the values for which the area was designated, will be determined in cooperation with the Alaska Department of Natural Resources, Division of Land and Water Management." This directive provided the impetus for a water rights assessment of the Gulkana National Wild River.

The legal and management strategies for protecting Gulkana River flows presented later in this report stem from an assessment of water rights protection options for the Beaver Creek National Wild River (Van Haveren et al., 1987). The reader is referred to that report for additional information on water rights protection strategies in Alaska.

Geographic Setting

The Gulkana River originates above Summit Lake at an approximate elevation of 4,000 feet. The upper half of the river traverses the broad rolling valleys and low ridges of the Gulkana Uplands. From above tree line at Summit Lake, the river flows 10 miles through a wide valley flanked by the foothills of the Alaska Range. The river then enters Paxson Lake. Dammed by the moraine of a receding glacier, Paxson Lake is approximately 10 miles long and 1 mile wide.

Three miles below the Paxson Lake outlet, the Gulkana is joined from the west by its Middle Fork. For the next 15 miles, the river meanders gently through rolling spruce-hardwood forested uplands before cutting through an east-west trending ridge at Canyon Rapids. Rapids dominate the river channel for over 8 miles before the river leaves the uplands and flows through the ancient glacial lakebed of the Copper River Lowlands.

About 40 river miles below Paxson Lake, the West Fork joins the main channel of the Gulkana. Below this confluence, the river has cut a narrow valley through the glacial deposits that form the almost level surface of the surrounding landscape. Eroded bluffs often stand 100 to 200 feet above the valley floor through the lower river area.

The Middle Fork originates in the rolling tundra uplands surrounding Dickey Lake. From this 1-mile-long lake, the Middle Fork flows 25 miles to the main Gulkana, dropping quickly from Dickey Lake into a broad, forested lowland.

Originating on the Lake Louise Plateau and in the Alphabet Hills, the West Fork flows easterly to the Gulkana and divides the Gulkana Upland area from the Copper River Lowlands. The South Branch of the West Fork drains a large lake-dotted upland of low relief. Each tributary is approximately 30 miles long and meanders through sparse spruce forests to its confluence. From this juncture, the West Fork flows roughly 48 miles to the main Gulkana channel in a small valley through adjacent lowlands.

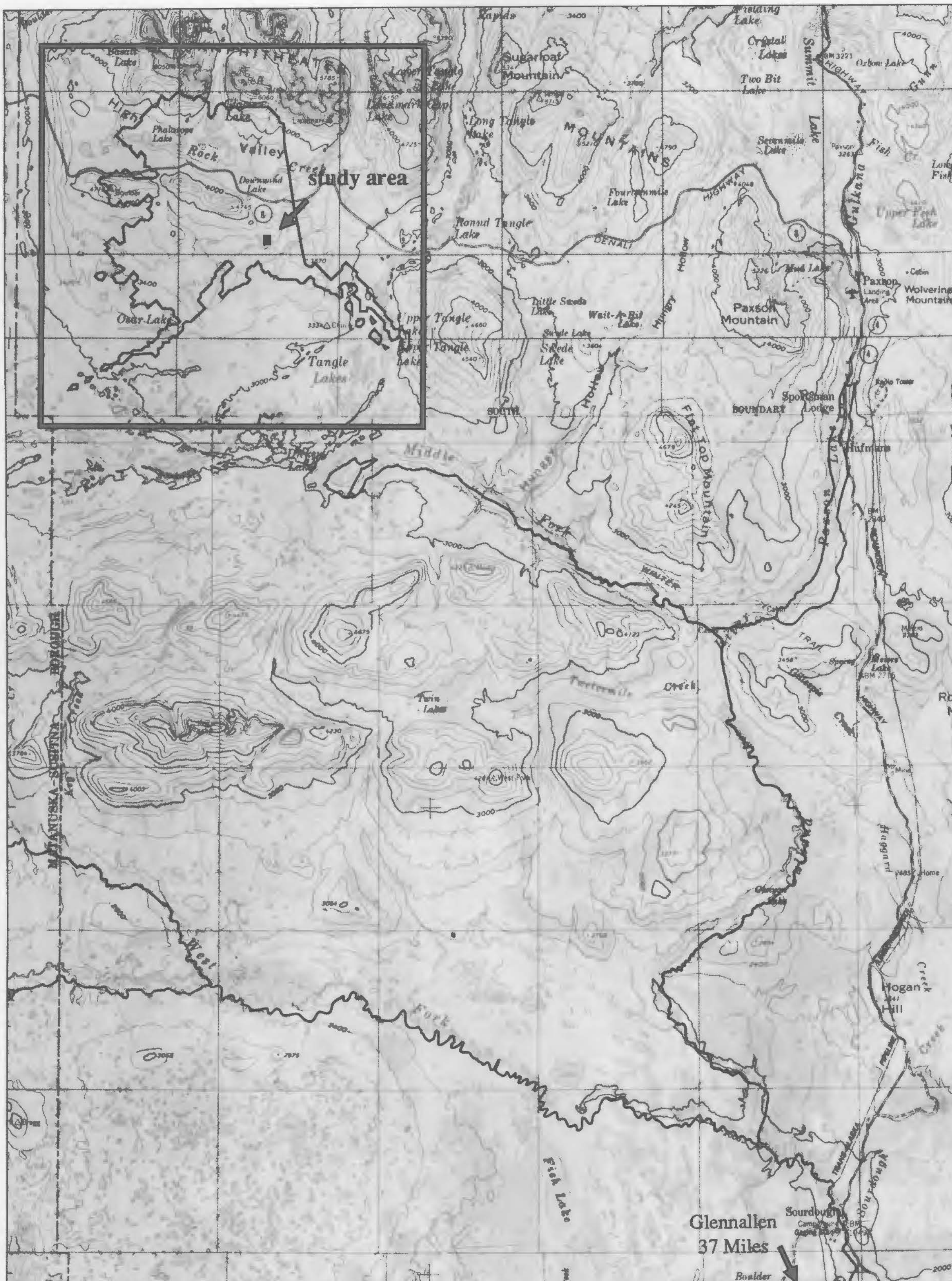

Figure 1. Location map for Gulkana National Wild River.

Study Objectives

The objectives of this water rights assessment were to:

1. Identify flow-dependent resource values;
2. Determine the natural flow regime (average annual flow durations and flood frequencies) of the Gulkana River at selected points along the designated National Wild River reach, including the tributary segments;
3. Develop hydrographs of flows required for protecting each of the flow-dependent river resource values, and
4. Develop legal and management suggestions for protecting recommended instream flows.

The general strategy used in this assessment has been employed in two previous BLM river studies on Beaver Creek, Alaska (Van Haveren et al., 1987) and the San Pedro River, Arizona (Jackson et al., 1987) and is formally described in Jackson et al. (1989). The approach utilizes an interdisciplinary team to conduct literature reviews and reconnaissance-level field studies as a basis for developing relationships between flows and water-dependent resource values. Jackson et al. (1989) have described the approach as consisting of six steps:

1. preliminary assessment and study design,
2. description of flow-dependent values,
3. description and quantification of hydrology and channel morphology,
4. analysis of the effects of flow level on resource values,
5. identification of flows required to protect river resource values, and
6. development of legal/management strategies to protect instream flows.

Quantification methods are tailored to the target stream and to the information needs required to support legal and management options. Professional judgment and team-based evaluations are used to relate flow needs to resource attributes whenever referenced, analytical procedures are unavailable, inapplicable, or impractical.

APPROACH AND METHODS

Existing hydrologic data for the Gulkana River were analyzed to determine general hydrologic characteristics and, more specifically, flow duration, flood frequency, and timing relationships. An extensive review of literature and BLM office files was coupled with a reconnaissance "flyover" and aerial video coverage to identify: (1) important river resource values and (2) critical river reaches to be sampled. The flyover and aerial video coverage, combined with the streamflow data and literature review, provided a basic understanding of the hydrology and channel morphology of the river, including adjustment processes and channel evolution.

An initial team meeting was held to review the video coverage of the river and discuss the field sampling approach and specific data analysis methods. This step in the study process is designed to facilitate cross-disciplinary observations and discussions of river resource values and characteristics. It also acts as a catalyst for individual team members to begin defining their respective resource value criteria. Prior to the field assessment, individual team members prepared their study methods and selected critical reaches to be sampled.

The Value-Driven Assessment Process

BLM has adopted an approach for determining instream flow requirements that recognizes and clearly delineates river resource values, uses appropriate methods to quantitatively describe how flow regimes affect those values, applies evaluative standards to identify recommended instream flows, and finally, develops legal and administrative mechanisms to ensure that flows are managed to protect river values (Jackson et al., 1989).

Throughout this approach, the evaluation and quantification process is interactive; a team of specialists work together to construct an interdisciplinary product. In this type of an evaluation process, there must be a designed interconnection of project components such that each supports the other and leads to a definable resource solution. Resource values, hydrology, and law are important project components, but their significance can only be weighed in terms of the extent to which they support and meld with other project components.

Preliminary Assessment and Study Design

Preliminary assessment and study design are required to identify the physical, biological, and social values of the resource; identify instream flow issues; and develop overall project objectives. For the Gulkana River, river resource values were identified during the original wild and scenic river study (USDI-BOR, 1976) and further defined in BLM's River Management Plan (USDI-BLM, 1983). Additional information was gathered from river user surveys. An interdisciplinary project team was formed during this step. Project team composition represented each of the primary resource values for which instream flows might be required. Resource specialists included an outdoor recreation specialist and a fisheries biologist. In addition, hydrology/hydraulics and geomorphology expertise was represented. Team members were selected based upon their technical/professional credentials and their ability to interact creatively with representatives of other disciplines (Figure 2).

Selection of critical reaches for the Gulkana River water rights assessment was based on the identification of wild river values and the measurable criteria used to quantitatively express those values. These reaches, sampled during the field assessment, are described in Table 1. The values shown for each river segment are those considered to be most critical, and providing the required flows for those values would protect other flow-dependent values as well.

Each of these reaches was sampled by the team during the period July 20-27, 1988. Hydraulic geometry cross sections were measured at representative locations in each critical reach. Team members were expected to choose representative locations corresponding to the river values of interest in that critical reach. River discharge measurements were taken at nearby points hydraulically suitable for stream gauging.

Description of Flow-Dependent Values

Stream corridor values identified during the preliminary assessment were further evaluated in this step. Individual evaluations by each team member and coordination among members were both required to identify and describe relevant aspects of all stream corridor values dependent on flow or flow-related conditions. Fisheries values were described in terms of useable habitat during specified life phases. For example, an important habitat criterion was the required depth for spawning migration. Recreation values required an analysis of certain depths or hydraulic conditions for boating, and flow-dependent features such as gravel bars for camping.

Hydrologic and Geomorphologic Quantification

Standard hydrologic, hydraulic, and geomorphic techniques were used for quantifying flow regimes and associated hydraulic and geomorphic attributes. The hydrologic quantification included analyses of low flows, mean monthly flows, and annual flow durations.

Long-term discharge data were not available for hydrologic analysis of the Gulkana River. Therefore, regionalized formulae, correlation analyses, and indirect (Manning equation) methods were employed to quantify the hydrologic regime. Indirect methods (and regionalized flow-hydraulic geometry relationships) were used primarily to validate regional methods.

The hydraulic quantification is based on at-station hydraulic geometry relationships. Using the Manning equation, relationships are developed between discharge and such variables as flow width, depth, mean velocity, cross-section area wetted perimeter, and hydraulic radius. Whereas either single or multiple transect methods may be employed, single transect methods were used for this study (Figure 3). As appropriate, substrate particle size information was developed at some study stations.

The geomorphic analysis is based on a thorough analysis of descriptive morphology, downstream hydraulic geometry relationships, and principles of stream energy dissipation and channel adjustment. The Gulkana River is described in terms of pattern, longitudinal profile, sediment composition, morphologic features, and both short-term and long-term adjustment processes.

Figure 2. A team of specialists works closely together to create an interdisciplinary product.

Table 1. Critical Reaches Sampled During the Field Assessment

Reach	Critical Resource Values
Middle Fork below Dickey Lake	1. Salmon and steelhead migration for spawning 2. Canoe/raft floatability 3. Camping quality of gravel bars
West Fork - South Branch	1. Canoe/raft floatability
West Fork - North Branch	1. Canoe/raft floatability 2. Salmon migration for spawning
West Fork Main Channel	1. Jet boat navigability in vicinity of Fish Lake tributary 2. Camping quality of gravel bars 3. Wildlife viewing
Gulkana Main Channel below Paxson Lake	1. Canoe/raft floatability 2. Salmon migration for spawning
Gulkana Main Channel - Canyon Rapids and 8 Miles Below	1. Canoe/raft floatability 2. Whitewater experience
Gulkana Main Channel below Canyon Rapids	1. Camping quality of gravel bars 2. Wildlife viewing
Gulkana Main Channel below West Fork confluence	1. Jet boat navigability

All geomorphic techniques employed are selected based upon their relevance in delineating flow-value dependencies. Specialists are expected to understand and describe physical processes as they relate to the various resource values—not simply to document mechanics. Thus, a great deal of qualitative analysis, in an interdisciplinary arena, is required to understand flow/geomorphic process/resource value dependencies.

Description of the Effects of Flows on Resource Values

This step describes the way flow-dependent values are affected by alternative flow regimes. Where feasible, descriptions of the effects of flows on resource values are based on quantified relationships. All relationships ultimately are used to substantiate judgments of required flows.

In several cases, it was either impossible or impractical to develop quantified relationships between flows and values. Then, the project team developed the flow-value dependencies descriptively, borrowing wherever possible from information developed during the literature review, field reconnaissance, user survey, or hydrologic quantification phases of the project. This was the case, for example, when describing the effects of very large (flood) flows on channel adjustment features.

Figure 3. Hydraulic geometry relationships were developed from river transect data.

Identification of Recommended Flows to Protect Values

The recommended flow regime represents a merging of resource values and hydrology, and results from a team evaluation of flow impacts. Both optimum and minimum acceptable flow levels are evaluated by team members representing the water-dependent resource values, based on descriptions of how alternative flow levels influence both instream and riparian zone water conditions and associated geomorphic processes.

Instream flow recommendations are expressed as fixed discharge rates by month. High flow recommendations were developed and expressed as a percentage of the quantified flood-frequency relationship.

Where flow needs varied from one resource value to another, flows were selected which protected the value with the highest flow requirement (as, for example, when recreational boating requires more water than fish habitat). Flow recommendations were checked to determine that higher flows did not impair the lower flow resource values.

For each flow-dependent resource value, there was a range of flows that the resource professional considered to be "acceptable." That range is bounded by upper and lower flow thresholds. Beyond those thresholds, flow levels are considered to be "unacceptable" and exceeding the thresholds could be detrimental to the resource value of interest. The domain of acceptable flows contains a narrower range of "optimum" flows as defined for each resource value. Within this optimum range, the resource value is maximized in terms of resource user expectations. An example would be the flow level at Canyon Rapids. Whitewater enthusiasts floating the Gulkana River have certain expectations about running Canyon Rapids. Since they have invested time and money in their trip, they expect to optimize their whitewater experience in Canyon Rapids and that experience depends in part on flow level.

Development of a Flow Protection Strategy

Developing a flow protection strategy requires evaluating and blending legal, administrative, and technical alternatives in a way that maintains or enhances flow-dependent values. The strategy must be realistic, efficiently administrable, and as flexible as possible in recognizing the many overlapping and competing interests in instream water supplies. For the Gulkana River, the primary focus is on establishing an instream flow water right under applicable State law.

An Alaska Instream Flow Reservation, if granted, will protect flows to the extent that the primary purposes of the Federal wild river designation will not be defeated. The keys to protecting instream flows under Alaskan law are to (1) specify an amount that protects resource values, (2) quantify the right so that it can be realistically measured and protected, (3) establish a meaningful priority date in relation to competing water uses, and (4) develop an effective administration strategy.

This instream flow assessment also considers that other (nonlegal) administrative and technical options might support the purposes of an instream flow water right. Land management actions (e.g., proper floodplain development, control of access, management of riparian vegetation), which enhance values or processes for which instream flows are required, are recommended.

Recreation Assessment

Glennallen District Office files contained a great deal of background information on the recreation resource of the Gulkana River. A literature and file search turned up several valuable references, including study reports by Lime (1980) and Kamler (1986) that describe different recreational uses and user experiences on the river. Annual river ranger reports offered detail on river resource characteristics and user experiences. In addition to the literature and file search, several Glennallen District resource specialists and other long-time river users were interviewed. This information is summarized in reports by Whittaker (1988, 1989).

The recreation assessment is based on three components: field reconnaissance, a survey of river users, and a review of floatability reports collected by the National Weather Service. Field reconnaissance included an 8-day trip on the Middle Fork and Main Stem, and two 3-day trips on the Main Stem only. The 8-day trip started when flow was at a summer low and finished with flow near a summer high, while the two shorter trips were taken at medium-low levels. This variety of flows provided valuable information about the effects of flow on boating and other recreation values.

A survey of Gulkana River boaters was conducted between June 21 and August 15, 1988. An interviewer stationed at Sourdough Campground surveyed the most experienced person from each party (Figure 4). All of the 101 parties contacted agreed to participate (56 upstream motorized boaters and 45 downstream float boaters). The survey asked questions about user and trip characteristics; reasons for taking the trip (e.g., fishing, being in a wild place, being with friends); and flow-dependent variables (e.g., floatability, finding places to fish or camp, quality of whitewater). The survey format and detailed results are presented in Appendix A. Relationships between

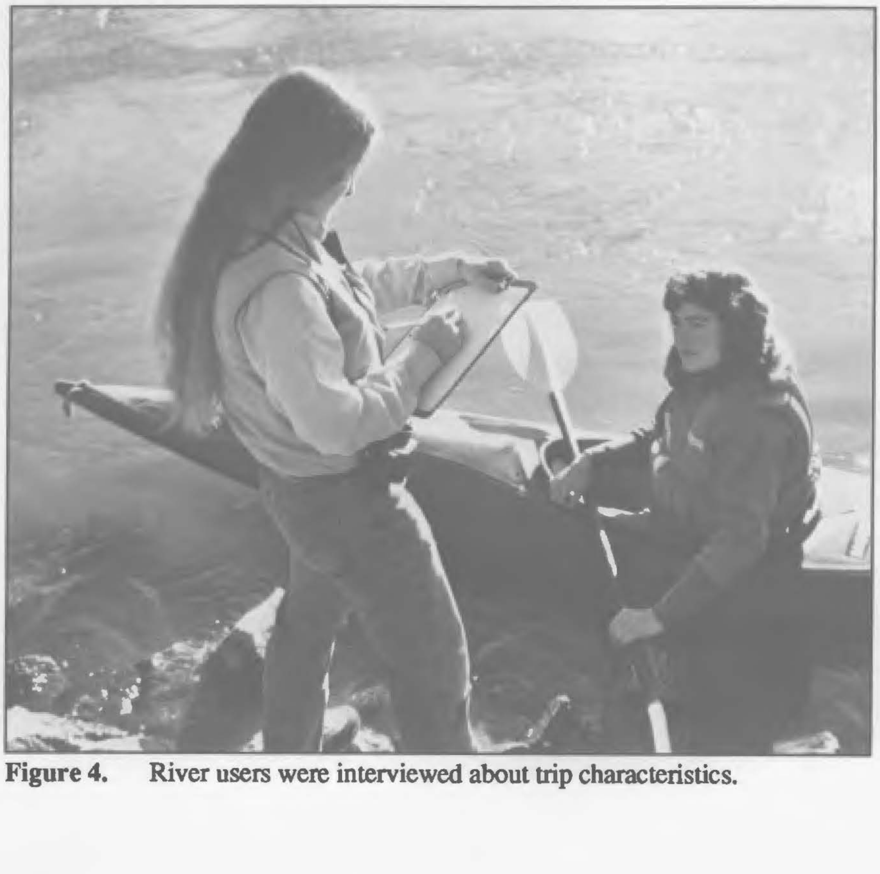

Figure 4. River users were interviewed about trip characteristics.

flow-dependent recreation variables and flow levels were developed using Pearson correlation coefficients ("r" values).

The National Weather Service River Forecast Center collects stage data for the Gulkana River and information about the floatability of the river at different stages (see Appendix B). The objective of the program is to correlate floatability with stage and thus provide an information service to potential floaters. The program has been in place since 1973, but correlations have not been complete and few cards have been returned in recent years.

Most of the cards on file at the River Forecast Center refer to Paxson-Sourdough floats by BLM river rangers. Table B-1 in Appendix B organizes the cards by low, ideal, and high water conditions. The stage readings used in this program are taken from a gauge located on the Gulkana Bridge, approximately 20 river miles downstream from Sourdough. Flows at the Gulkana Bridge have been converted to flows at Sourdough for comparison with other data given in this report. Because of lag time, those stage readings are only generally indicative of flows throughout the Gulkana River system; actual flows at the time users were on critical reaches may have been different.

Fishery Habitat Assessment

Fishery habitat information was collected from literature sources, Glennallen District files, personal interviews, and field observations. During the field assessment of July 20-27, 1988, daily observations were made of overall habitat quality, riparian vegetation, pool-riffle ratio, substrate type, and streambank condition. Kick samples were used to qualitatively assess macroinvertebrate communities. Hook-and-line sampling was employed to confirm occurrence and estimate length and weight characteristics of dominant species (Figure 5). Hydraulic analyses were designed to provide relationships between flows and hydraulic aspects of fisheries habitat, including depths, wetted perimeters, and flow velocities.

Hydrology and Geomorphology Assessment

Traditional hydrologic analyses were performed on the U.S. Geological Survey data at the Sourdough stream gauge (USGS #15200280). Those analyses were adjusted slightly to account for the fact that the period of record was somewhat dry compared to longer-term regional norms. Analyses were also performed using a synthesized discharge record at Sourdough, the record being extended by correlation with a nearby stream gauge. Both the direct gauge record analyses and the analysis of the synthesized record were compared to the results of a regional analysis using the discharge relationships in Parks and Madison (1985). Bank-full (1.5-year return period) flows were also field validated using hydraulic geometry survey methods (Parsons and Hudson, 1985). Professional judgement was used to resolve the small differences resulting from the different analytical methods to arrive at a final discharge summary for the Gulkana River at Sourdough. Finally, the discharge summaries developed for Sourdough were transposed to six other key locations on the National Wild River using area-discharge relationships in Parks and Madison (1985). Hydraulic geometry relationships were developed using traditional field survey-Manning equation methods (Parsons and Hudson, 1985).

Hydrologic summaries were developed for mean annual discharge, flood magnitude and frequency (Log Pearson III analysis), 30-day and 10-year low flows, mean monthly flows, and average annual daily flow duration. The longer-period (20-year) synthetic record was developed using correlation with the Susitna River gauge (USGS #15292000) at Gold Creek. Correlations were poor for the low flow periods, thus only floodflow analyses were performed on the synthesized record. Correlation coefficients averaged 0.72 for the high flow period. This correlation was higher than for the other regional streams evaluated—Tonsina River, Copper River, McClaren River, and Talkeetna River (personal communication with Bob Lambke, U.S. Geological Survey, Anchorage Subdistrict, Anchorage, Alaska).

Hydraulic geometry relationships were developed for 31 sites on the National Wild River. Field cross-section survey data came from the three sources: Lyle (1980), Huntsinger (1983), and the field reconnaissance conducted as part of this study (Figure 6). Field data locations and sources are

Figure 5. Length and weight characteristics of dominant fish species were noted.

of the cross-section surveys. All discharge readings for this study were acquired using a March-McBirney current meter and standard stream gauging techniques.

Daily discharges during the 1988 water year were developed by correlating stage readings at the Sourdough Alyeska Pipeline Bridge to the USGS Sourdough gauge rating table. Benchmarks were related using standard survey techniques.

Descriptive geomorphic information, such as sinuosities, channel gradients, channel widths, valley widths, and landscape positions, was collected from 15-min quadrangle maps, aerial photographs, and field observations. Information on particle size distribution of channel bed material, pool-riffle ratios, gravel bar characteristics, and channel adjustment processes was developed from field observations and integrated with the hydrologic and other resource data during the data analysis stage.

summarized in Table 2. All data were analyzed using CHANL, a Manning equation-based computer program (Parsons and Hudson, 1985). Relationships were developed between discharge and average depth, wetted perimeter, average velocity, and cross-section area. Manning "n" values were back-calculated given discharge measurements at the time

Figure 6. Hydraulic geometry data were developed from surveys of 31 channel cross-section sites on the Gulkana National Wild River.

Table 2. Field Hydraulic Geometry (Cross-Section) Data Locations and Sources for the Gulkana River, Alaska.

Location	Source		
	Lyle (1980)	Huntsinger (1983)	Project Team
Main Stem			
Outlet, Paxson		X	
RM=2.5			X
RM=3	X		
RM=5	X		
RM=7	X		
RM=10	X		
RM=18	X		
RM=25	X		
RM=33.5	X		
RM=38		X	
RM=40			X
Sourdough			X
Middle Fork			
RM=0	X		
Below Dickey Lake			X
RM=2.5			X
RM=3	X		
RM=6	X		
RM=10	X		
RM=16	X		
RM=22.5			X
RM=24	X		
West Fork			
RM=37		X	
RM=63		X	
RM=83		X	
South Branch of West Fork			
At confluence with North Branch		X	
Upstream from confluence with North Branch		X	
RM=26			X
RM=0		X	
North Branch of West Fork			
At confluence with South Branch			X
RM=9			X
RM=2			X

FLOW-DEPENDENT RESOURCE VALUES

River Corridor Values

The Bureau of Outdoor Recreation (BOR) studied the Gulkana River in June 1975 for potential addition to the National Wild and Scenic Rivers System (USDI, 1976). All river segments included in the System receive their designation based on certain specific river resource values and characteristics. For the Gulkana River, BOR identified the following river attributes:

- located in a largely wilderness environment
- the largest clear-water river in the region
- water quality and water clarity are normally excellent
- one of the most popular sport fishing streams in Alaska
- outstanding habitat for both resident and anadromous fish species
- the leading king (Chinook) and red (sockeye) salmon spawning stream in the Copper River basin
- grayling, rainbow trout, and steelhead are resident species
- excellent floating river to descend with canoes, kayaks, or rafts
- a variety of mostly road-accessible water for the floater and powerboater
- closely flanked by low rolling hills with the Wrangell Mountains in the background, a distinct scenic beauty
- excellent variety of wildlife including moose, bear, bald eagles, and waterfowl
- large numbers of nesting sites for bald eagles

The Gulkana River Management Plan (USDI-BLM, 1983) cites powerboat use of the lower river, including the main channel below the West Fork confluence and the West Fork itself. People occasionally float the river in the fall to hunt for moose. According to interviews with Glennallen District staff, jet boats are used in the fall to gain access for moose hunting on the West Fork as far upriver as Fish Lake.

Since the objective is to relate river values to streamflows, the team selected, for detailed assessment, those values determined to be flow-dependent. Those values are primarily fishery habitat and recreation, including such specific values as river floating with rafts, kayaks, and canoes; powerboating; camping on river gravel bars; sightseeing and photography; and fishing and hunting in the river corridor.

The Recreation Resource

The Gulkana National Wild River (including Middle Fork and West Fork) is the largest clear-water river system in the Copper River Basin. One of a handful of road-accessible rivers in the state and less than 5 hours' drive from Fairbanks (pop. 75,000) and Anchorage (pop. 250,000), the river is among the most popular recreation resources in south-central Alaska.

The three forks of the Gulkana flow through the rolling valleys and low ridges of an upland spruce-dominated forest. Lakes are abundant in the surrounding hills. For several short stretches of river, most notably at Canyon Rapids, the river cuts sharply through ridges, providing gorge-like settings. Soils are poorly drained and often tussocky. Vegetation includes spruce forests and thick willow, alder, and berry underbrush. Vegetation usually grows along the river's edge, although there are numerous gravel bars providing a more open river corridor.

Vistas on the Gulkana are not spectacular, offering views of broad forested hills and ridges rather than rugged peaks or canyons. However, at the start of the Paxson-Sourdough trip, floaters can see the distant snow- and glacier-covered peaks of the Alaska Range behind Paxson Lake (Figure 7). Main Stem boaters can catch glimpses of the Wrangell Mountains as they approach Sourdough.

For most of their length, the three forks of the Gulkana are not whitewater rivers, although each has stretches that would fit that description. There is a 2-

to 3-mile stretch of Class II and III rapids on the Middle Fork, a 2- to 3-mile stretch of Class II rapids on the West Fork, two stretches of Class II rapids on the Main Stem (3 miles and 8 miles), and a quarter-mile stretch of Class III-IV rapids in the canyon on the Main Stem. At low water, almost all of these stretches become difficult to run because oars or paddles hit bottom or boats run aground. Canyon Rapids has a large hole that stops and sometimes flips rafts in normal to high flows, although there is an alternative route at these levels. Inexperienced canoeists can wrap their boats on sweepers or rocks at high flows or in the canyon at any flow (Figure 8).

There are 11 species of fish in the Gulkana, 4 of which are prized by Alaskan anglers. King salmon run in late June until early August and go up the Main Stem and Middle Fork, with a considerably smaller run up the West Fork. Red salmon run through the king season into late August, with more going up the Main Stem than the Middle Fork. Rainbow trout and steelhead are present in the Main Stem and Middle Forks, particularly in the high-gradient (rapids) reaches. Grayling are abundant on all three forks.

An abundance of wildlife is in the Gulkana area. Hunted animals include moose, caribou, black bear, and brown bear. Trapped animals include wolves, marten, wolverines, otters, minks, foxes, lynx, and beaver. The most commonly seen mammals are moose, bears, caribou, and beaver. There is an equally large variety and abundance of bird life on the Gulkana. The most prominent of these species is the bald eagle; Main Stem floaters may see over 50 on a single trip (Figure 9). Other birds include trumpeter swans, ducks, geese, terns, gulls, kingfishers, and a variety of songbirds.

The Gulkana is largely a wilderness river with few developments. Aside from the launch areas and attached campgrounds at Tangle Lakes, Paxson Lake, and Sourdough, the BLM maintains only four pit toilets on the system, all on the Main Stem. There are no maintained facilities on the Middle or West Fork. A number of old mining and trapping cabins are in the river corridor, and some are still used, particularly in winter. The BLM also maintains several hiking/all-terrain vehicle (ATV) trails from State highways into the river corridor.

There are a number of excellent camping sites along the river. A BLM inventory in 1977 identified 106 different sites on the Main Stem, 79 established and 27 potential sites. The majority (68 percent) of sites were located on gravel bars. With the exception of the sites around the Middle Fork confluence, at "Outhouse Island," at Canyon Rapids, and the several bars below the West Fork confluence, sites are infrequently used and traces of use are minimal. Campsites on the Middle or West Fork are perhaps even more plentiful, and because they are almost never used, are much more pristine.

In summary, the Gulkana National Wild River

Figure 7. Distant snow- and glacier-covered peaks of the Alaska Range are visible at the start of the Paxson-Sourdough trip.

Figure 8. Canyon rapids may be negotiated at moderate flows by experienced canoeists. Inexperienced canoeists can wrap their boats on sweepers or rocks at any flow level in the canyon.

system is an excellent recreational resource, providing opportunities for fishing, hunting, floating, boating, sightseeing, and camping in a primitive yet accessible Alaskan wilderness.

Figure 9. Bald eagle on the Gulkana National Wild River.

Recreation Activities and Use

Recreationists use the Gulkana in a variety of ways. The vast majority of users float or boat the river, with smaller numbers entering the river corridor by plane, by all-terrain vehicle, or on foot. This report focuses on boating use, characterized on the basis of background and survey data.

There are essentially four different boating trips available on the Gulkana River system. Powerboaters or upstream users, who are encouraged not to travel on the Middle Fork or the Main Stem above the confluence with the West Fork before August 15, generally take trips from Sourdough to the area around the West Fork confluence (see Figure 1). Floaters or downstream users, on the other hand, have the option of floating the Main Stem, the Middle Fork, or the West Fork.

Upstream trips begin and end at Sourdough Campground. Boaters usually travel 8 or 10 miles upstream in search of fishing holes. The majority (73 percent) of those with powerboats have jet units; 25 percent, propellers; and 2 percent, airboats.

Main Stem floaters put in at Paxson Lake and go downstream to Sourdough Campground, both of which are on the Richardson Highway. This is a 48-mile trip that takes from 3 to 5 days. The majority (68 percent) of Main Stem users float in rafts; 22 percent paddle canoes; and 9 percent use a combination of canoes and rafts.

Float trips on the Middle Fork can begin at the Tangle River Campground on the Denali Highway, although this route includes a difficult 1.25-mile portage. Middle Fork trips can also begin at Dickey Lake, accessed by float plane. The float from Dickey Lake to the confluence with the Main Stem is 25 miles. Very few users float the Middle Fork and there is little information available about their trips. Middle Fork users usually terminate at Sourdough.

Float trips on the West Fork can begin at Lake Louise (although this includes a series of short portages between lakes and the Tyone River), or at the headwater lakes of either the North or South Branches of the West Fork, accessed by float plane. The trip from Lake Louise to the confluence with the Main Stem is over 100 miles. As with the Middle Fork, few users travel the West Fork and river managers know little about their trips. West Fork floaters probably paddle canoes or small rafts since some segments of the river are extremely shallow and narrow. Users usually terminate at Sourdough.

Trail access to the Gulkana is limited in the summer, with only three major trails available to hikers or ATVs. The Swede Lake Trail (13 miles) provides access to the Middle Fork, the Meier's Lake Trail (7 miles) provides access to the confluence of the Middle Fork and the Main Stem, and the Haggard Creek Trail (6 miles) provides access to Canyon Lake and Canyon Rapids. Float planes can also use Canyon Lake and the Haggard Creek Trail to access Canyon Rapids (1 mile). In winter, the river and several other trails are accessible by snow machine.

BLM utilizes different methods to estimate use levels on the Gulkana. Different sources include State Fish and Game creel censuses; airplane flights over the river on random days; and traffic counts at campgrounds, launch areas, and portages, supplemented by observations and small-scale surveys to adjust for double counts and party-size differences. Each of these methods has potential problems, but they provide a valuable profile of use.

Total use on the Gulkana above Sourdough is estimated at between 3,000 and 4,000 visitors per year. All but approximately 200 visitors float or boat the river. Official BLM estimates suggest that fewer than 50 users per year take trips down either the Middle or West Forks; 1,800 to 2,400 take trips down from Paxson to Sourdough; and 600 to 1000 take upstream (powerboat) trips. Another 1,000 use the lower river below Sourdough.

Total use on the river for the past 15 years is shown in Figure 10. Differences from year to year depend on a number of factors, including growth or decline in State population, local activities (e.g., the construction of the trans-Alaska pipeline), size of fish runs, and weather conditions. Although current total use is substantially higher than in the early and mid-70's, it appears to have declined somewhat and then leveled off since the early 80's. River managers expect use to remain relatively stable unless the State economy and population grow dramatically.

Use on all segments of the river is higher during the salmon runs in late June and early July, with the peak weekend coinciding with the Fourth of July holiday. Upstream use is particularly sensitive to fishing conditions, declining dramatically after the king salmon begin to spawn. Downstream Main Stem users continue to float the river throughout the summer if river levels permit. There are noticeable increases in both upstream and downstream use during the hunting season if river levels permit, but this use is far below the peaks during the salmon season. Use "seasons" are summarized in Table 3.

The River Experience and Trip Attributes

A list of trip attributes helps to characterize Gulkana River experiences and provide a structure for examining how flow levels affect those experiences. The list was developed from results of the user survey (particularly the "reasons for boating" questions), interviews of expert users, and field work. Attributes of trips on the Gulkana system are summarized in Table 4.

Upstream Users

Upstream users were asked to rate the importance of 15 reasons for boating on the Gulkana. Results are given in Table 5. These rankings, taken in conjunction with other information known about upstream trips, suggest several conclusions about the upstream river experience.

First, *fishing* is a central focus of upstream trips, with virtually all users rating it as an "extremely important" reason for boating the Gulkana. When the salmon are in the river, as many as 40 powerboats may be on the river between Sourdough and the West Fork; if the river is high and muddy during the king run, there may be only a handful.

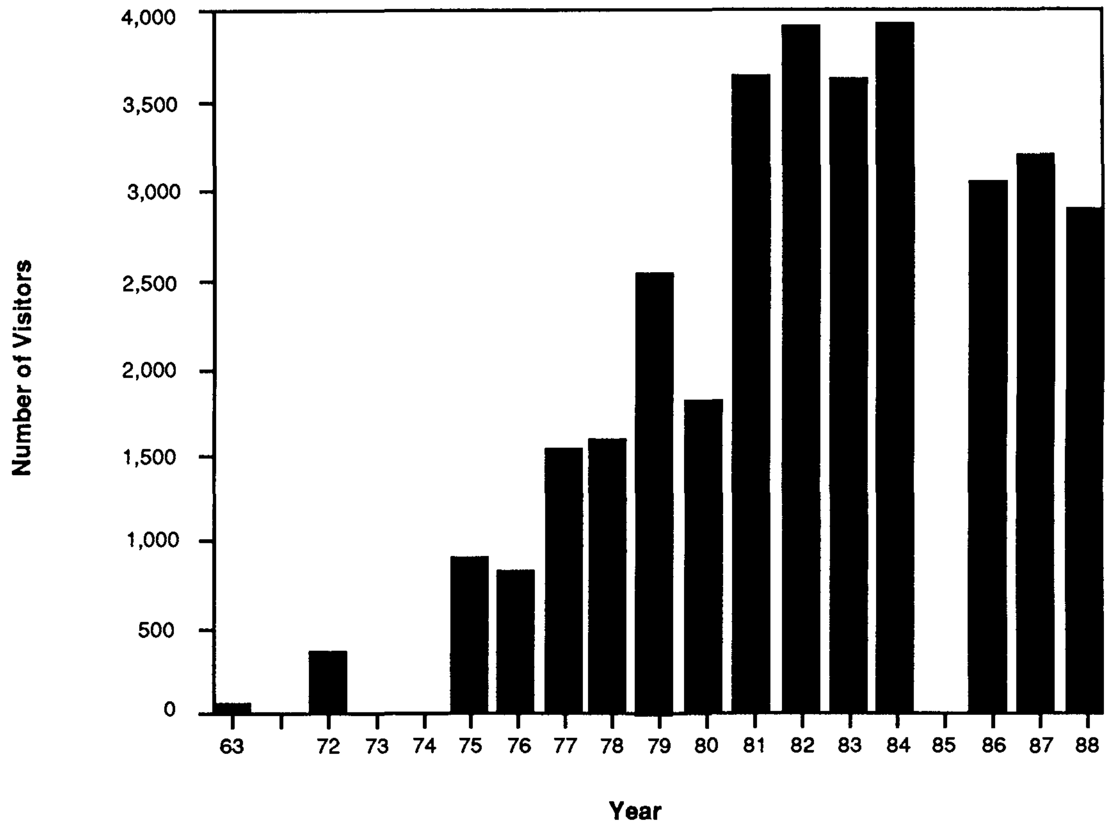

Figure 10. Total use on the river for the past 15 years.

Table 3. Use "Seasons" for Recreation Activities.

	May	June	July	August	September
Whitewater boating (3,000 ft³/s)	■	■			
Family/novice boating (2,100 ft³/s required)		■	■	(moderate water times)	
Low water/drag boating (1,400 ft³/s)				■	(lower water times)
Moose hunting (drag boating) (1,400 ft³/s)				(moose season)	■
Jet boating		■	■	■	■
Fishing					
King Salmon		■	■		
Sockeye Salmon		■	■		
Trout	■	■	■	■	■
Grayling	■	■	■	■	■

Table 4. Summary of Trip Attributes for Gulkana National Wild River Float Trips.*

Attribute	Main Stem Trips Upstream	Main Stem Trips Downstream	Middle and West Forks
Natural/Wilderness Setting			
- remote from development	1	2	3
- few traces of use	2	2	3
- natural processes	3	3	3
Viewing Scenery and Wildlife			
- open river corridor/vistas	3	3	3
- variety of wildlife	2	3	3
Fishing			
- open banks or bars	3	3	3
- variety/abundance of species	3	3	3
Social Interaction/Solitude **within-party/solitude:**			
- single-party sites	2	3	3
- time for activities off-river	3	3	3
- few river encounters	2	3	3
outside-party:			
- encounters at launches	2	1	1
- encounters at rapids	—	1	1
Floatability/Navigability			
- few/no portages	—	3	2
- avoidable sweepers	—	3	3
- minimum dragging/hits	3	3	3
Whitewater			
- challenging maneuvers	—	3	3
- runnable waves/hydraulics	—	3	3
- safety/portages available	—	3	1
Camping			
- natural/aesthetic setting	3	3	3
- scenic views of river	3	3	3
- minimum of insects	2	2	2
- place to secure boats	2	2	2
- flat areas for tents	2	2	2
- close proximity to river	2	2	2
- isolation from other camps	2	3	3
- good water quality	2	2	2
Historical Sites (cabins)	—	1	1
Hiking Opportunities (trails)	1	1	1
Hunting Opportunities			
- abundance of game	2	2	2

*1 = not important 2 = important 3 = very important — = not relevant

The majority (52 percent) of upstream users fish solely for salmon and 27 percent fish only for king salmon. The balance fish for trout and grayling as well. Users generally fish from gravel bars (95 percent) or other spots where they could avoid snagging lures, and try to cast into holes where fish congregate (Figure 11).

Second, *social interaction* (being with friends and family) is an essential part of Gulkana experiences. Consistent with many other studies of outdoor recreation, users enjoy sharing their experiences with their own party. This should not be confused with the desire to experience solitude, which was also rated as "very important." Upstream users had some interest in meeting members of other parties, although they rated this lower.

Users looked for single party campsites to increase solitude. Take-out points appear to be the focus of any outside-party interaction, as boaters compare equipment, fish, and river stories. Average party size for upstream users was 3.6 people.

Third, upstream boaters placed a high value on the *navigability* of the river. The Gulkana is one of only a handful of road-accessible, boatable, salmon rivers in the State, and the closest one to Fairbanks. Over 93 percent of the upstream users are from Alaska, with 61 percent from Fairbanks.

Navigating the river takes a combination of skill, experience, and equipment. Most upstream users have the experience and probably the skill; they averaged over 19.6 previous trips on the river and over 9 years of boating experience (only 18 percent were making their first trip on the river). Over 70 percent used jet boats and airboats that drafted less than 12 inches.

The majority (71 percent) of upstream users say they generally checked water levels before traveling to the river. Thirty percent learn by word of mouth; 27 percent call Fish and Game offices; and 13 percent call the National Weather Service River Forecast Center. The remainder check the river themselves.

Fourth, upstream users are attracted by the Gulkana's *natural environment, scenery, and wildlife*, attributes that are often associated with aesthetic characteristics (Figure 12). Most powerboaters ran their boats only to get to camps and fishing spots, and most indicated a preference for peace and quiet. A number of upstream users expressed a dislike for operators who continually ran up and down the river throughout the day, or worse, in the evenings.

The view of the Wrangell Mountains is definitely an attribute of these trips, as are abundant sightings of eagles, the most commonly seen wildlife species. Upstream users were asked which wildlife species did or would have enhanced their trips. Fifty-seven percent named eagles; another 52 percent named moose and caribou; 48 percent, bears; 18 percent, small mammals such as beaver or otter; and 16 percent, waterfowl or other birds. Photographic opportunities, another trip attribute, were enhanced by wildlife sightings and scenic vistas.

Detracting from the natural aspect of upstream river trips are abundant "signs of use" impacts such as litter,

Table 5. Reasons for Boating: Upstream Users.

Rank	Reason	Rating *
1.	Fishing	4.9
2.	Being with friends and family	4.8
3.	Navigability	4.5
4.	Being in a natural or wild place	4.5
5.	Good weather	4.3
6.	Solitude	4.0
7.	Viewing wildlife	3.8
8.	Viewing scenery	3.6
9.	Camping	3.6
10.	Photographic opportunities	3.0
11.	Meeting other users (not in party	2.5
12.	Viewing historical sites (cabins)	1.7
13.	Running whitewater	1.5
14.	Hiking	1.3
15.	Hunting	1.1

* *No significant differences (p>.05) among reasons in brackets.*

Figure 11. Fishing for salmon is popular with river users.

fire rings, and human waste. These impacts are more evident on this section of the river than any other. During the salmon season, some river users build makeshift "smokers" which they often abandon, detracting from the "wilderness feel" of the river.

Fifth, *camping* is a major component of many upstream trips. Sixty-six percent of upstream users camp along the river; 21 percent stay at Sourdough Campground; and 13 percent use the river only during the day. The average trip length is 2.95 days.

As with "being in a natural place," some camping attributes are tied to aesthetics. A majority of boaters (64 percent of those who camp) prefer to stay on gravel bars with views of the river and scenery, and where biting insects are fewer. Other practical concerns important to campers are good places to tie boats, flat spots for tents, driftwood for fires, and good quality water for cooking.

Finally, upstream users are less interested in *whitewater* (there is very little on this section of the River), *hiking* (brush is very thick), or *historical sites* (none of the cabins are considered historical nor particularly aesthetic). The upstream users sampled also rated *hunting* as unimportant, but these surveys were not conducted during the hunting season. (As many as 15 hunting parties may boat the river in the fall.)

Figure 12. Upstream users are attracted by the Gulkana River's natural environment, scenery, and wildlife.

Downstream users were asked to rate the importance of the same 15 reasons for boating the Gulkana. Results are given in Table 6. These rankings, in conjunction with other information about downstream trips, suggest several conclusions about the downstream river experience.

First, the central focus of downstream trips is *being in a natural or wilderness-like place* (Figure 13). Unlike many upstream users who are there to fish, many downstream users float down the river just to get away from manmade environments. Aesthetic attributes are important here: observing natural processes, being on or near a flowing river, having peace and quiet. *Viewing wildlife and scenery* is also a component of the downstream experience.

A number of scenic views presented themselves to downstream floaters, most notably on Paxson Lake looking back to the Alaska Range, through the gorge-like settings around Canyon Rapids, and at the ends of trips near Sourdough and the Wrangell Mountains. Wildlife, such as moose, caribou, bear, and eagles, is common. Downstream users were asked which wildlife species would enhance their trips. Sixty-nine percent named bears, moose, and caribou; another 64 percent named eagles; 31 percent named small mammals such as beaver and otter; and 22 percent named waterfowl or other birds. Compared to upstream users, higher percentages of downstream users named wildlife species, perhaps indicating greater enthusiasm for viewing wildlife. Interest in photography was high among downstream users.

Signs of use, such as litter, fire rings, or human waste, can detract from the natural part of Gulkana experiences, but camps generally receive less pressure upstream of the West Fork confluence, and the river appears more pristine (Figure 14). The few heavily used camping areas (the Middle Fork confluence, "Outhouse Island," and Canyon Rapids) can be avoided by users interested in experiencing more natural conditions.

Second, *social interaction* (being with friends and family) is an important part of Gulkana experiences. As with upstream boaters, downstream users enjoy sharing experiences within their party, while valuing solitude from other groups. Floaters rate "meeting other users" fairly low. Downstream floater groups average 4.8 people, larger than the 3.6 average of upstream groups.

Downstream users prefer single party sites and prefer not to camp within sight or sound of other users. They also prefer a minimum of river encounters with other groups—considerably fewer than upstream users. The only time downstream floaters were interested in seeing other users was at Canyon Rapids, where they might compare notes on how to approach the whitewater.

Third, downstream users place a high value on the *floatability* of the river. Again, the Gulkana is one of the few road-accessible rivers in the state, and river users were aware that it may not be floatable at low water levels. The majority of downstream floaters (89 percent) are from Alaska.

Floatability concerns for downstream trips were different for different types of boats. Rafters are concerned about getting stuck on rocks or puncturing a

Table 6. Reasons for Boating: Downstream Users.

Rank	Reason	Rating *
1.	Being in a natural or wild place	4.9
2.	Being with friends and family	4.7
3.	Floatability	4.6
4.	Running whitewater	4.3
5.	Camping	4.2
6.	Fishing	4.1
7.	Solitude	3.8
8.	Viewing wildlife	3.7
9.	Good weather	3.7
10.	Viewing scenery	3.7
11.	Photographic opportunities	3.2
12.	Meeting other users (not in party)	1.9
13.	Viewing historical sites (cabins)	1.8
14.	Hiking	1.3
15.	Hunting	1.0

* *No significant differences (p>.05) among reasons in brackets.*

Figure 13. A central focus of downstream trips is being in a natural or wildernesslike setting.

floor or tube; with canoes, the issue is glancing off a rock and swamping, with the possibility of wrapping the boat on other rocks downstream. Users in both craft also have to beware of sweepers. Floatability problems generally appear at lower flow levels.

A *reasonable rate of travel* is another attribute of Gulkana trips valued by downstream users. For the most part, the Main Stem is a meandering stream without a strong current. At low flows, parts of the river hardly move. Most river users prefer not to paddle hard in order to progress down the river. However, when asked whether low flows and a slow rate of travel would cause them to work harder each day or spend an extra day on the river, a majority (64 percent) chose the former.

Fourth, downstream users clearly value *whitewater* on the Gulkana, rating it "very important." Canyon Rapids is a focal point of most downstream trips; depending on flow levels, it may be tricky, fun, or dangerous (Figure 15). The hole at the base of the falls stops 13 to 14 foot rafts even in medium flows. Other rapids on the Main Stem are less challenging but still thrilling and fun at most water levels.

A key to successful negotiation of any whitewater is experience. Downstream users had taken an average of 7.4 trips down the river, and averaged over 9 years experience in floating rivers.

Fifth, *camping* is a focus of downstream trips. Users spend an average of 3.7 nights on the river. Many of the camping attributes discussed for upstream boaters apply to downstream boaters in that they prefer sites that are natural-looking, isolated from other users, in close proximity to the river, with views, fishing spots, docking ties, flat spots for tents, potable water, and driftwood for fires. Eighty percent prefer camping on gravel bars in order to avoid insects and enjoy better views (Figure 16).

Sixth, *fishing* is not as important for downstream users as for upstream users, although still rated as "very important." The majority (69 percent) of downstream users fish for salmon, trout, and grayling, while 24 percent fish for grayling only. The majority (96 percent) of users fish from gravel bars. A good rainbow trout fishery exists in the Canyon Rapids area.

Finally, as with upstream users, *hiking, viewing historical sites, and hunting* were less important attributes of trips down the Main Stem. However, an interesting old trapper's cabin just below the confluence with the Middle Fork draws some attention from floaters (Figure 17). Some boaters

Figure 14. On the North Branch of the West Fork, the river appears pristine.

take trips during the hunting season specifically to hunt.

Middle Fork and West Fork Users

Few floaters take Middle and West Fork trips, and none were sampled during the 1988 field season. However, field work and interviews with resource managers suggest conclusions similar to those for the downstream floaters discussed above, with the following exceptions.

First, *being in a natural or wilderness-like setting* is probably an even more important attribute of trips. Both the Middle and the West Forks are considerably more remote than the Main Stem, and both have far fewer traces of use. In contrast to the Main Stem, management has chosen not to cut out sweepers, sign rapids, or put in portage

Figure 15. Canyon Rapids is a focal point of most downstream trips.

Figure 16. Most boaters prefer camping on gravel bars in order to avoid insects and enjoy better views.

trails that might detract from a sense of wilderness. Trips on these tributaries can last from 7 to 20 days, further heightening a sense of remoteness. *Wildlife* may also be more abundant on the forks, perhaps because there is less human use. Bear, moose, caribou, and wolf tracks appear on most beaches on either fork, whereas they are less common on the Main Stem.

Second, the *floatability* issue on either fork is perhaps even more critical to trips, as travel begins on very shallow and narrow streams. There is not a great deal of floatability information available, and resource managers themselves are only now beginning to understand which parts of the river are floatable. The South Branch of the West Fork, which may have been floated only a half dozen times in the past 20 years, flows through a number of small lakes before finally becoming a river. On a trip in 1988, resource managers paddled a canoe through one stretch barely 4 feet wide, with vegetation occasionally spanning the stream. On a low water Middle Fork trip for this study, team members spent part of 1 day and most of the next hauling a canoe and two small rafts down the river; the rapids could not be run (Figure 18).

Third, *fishing* is probably a less important part of West Fork trips. The fishing is excellent on the Middle Fork and good on the Main Stem, but only fair to poor on the West Fork. The West Fork carries greater sediment loads and has poorer spawning areas.

Finally, *solitude* is probably a more important attribute on Middle Fork or West Fork trips. It would be rare to encounter another party on either of these forks (Figure 19).

Attribute-Flow Relationships

Instream flows affect the different river experiences in a number of ways, sometimes directly, but more often indirectly. The challenge is to describe relationships between attributes and flows, and find ways to evaluate flow needs. The following discussion, based upon expert judgment and field work with input from the user survey, helps define those relationships, noting required, ideal, and maximum water depth conditions or instream flows that correspond to high-quality recreation opportunities.

Results from the user survey, although useful here, have at least three limitations that

Figure 17. Being able to view historical sites such as this old trapper's cabin is a benefit of Gulkana River trips.

should be noted. First, users were asked to evaluate only the flows they experienced; because 1988 was an atypically high flow year, few users were able to tell about low flows. Second, flow data were recorded using information from gauges at Sourdough and Gulkana Bridge, both of which are downstream of the study reach (see Figure 1). Flows at these gauges are assumed to be representative of flows experienced by users upstream. This assumption is probably valid during nonrain periods. Tributary streams may fluctuate during and after precipitation events with no resultant effects on the downstream gauges. Large or prolonged storms may increase flows downstream after a lag of 2 or 3 days. Finally, only a single flow was assigned to each user surveyed, even though users averaged 3 to 4 days on the river, often experiencing a range of flows.

Navigability/Floatability

Navigability or floatability is the attribute most directly affected by flow levels. Users obviously do not like to hit bottom in powerboats, get their rafts stuck on rocks, or wrap canoes around obstructions, and the chances of these problems generally increase as flows drop (Figure 20).

Users were asked to evaluate the flows they experienced with regard to navigability or floatability (see Tables 7 and 8). Simple linear correlations between flows and user evaluations are significant for both upstream and downstream users (r=.37 and r=.30, respectively), and correlations for downstream users with more experience (three or more trips) were particularly strong (r=.46). These results indicate that many users are sensitive to relationships between flows and floatability. The results also suggest that a number of other factors may influence floatability/navigability for different boats and different users.

In flat water conditions, with a uniform river bottom, different craft require different depths to operate effectively. Presuming moderate loads, powerboats with jet units need approximately 6 to 12 inches, powerboats with props require 18 to 30 inches, and rafts or canoes require 5 to 7 inches (Figure 21). The required flow for these craft, using these figures, would be the amount

Figure 18. During low water on the Middle Fork, team members spent most of 2 days dragging rafts and canoes down the river. The Middle Fork Rapids could not be run.

that fills a boating channel (approximately 6 feet in width) with the corresponding depth. In actual river conditions, these figures are less reliable; boaters may be able and willing to negotiate the river with less water, or unable to do so with more. Jet boats can actually skip over dry land in some circumstances, and the consequences of hitting relatively soft bottom with a jet unit are not nearly as severe as for prop-driven boats. On the other hand, powerboats move in excess of 20 miles an hour and unskilled operators may not be able to maneuver out of the way of occasional rocks in the main channel even if there is a path around it.

Rafts loaded correctly may spin off rather than lodge on rocks, and the rafter's skill is at least as important as the depth of water. Canoes may hit rocks at slightly greater depths than rafts, but many models are made of materials which allow the craft to slide off easily. In addition, canoes are more maneuverable than rafts. However, a miscalculation in an open canoe is of greater consequence than one in a raft.

Skill, experience, and sometimes luck are all important in negotiating critical stretches, particularly for downstream boaters. Skilled rafters can float at average levels and get down most of the Main Stem without ever getting stuck, while novices may find their boats stuck on many boulders even at relatively high flows (Figure 22). Similar statements can be made about canoeists or powerboaters. In addition, getting stuck or hitting rocks a few times may be an acceptable, perhaps even amusing aspect of users' trips, but getting stuck or hitting several times is undesirable. There are certain water levels that are clearly less than ideal. The data reported in Table 9, based on "floatability cards" filled out by users (see Appendix B), and resource reconnaissance were used to help define those levels.

In general, it appears that upstream users (particularly prop boaters) encountered navigability problems when the river dropped to about 2,200 ft^3/s at Sourdough. Four out of 14 prop boaters interviewed this summer ran aground and had their boats disabled at this level. Jet boat operators who know the river channel have no problems at this flow, but there is no margin of error for inexperienced operators.

Experienced downstream users who frequently drag their boats or pull them off rocks can survive

Figure 19. Solitude is an important attribute on Middle Fork or West Fork trips.

trips with flows as low as 1,200 ft^3/s at Sourdough, although it becomes difficult to call this a "boating experience." Novice boaters would find a trip at this level to be a major ordeal, almost certainly damaging equipment. Reconnaissance trips suggest that skilled floaters can float the entire river at 2,100 ft^3/s at Sourdough, although these trips still involve frequent hits and perhaps some lining/dragging of boats in critical reaches. Novices would find this level about the lowest acceptable, with lower levels requiring too much time and energy dragging boats off rocks or bars.

Users on the Middle or West Forks probably require similar flows at Sourdough (2,100 to 2,200 ft^3/s) in order to ensure floatable conditions upstream, although these users are probably more tolerant of dragging boats across shallow stretches. Users on the Forks are probably aware of the narrow and shallow stretches near their sources, and are better prepared to cope with them. Users who do not fly in to these rivers also have to plan for several portages; they are probably traveling light and could more easily drag their boats and gear.

For further discussion of how these floatability/navigability figures translate into flows in the critical stretches of the river, see the section on Instream

Figure 20. The chances of getting rafts stuck on rocks or wrapping canoes around obstructions generally increase as flows decrease.

Table 7. Flow Evaluations for Navigability: Experienced Upstream Users (two or more trips).

Flows (ft^3/s) rated as...	Low	Ideal	High
Range	2,140-2,215	2,005-2,925	2,180-2,925
Mean	2,180	2,270	2,520
n	2	29	15
Correlation with Flow Levels: r=.37 (p=.006, n=46)			

Table 8. Flow Evaluations for Floatability: Experienced Downstream Users (two or more trips).

Flows (ft^3/s) rated as...	Low	Ideal	High
Range	1,990-2,590	2,005-2,925	2,005-3,835
Mean	2,270	2,280	2,420
n	6	26	5
Correlation with Flow Levels: r=.30 (p=.034, n=37)			
Corr. with Flow Levels (users with 3+ trips): r=.46 (p=.007, n=28)			

Figure 21. Rafts with moderate loads require 5 to 7 inches of water depth to float effectively.

Flow Recommendations to Protect Critical Resource Values.

Whitewater

Another attribute directly affected by flow levels is whitewater. This is the other half of the floatability equation for downstream users; it is not relevant for upstream users. There are two issues here: floaters want thrilling and fun whitewater, and they are concerned about safety. At different flow levels, whitewater characteristics differ.

In general, high flows mean larger waves, and the greater power in the river requires earlier and stronger boater reactions. On the other hand, some rapids are "washed out" at higher flows, and therefore uninteresting. The consequences of mistakes are more severe at higher flows. At low levels, there are more rocks to dodge, but waves are smaller and the river has less power. Mistakes at low flows are usually not as threatening to people or equipment.

Safety is an issue primarily on only two stretches of the Gulkana River system. A quarter-mile long gorge on the Middle Fork presents problems for open canoeists in medium to high water (it is unfloatable in low water and must be lined), and Canyon Rapids on the Main Stem can be difficult for all boaters at high flows (Figure 23). Even experienced rafters can flip

Table 9. Flow Evaluations for Floatability: National Weather Service "Floatability Cards."

Trips rated as...*	Low	Ideal	High
Range	1,070-2,590	2,755-4,140	2,755-7,860
Mean	1,854	3,284	5,405
n	10	6	6

* Low = many hits; some dragging required
Ideal = few hits; no dragging
High = no hits; camps flooded; rapids are class IV

Figure 22. Maneuvering rafts through rapids requires both skill and sufficient flows.

their boats or lose passengers here. Thirty percent of all Main Stem boaters surveyed completely portaged Canyon Rapids while another 45 percent portaged some of their gear in order to make their boats more maneuverable; 80 percent of the canoeists completely portaged. Lives have been lost in the Canyon Rapids reach.

Downstream users were asked to evaluate flows with regard to fun rides and safe rides through the rapids (see Tables 10 and 11). Correlations between flows and evaluations are statistically significant (r=.45 and .48, respectively), suggesting that users are sensitive to these relationships. Experienced floaters show even higher correlations between evaluations of fun whitewater and flows, indicating they are more aware of this relationship.

These results, taken with other information about how flows affect whitewater conditions, suggest that flows at Sourdough below 2,100 ft^3/s were considered too low for thrilling or safe rides. The safety issue here probably refers to equipment damage from hitting rocks. These results also suggest that with flows at Sourdough over 3,000 ft^3/s, a few users begin to sense a safety risk, but that many users consider these high flows ideal for fun whitewater. Results from National Weather Service floatability cards suggest similar results (discussed more completely in Appendix B), with the average "ideal" rating corresponding to 3,284 ft^3/s.

Natural/Wilderness Setting

A natural or primitive setting is another attribute affected by flow levels, although these relationships are less obvious. River flows at certain levels, for example, are needed to maintain a natural state of riparian vegetation. Any substantial change to the natural flow regime may cause changes in vegetation composition, perhaps detracting from the aesthetic appeal of the river setting. In addition, drought conditions in any single year may detract from the river's aesthetic appeal.

Users during the 1988 season were asked to evaluate flows they experienced in terms of aesthetics (see Table 12). A significant correlation is shown between flows and evaluations (r=.36), suggesting users were sensitive to this relationship. Based on these results, flows at Sourdough between 2,100 and 2,500 ft^3/s are probably the most aesthetically appealing. The lower evaluations of high flows probably refer to the turbidity, which increases as water levels rise.

Peak high-end flows at breakup (historical levels) are also needed to maintain the natural state of the river. These high-flow events sweep vegetation off gravel bars, deposit soils in other areas, and are at least partially responsible for the vegetation composition and plant succession processes. The same high-end flows would also help erase previous years' traces of use, adding to the naturalness of the river setting. This issue is discussed in the channel morphology section of this report.

Viewing Scenery and Wildlife

The flora and fauna of the Gulkana area clearly depend on flows. Peak high flows (historical levels) are needed to create open gravel and sand bars which create viewsheds for scenery and wildlife. In addition, required low flows and peak high flows (historical levels) are needed to provide quality fish and wildlife habitat. Any substantial change to the natural flow regime can result in loss of native vegetation or initiate other ecological changes which can cause a decline in the quality or quantity of wildlife habitat.

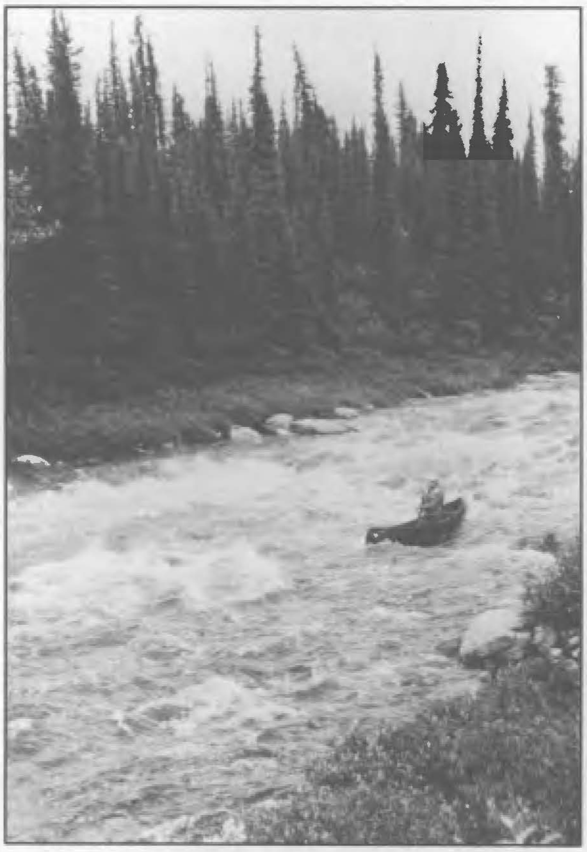

Figure 23. Canyon Rapids can be difficult for all boaters at all flows.

Table 10. Flow Evaluations for Fun Whitewater: Experienced Downstream Users (two or more trips).

Flows (ft^3/s) rated as...	Low	Ideal	High
Range	1,950-2,590	2,005-2,925	2,125-3,835
Mean	2,255	2,280	2,895
n	11	24	2
Correlation with Flow Levels: r=.45 (p=.003, n=37)			
Correlation with Flow Levels (users with 3+ trips): r=.55 (p=.001, n=28)			

Table 11. Flow Evaluations for Safe Whitewater: Experienced Downstream Users (two or more trips).

Flows (ft^3/s) rated as...	Low	Ideal	High
Range	1,990-2,430	2,005-2,925	2,005-3,835
Mean	2,110	2,280	2,280
n	5	25	7
Correlation with Flow Levels: r=.48 (p=.001, n=37)			

Fishing

Fishing is among the major attractions of a Gulkana trip, and flows influence the quality of this attribute (Figure 24). Peak high flows (historical levels) are needed to keep gravel bars free of vegetation, thus opening up good places from which to fish. Peak flows are also instrumental in creating desirable morphological features in the river channel, such as deep holes with associated eddies where fish congregate. Sufficient flows (historical levels) are also needed to allow fish to survive over winter. While the fishery habitat section of this report focuses on this issue, it is important to recognize that any decline in the Gulkana fishery also represents a decline in recreation opportunities and a threat to downstream commercial fisheries.

Flows also affect Gulkana fishing experiences during the use season. High flows tend to increase the turbidity of the water, causing a short-term decline in fishing success. However, high flows also import nutrients which improve aquatic productivity.

Users were asked to evaluate the flows they experienced in terms of fishing success (see Tables 13 and 14). Both data sets show moderate correlations between flows and fishing success (r=.34 for catching salmon; r=.45 for catching other fish species), suggesting that users are sensitive to these relationships. These results offer little information about how users perceive angling success at low flows, but they verify the problem with high flows. Flows greater than 2,400 ft^3/s at Sourdough are probably beginning to get too high for ideal fishing conditions.

Table 12. Flow Evaluations for River Aesthetics: All Experienced Users (two or more trips).

Flows (ft^3/s) rated as...	Low	Ideal	High
Range	2,140-2,280	1,950-2,925	2,005-3,835
Mean	2,180	2,285	2,510
n	2	66	14
Correlation with Flow Levels: r=.36 (p=.000, n=82)			

Extremely high flows during the fishing season can flood gravel bars and other places where users fish. Ninety-five percent of all boaters fish from gravel bars. Although high water levels limit this use, high flows are necessary for rejuvenation of gravel bars.

Users were asked to evaluate the flows they experienced in regard to finding places from which to fish (see Table 15). The correlation between flows and evaluations here was statistically significant but low. It may be that even during high flows anglers can wade out to good fishing spots, although they may prefer to fish from the bank. Another more likely explanation is that fishing is poor at high flows, so few users are concerned about the lack of good fishing spots. Some users perceive that good fishing spots are flooded at high water, probably around 2,500 ft^3/s at Sourdough. Team reconnaissance suggests that many good fishing spots remain at this level, but the water becomes turbid and anglers may be increasingly selective.

Camping

Camping is an attribute of Gulkana trips affected by flow levels, although again the relationships are indirect and less obvious. Peak flows (historical levels), for example, maintain a number of campsite-related attributes. In creating and sustaining clean gravel bars, high flow events provide viewsheds for scenery and wildlife, places from which to fish, good places for tents and boats, a minimum of insects, and ease of access to the water (Figure 25). Boaters overwhelmingly preferred these bars for camping; 64 percent of upstream users who camped on river stayed on gravel bars, as well as 80 percent of downstream users.

High flows during the use season, on the other hand, can temporarily flood these bars and prevent their use. Users were asked to evaluate the flows they experienced with respect to finding places to camp (see Table 16). Correlations between flows and evaluations are significant (r=.39), indicating that users are sensitive to this relationship. Results suggest that users perceive flows at Sourdough over 2,400 ft^3/s as being too high. Team reconnaissance suggests that many bars are still usable at this level, but are smaller than normal, and thus not as aesthetically pleasing.

Social Interaction/Solitude

Relationships between flow levels and social interaction among users are also less obvious, but can be significant. A survey of guides and veteran floaters on the Colorado River through Grand Canyon (Bishop et al., 1987) documented that users travel slower at lower flows, thus spending more time in contact with each other, decreasing solitude, and increasing camp competition. At slower rates of travel, users also must work harder to have the same amount of time for camping or fishing, when within-group interaction is important.

Downstream floaters were asked to evaluate the flows they experienced with regard to their rate of travel (see Table 17). The correlation between flows and evaluations was significant (r=.37), which was interpreted to mean that users are sensitive to the rate of travel during their trips. These results suggest that flows of less than 2,200 ft^3/s at Sourdough begin to be too slow for many users' tastes.

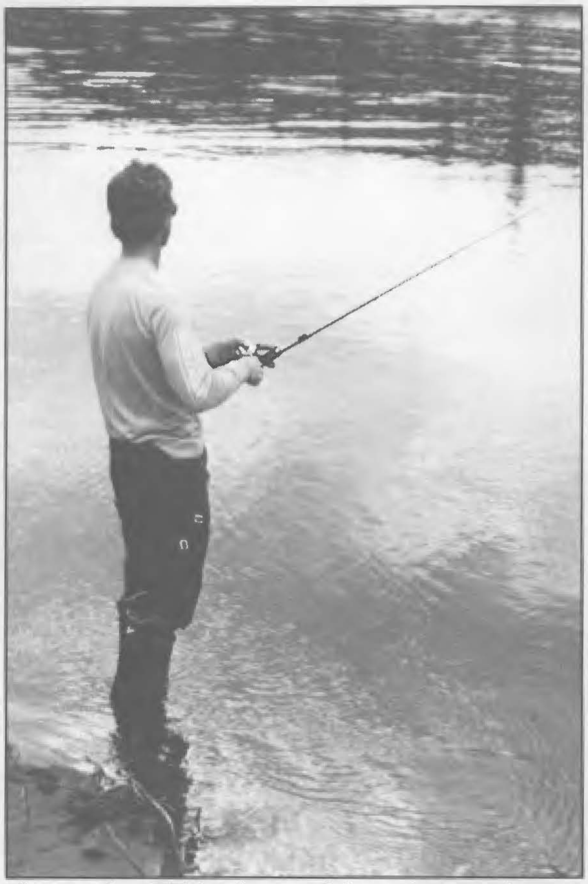

Figure 24. Fishing is one of the main attractions of a Gulkana trip and flows influence the quality of the fishing experience.

Hiking

Hiking along the Gulkana is generally difficult because of thick brush and boaters did not indicate a

Table 13. Flow Evaluations for Catching Salmon: All Experienced Users (two or more trips).

Trips rated as...*	Low	Ideal	High
Range	1,070-2,590	2,755-4,140	2,755-7,860
Mean	1,854	3,284	5,405
n	10	6	6

* Low = many hits; some dragging required
Ideal = few hits; no dragging
High = no hits; camps flooded; rapids are class IV

Table 14. Flow Evaluations for Catching Trout and Grayling: All Experienced Users (two or more trips).

Flows (ft^3/s) rated as...	Low	Ideal	High
Range	1,950-2,590	2,005-2,925	2,125-3,835
Mean	2,255	2,280	2,895
n	11	24	2

Correlation with Flow Levels: r=.45 (p=.003, n=37)

Corr. with Flow Levels (users with 3+ trips): .55 (p=.001, n=28)

Table 15. Flow Evaluations for Finding Fishing Spots: All Experienced Users (two or more trips).

Flows (ft^3/s) rated as...	Low	Ideal	High
Range	2,140-2,280	1,950-3,835	2,005-2,925
Mean	2,255	2,280	2,430
n	3	55	25

Correlation with Flow Levels: r=.18 (p=.055, n=83)

because of thick brush and boaters did not indicate a great deal of interest in this activity. Nonetheless, hiking opportunities can be affected by flows, as high water in the spring creates bars good for hiking during low water periods, and high water during the use season can flood them, making them inaccessible

Hunting

Hunters who enter the river corridor often attempt to cross the river on their all-terrain vehicles, which is another less obvious but important way that flow levels affect recreation opportunities. In order to ford the river on ATVs, users require depths less than 18 inches and relatively slow currents. Fordings thus become difficult during high flows, although BLM personnel have taken ATVs across at the popular Middle Fork-Main Stem confluence (Meier Lake Trail) in all but very high flows.

Fishery Habitat

The Bureau of Outdoor Recreation report on the Gulkana River (USDI, 1976) considers the Gulkana River one of the most popular sport fishing streams in Alaska. Albin (1977) has identified 11 fish species known to inhabit or migrate through the "wild" river corridor. They are:

Figure 25. High flow events are responsible for maintaining and cleaning gravel bars, which provide good camping sites.

Table 16. Flow Evaluations for Finding Quality Campsites: All Experienced Users (two or more trips).

Flows (ft^3/s) rated as...	Low	Ideal	High
Range	—	1,950-2,925	2,005-3,835
Mean	—	2,280	2,430
n	0	62	5
Correlation with Flow Levels: r=.39 (p=.001, n=67)			

Table 17. Flow Evaluations for Speed of Trip: Experienced Downstream Users (two or more trips).

Flows (ft^3/s) rated as...	Low	Ideal	High
Range	1,950-2,430	2,005-2,925	2,140-3,835
Mean	2,255	2,255	2,540
n	5	27	5
Correlation with Flow Levels: r=.37 (p=.011, n=37)			

2. Sockeye (Red) salmon (*Oncorhynchus nerka*)
3. Rainbow trout-steelhead (*Salmo gairdneri*)
4. Lake trout (*Salvelinus namaycush*)
5. Arctic grayling (*Thymallus arcticus*)
6. Round whitefish (*Prosopium cylindraceum*)
7. Humpback whitefish (*Coregonus pidschian*)
8. Burbot (*Lota lota*)
9. Longnose sucker (*Catostomus catostomus*)
10. Slimy sculpin (*Cottus cognatus*)
11. Pacific lamprey (*Entosphenus tridentatus*)

The chinook salmon, sockeye salmon, steelhead, and Pacific lamprey are anadromous—hatching in fresh water, migrating to the sea for a period of growth, and returning to fresh water to spawn and in some cases to die. The remainder are termed resident species—spending their entire lives in fresh water, but on occasion moving considerable distance to spawn or overwinter.

The Gulkana River is the leading chinook and sockeye salmon spawning stream in the Copper River drainage (USDA, 1976). Aerial counts by the Alaska Department of Fish and Game tallied an average of 21,173, with a high of 49,000, sockeye salmon between 1966 and 1987. From 1967 to 1987, the minimum estimate of chinook salmon averaged 981 individuals with a peak of 3,182. This salmon fishery has contributed significantly to commercial, subsistence, and sport fishing in the region.

For the purpose of this report, emphasis will be placed on chinook salmon, sockeye salmon, rainbow trout-steelhead, and arctic grayling because of their commercial and/or sport fishing values, and on longnose sucker for their potential as a food source for nesting bald eagles. Habitat characteristics, life cycles, and flow-habitat relationships are discussed for the individual species. Aquatic habitat maps showing fish occurrence by species and life stage are provided in Appendix C.

Chinook Salmon

The chinook salmon seem to have the most diverse life history of any of the five Pacific salmon, and are also the largest in average size. The largest known weight for a chinook salmon is 57.2 kg. Weights ranging from 6 to 23 kg are common in sport and commercial catches (Raleigh et al., 1986).

Chinook salmon are anadromous and, as a general rule, have a life history pattern of 1.3 in the Gulkana River, although there are also some 1.2 and 1.4 fish (Albin, 1977). For example, an age 1.3 fish would live one winter (egg) in fresh water, one winter (juvenile) in fresh water, three winters in the ocean, and have a 5-year life cycle from egg to adult.

Chinook salmon adults stop feeding when they enter a river to spawn and die after spawning. For the Gulkana River, this event begins in early to mid-June. Most adults spend several weeks in fresh water before spawning. Albin (1977) found that spawning occurs from mid-July through late August in the Gulkana River. Heaviest concentrations are found in the first mile below the outlet of Paxson Lake, from the Middle Fork down to Twelvemile Creek, and between Canyon Rapids and the confluence of the West Fork. Few fish seem to spawn below the Sourdough Lodge and none above the outlet of Paxson Lake. Some spawning occurs in the Middle Fork of the Gulkana River between Dickey Lake and its confluence with the Main Stem, and in Hungry Hollow Creek (Figure 26).

Fecundity of chinook salmon varies by size and to some extent by race. In general, fecundity varies from a few thousand to as many as 20,000 eggs per female (Vronskiy, 1972). Female chinook salmon usually choose a nesting site in gravel deposits at the lower lip of a pool just above a riffle (Briggs, 1953). Females make redds by turning on their sides and repeatedly flexing their bodies, forcing fine sediment into the water column. The completed nest is oval in shape with a mound of gravel deposited immediately downstream. The fertilized eggs are buried 20 to 60 cm below the gravel surface (Vronskiy, 1972). Chambers (1956) lists percentages of gravel for chinook redds of about 21 percent for 0.3 to 1.25 cm; 41 percent for 1.25 to 6 cm; 24 percent for 6 to 10 cm; and 14 percent for 10 to 15 cm. Huntington (1985) reported that the most heavily used spawning beds tend to develop parallel bands of elevated gravel. Bands of 0.6- to 2.4-m amplitude with a periodicity of 6.0 to 18.0 m have been reported. Huntington also states that the presence of these bands indicates prime spawning areas for salmon. Burner (1951) observed that chinook salmon redds averaged about 6 m^2 in size.

There is a definite relationship between flow regime and the quality of salmonid riverine habitat. Adequate flows must be maintained to meet the needs of developing embryos and yolk sac fry in the gravel; abnormally low or high flows can be destructive. Significant mortalities to salmon embryos and sac fry have been reported due to desiccation or freezing of redds caused by too-low, late fall-winter flows, and from natal gravel movement and downstream displacement of newly emerged fry during abnormally high freshets (Andrew and Geen, 1960).

Raleigh et al. (1986) state that survival of developing eggs and sac fry is primarily dependent on the interactions of four variables: temperature, dissolved oxygen, water velocity, and gravel permeability.

Water velocity and minimal depth appear to be factors influencing spawning site selection and survival of embryos. Velocity appears to be a major factor and minimal depth a secondary factor. An acceptable minimal spawning depth for chinook salmon depends upon the amount of flow fluctuation, but in rivers such as the Gulkana with relatively stable flow regimes (base flow $\geq$ 50 percent of the average annual daily flow), they concluded that an acceptable minimal spawning depth for chinook salmon would be $\geq$0.2 m (Raleigh et al., 1986). The major functions of water velocity during spawning and embryo incubation are to:

1. Move displaced substrate materials downstream during redd construction.
2. Carry dissolved O_2 to the developing embryos.
3. Remove metabolic wastes from the redd.

Figure 26. Some salmon spawning occurs in the Middle Fork. King salmon were observed 1.5 miles below Dickey Lake.

Andrew and Geen (1960) list spawning velocity ranges of 0.45 to 0.76 m/s for spring chinook and 0.35 to 1.15 m/s for fall chinook salmon. Few chinook were observed spawning in velocities >1.15 m/s. Raleigh et al. (1986) conclude that the useable spawning and embryo incubation velocity range is about 0.20 to 1.15 m/s with the optimal range of about 0.30 to 0.90 m/s, dependent upon the permeability of the eggs, their average size, and the average size of a spawning adult. Raleigh et al. (1986) believe that chinook salmon spawning in colder northern latitudes may select slightly lower velocity water for spawning.

Minimum depths are also necessary to ensure upstream migration for adult salmon. During low flow, riffles may be too shallow for adult passage. Thompson (1972) found that tolerance limits for chinook salmon upstream migration are $\geq$0.24 m.

Although spawning may occur over a wide range of water temperatures (4.4 to 18.0 °C), suitable temperature regimes for incubating embryos are more restrictive. Chambers (1956) reported chinook usually spawned during temperatures ranging from 5.0 to 13.4 °C. Raleigh et al. (1986) state that incubation >2 but $\leq$3.5 weeks at temperatures $\geq$4.5 but $\leq$12.8 °C is necessary for survival of chinook embryos. Eddy (1972) found that survival of chinook eggs from fertilization to fry emergence ranged from 90 percent to 100 percent at a constant O_2 concentration of 3.5, 5.0, 7.3 and 10.5 mg/L at a temperature of 10.5 °C. Survival dropped to zero at a constant temperature of 15.0 °C.

Chinook salmon fry usually emerge from the gravel at night, probably as an antipredation measure (Bams, 1969). The fry in the Gulkana River usually spend 1 year in fresh water before starting their migration to the sea. After emerging, most fry immediately disperse downstream, possibly because of their new nondemersal habits and loss of visual contact with the stream substrate (Reimers, 1973). After emergence, the fry develop neutral buoyancy, begin exogenous feeding, and develop social behavior (Bams, 1969). Back-eddies, backwater sloughs, and slow moving water become important habitat. After the initial hiding period, chinook salmon fry seek fine substrate and low water velocities, progressively moving into deeper, faster, and rockier habitats (Everest and Chapman, 1972). The wetted perimeter (with adequate depth) is a good indicator of the quality of salmon habitat, especially for juveniles. An increase in the wetted perimeter is usually expressed in more edge effect, which provides cover for juvenile survival as well as sites for macroinvertebrate production. Overwintering chinook juveniles hide under large rocks and debris, a habit shift apparently triggered by low water temperature (Chapman and Bjornn, 1969). Raleigh et al. (1986) concluded that young-of-the-year chinook salmon tend to select water velocities 0 to 60 cm/s with an optimal range of 0 to 40 cm/s at depths of ≥15 cm. As the fry begin to smolt, they become silvery and slimmer and change their behavior, and they usually emigrate in schools downstream to the ocean (Allen and Hassler, 1986).

Sockeye Salmon

Sockeye salmon are anadromous, returning once to spawn and die. Unlike the chinook salmon of the Gulkana River, they are divided into a number of populations that are fairly distinct with respect to migration timing, and to time and place of spawning (Albin, 1977). Mature sockeye salmon weigh an average of 2.8 kg and average 60 cm in length (range 45 to 76 cm), but some do exceed 4.5 kg (Hartman, 1971).

During the years they sampled the Gulkana River, Roberson and Fridgen (1974) found that the 1.3-age class dominated the population. This was followed by 1.2-, 2.2-, and 2.3-age classes in that order. Some years (e.g., 1971, 1972), a change was noted in the contribution from the 2.3-age class that can be traced to specific spawning area contributions.

Albin (1977) found that adult sockeye salmon first enter the Gulkana River in early June and begin to arrive at Paxson Lake by mid-June. Peak runs usually occur in July, but fish continue to enter the system through late August. Stocks with early mean arrival dates tend to spawn in the uppermost areas of the drainage. Migratory timing is usually determined by the precision of the factors that will provide for successful spawning, but timing of arrival on the spawning grounds does not always signify time of spawning (Merritt and Roberson, 1986). Some sockeye salmon arrive early, only to mill around for several months before starting to spawn. The spawn is augmented by a hatchery, operated by Alaska Fish and Game, above Paxson Lake.

Sockeye salmon are able to spawn in a variety of habitats. They will utilize lateral streams, rivers, and lake margins. The Canada Department of Fisheries (1959) has documented sockeye salmon spawning in lakes at depths >21 m. Assuming average intragravel temperatures are lowest in small streams, higher in rivers, and highest in lakes, early stocks tend to spawn in streams, whereas late stocks tend to spawn in lakes (Merritt and Roberson, 1986). In general, spawning coincides with water temperatures of 4.5 to 10.0 °C (Hartman, 1971). Spawning occurs from July to October and is divided into two groups. Spring spawners enter the system before mid-August and fall spawners enter later.

Merritt and Roberson (1986), who conducted studies between 1967 and 1984, found that 87 percent of the sockeye salmon that entered the Gulkana River spawn in the upper Gulkana River-Fish Lake area. The remaining 13 percent spawn in the lower Gulkana River. Even though the majority of sockeye salmon spawn outside the designated National Wild River, the lower Gulkana River does play an important role as an access route.

Albin (1977) found that spawning sockeye salmon utilize the outlet of Paxson Lake; the confluence of the Middle Fork, Swede Lake, Middle Fork at Swede Creek, Dickey Lake, Victor Creek, Keg Creek; and the North Branch of the West Fork draining Monsoon Lake. Sockeye salmon were found spawning at the outlet of Paxson Lake from late July to mid-September, at the confluence of the Middle Fork from late July to early September, in Swede Lake in August, Dickey Lake in early July, and in the West Fork Branches from mid-July to early August.

Roberson and Fridgen (1974) collected a sample (N=49) in 1971 to evaluate the approximate egg production of sockeye salmon in the Copper River drainage. Mean fecundity for the sample was 3,840 eggs per female. Eggs incubate in the gravel until spring when they hatch. They are buried 25 to 40 cm below the gravel surface (Hartman 1971). Hoopes (1972) found that sockeye salmon spawned most frequently in areas where the particles were intermediate in size. In sections of high spawning density and intermediate gradient, cobbles larger than 7.6 cm made up about 7 percent of the bottom; cobbles 2.5 to 7.6 cm made up about 50 percent; particles 1.3 to 2.5 cm made up about 20 percent; and particles less than 1.3 cm made up the remainder. Juvenile sockeye salmon will then spend 1 or 2 years in fresh water before migrating to the ocean in the spring or summer. Generally, this time is spent in lake habitat where zooplankton production is abundant. Albin (1977) did find some rearing habitat in backwater areas of stream reaches at the confluence of the Middle Fork.

Water velocity and depth do not appear to be important in selecting spawning sites for sockeye salmon. Hoopes (1972) found that, although pronounced changes in water depth and velocity may occur briefly during the spawning season, sections with high and low densities of spawners often had similar water depths and velocities. Areas of high spawning densities ranged from 15 to 32 cm in depth with velocities of 0.35 to 0.59 m/s; areas of low density ranged from 15 to 28 cm in depth with velocities of 0.39 to 0.70 m/s.

With most of the sockeye salmon spawning upstream of the designated National Wild River corridor, minimal depths are very important to assure upstream migration. Since the chinook and sockeye salmon enter the Gulkana River around the same time, meeting the minimal standards for the chinook salmon should provide adequate depths to ensure sockeye salmon migration.

Rainbow Trout-Steelhead

In the Gulkana River, rainbow trout can be divided into two ecological forms: (1) anadromous steelhead trout and (2) resident stream trout. Unlike the Pacific salmon, steelhead do not always die after spawning and will return to the ocean to grow and spawn again. As many as 3 to 53 percent may return to sea and spawn again (Fulton, 1970). Steelhead may grow to 122 cm and weigh as much as 16 kg. The average angler's catch is 3.6 to 4.0 kg (Scott and Crossman, 1973).

Steelhead trout in the Gulkana River are considered winter-run steelheads because they enter fresh water in the fall, overwinter, and spawn in the spring. They spawn below Dickey Lake and in Hungry Hollow Creek. The size of run is estimated to be about 1,000 fish (Albin, 1977). The resident rainbow trout exist in the Main Stem below Paxson Lake and in the Middle Fork of the Gulkana River. These rainbows spawn almost exclusively in tributaries to the Middle Fork or Main Stem. Spawning takes place from mid-April through the end of June.

Females generally select a redd site in gravel substrate at the head of a riffle or downstream edge of a pool (Orcutt et al., 1968). The redd, constructed primarily by the female, is typically longer than the female and deeper than her greatest body depth (Greely, 1932). Average depth of egg deposition is 15 cm (Hooper, 1973). Incubation time varies inversely with temperature. Eggs usually hatch within 28 to 40 days (Cope 1957). Raleigh et al. (1984) list optimal spawning gravel conditions to include $<$ 5 percent fines; $\geq$30 percent fine are assumed to result in low survival of embryos and emerging sac fry. Optimal spawning substrate averages 1.5 to 6.0 cm for rainbows $\leq$50.0 cm long and 1.5 to 10.0 cm for spawners $\geq$50.0 cm long (Orcutt et al., 1968). Average fecundity of rainbow trout is related to length, ranging from 500 to 3,161 eggs per female (Carlander, 1969).

As with any salmonid, there is a definite link between the annual flow regime and the quality of habitat. The most critical period is during base flow. A base flow $\geq$50 percent of the average annual daily flow is considered excellent for maintaining quality habitat, 25 to 50 percent is considered fair, and $<$25 percent is considered poor (Binns and Eiserman, 1979). Raleigh et al. (1984) state that optimal water velocity above rainbow trout redds is between 30 and 70 cm/s. Velocities less than 10 cm/s or greater than 90 cm/s are unsuitable.

Rainbow trout-steelhead fry remain in the gravel for about 2 weeks before emerging. As they move to rearing areas they exhibit three movement patterns:

1. movement downstream to a larger river, lake, or to the ocean,
2. movement upstream from an outlet river to a lake,
3. local movement within a common spawning and rearing area to areas of low velocity and cover (Raleigh and Chapman, 1971).

Fry require shallower and slower velocity than do other stages of life (Horner and Bjornn, 1976). Fry utilize velocities less than 30 cm/s, but velocities less than 8 cm/s are preferred (Griffith, 1972).

Rainbow trout-steelhead fry overwinter in shallow areas of low velocities, with rubble being the principal cover (Bustard and Narver, 1975). Optimal size substrate ranges from 10 to 40 cm in diameter (Hartman, 1965). In some streams, the major factor limiting salmonid densities may be the amount of adequate overwintering habitat, rather than the amount of summer rearing habitat (Bustard and Narver, 1975). The wetted perimeter (with adequate depth) is a good indicator of the quality of trout habitat, especially for juveniles. An increase in the wetted perimeter is usually expressed in more edge effect, which provides cover for juvenile survival as well as sites for macroinvertebrate production.

Steelhead smolt usually migrate in late spring. Photoperiod appears to be the dominant triggering mechanism for parr-smolt transformation (Wagner, 1968). Smolts that have not migrated by the summer solstice revert to parr and attempt to migrate the following season (Zaugg and Wagner, 1973). Juveniles can reside in fresh water from 1 to 4 years before migration takes place. They spend from 1 to 4 years in the ocean before returning to spawn (Chapman, 1958).

Adult and juvenile rainbow trout-steelhead are opportunistic feeders. Their diet for the most part consists mainly of aquatic insects (Allen, 1969), but foods such as zooplankton (McAfee, 1966), terrestrial insects, and fish are locally or seasonally important (Carlander, 1969). The relative importance of aquatic and terrestrial insects to resident stream rainbow trout varies greatly among different environments, seasonally and dielly, and with the age of the trout (Bission, 1978).

Arctic Grayling

Albin (1977) found arctic grayling to be residents of the entire Gulkana River system. They were observed in greatest abundance in the Middle Fork below Dickey Lake and in the Main Stem between the Middle Fork and Canyon Rapids. Under average conditions, the arctic grayling should reach a length of 25 cm in its third year of life (Beckman, 1952), with the largest grayling recorded in Alaska being 54.6 cm in length and weighing 2.13 kg (Van Haveren et al., 1987). The arctic grayling has a much longer life span than most other salmonids. Armstrong (1982) found it to be 15 to 22 years.

Even though arctic grayling are nonanadromous, they do move considerable distances between winter habitat and spawning sites. Hubert et al. (1985) have reported arctic grayling migrating 6 to 90 miles to find suitable spawning habitat. Grayling tagged at Poplar Grove Creek (Richardson Highway, mile 138) have been recovered as far away as Paxson Lake in the Gulkana River. This migration begins as early as April and continues through June with the peak of activity mid-May to early June (Albin, 1977). Tributary streams such as Twelvemile Creek, Sourdough Creek, and Poplar Grove Creek are preferred sites for spawning. After spawning, the adults return to the larger rivers.

Adult females, 25 to 35 cm in length, will produce 6,000 eggs on the average (Beckman, 1952). Unlike most salmonids, arctic grayling do not construct redds, but small depressions do result from spawning activities. Males initiate spawning activity and establish territories of from 1 to 10 m^2 (Van Haveren et al., 1987). The adhesive eggs of the arctic grayling are coated by sand and small gravel as they settle to the stream bottom (Hubert et al., 1985).

Not constructing a well defined redd results in many eggs drifting downstream soon after spawning (Warner, 1955). This results in heavy mortality during embryo development—estimated to be as high as 96 percent (Kruse, 1959).

Spawning sites of the arctic grayling are usually located at the tail end of a riffle or pool, in rubble and gravel substrate, but grayling have been observed to spawn over mud-bottoms and vegetation in pools, above rapids, and in shallow backwaters (Van Haveren et al., 1987). Optimal velocities at spawning sites range from 0.3 to 1.5 m/s. Spawning occurs in water temperatures ranging from 2 to 10 °C, with the majority of activity in the upper range (Hubert et al., 1985).

Arctic grayling eggs will hatch within 23 days at a water temperature of 7 °C. After the fry emerge from the substrate, they remain in the small tributaries throughout the summer (Craig and Poulin, 1975). Juvenile grayling seek out backwater, side channels, and sloughs as preferred habitat and then in late summer become more territorial, moving into deeper water (Armstrong, 1982). Interstitial space, shadows, and boulders all provide important cover for juveniles (Krueger, 1981; Webb, 1986).

Fry begin to feed 4 days after hatching (Brown and Buck, 1939). Like all salmonids, they are sight feeders. Hubert et al. (1985) found that fry feed primarily on small immature aquatic insects. As juveniles and adults, their diets shift and they depend more heavily on benthic and terrestrial insects, as well as on fish or fish eggs (Reed, 1964; Vascotto and Morrow, 1973). The wetted perimeter (with adequate depth) is a good indicator of the quality of grayling habitat, especially for juveniles. An increase in the wetted perimeter is usually expressed in more edge effect, which provides cover for juvenile survival as well as sites for macroinvertebrate production.

In summer, adult arctic grayling in the Gulkana River are found in riffles and in fast (rocky bottom) run sections (Albin, 1977). Vincent (1962) defines preferred arctic grayling habitat as water with a range in velocity of 0.3 to 0.6 m/s; a range in gradient of 0.09 to 0.28 percent, with a maximum gradient of 0.38 percent. A study conducted in Montana (Liknes, 1981) found arctic grayling to be more abundant at flows of 0.21 m/s and a gradient of 0.29 percent.

Longnose Sucker

Longnose suckers are resident species of the Gulkana River. Albin (1977) found them in the Main Stem, the Middle Fork, and in the West Fork of the Gulkana River. They were the most abundant in the middle section of the West Fork where there were many schools of 50 individuals or more.

The longnose suckers may be an important food source for nesting bald eagles on the West Fork. Albin (1977) observed an eagle attack on a longnose sucker on the West Fork in 1977. Lack of significant numbers of other fish species in the West Fork may heighten the importance of the longnose sucker to the bald eagle.

Generally, longnose suckers attain a length of 18 cm their second year and can attain lengths of 76 cm as adults (Beckman, 1952). Scott and Crossman (1973) found the longnose sucker to be a long-lived (22-24 years) fish. Sexual maturity is obtained between their fifth and ninth years.

Longnose suckers are spring spawners, ascending tributary streams such as Poplar Grove Creek to spawn (Albin, 1977). The spawning period for the species is short. Large numbers of fish in breeding colors move into an area of slow shallow water with a gravel bottom, spawn, and move downstream in a period of a week (Woodling, 1985).

A 30-cm female produces on the average 50,000 eggs (Beckman, 1952). Nests are not built and the fertilized eggs drift downstream adhering to the substrate in pools and eddies (Woodling, 1985). Two to four males crowd around each female pressing against her during 3- to 4-second spawning acts that number between 6 and 40 each hour (Scott and Crossman, 1973).

In streams or rivers, adult longnose suckers can be found in pools and runs, but prefer water in areas of moderate to high velocities. Younger longnose suckers, less than 15 cm, are found in pools and runs with moderate velocity and backwater areas (Propst, 1982). Riprap banks, boulders, and undercut banks are preferred locations.

Longnose suckers are bottom feeders. They feed primarily on invertebrates, but plant material is often ingested by this indiscriminate bottom feeding (Scott and Crossman, 1973). In waters with other salmonids, they do compete for the available bottom food, but in turn may become beneficial by producing many fry, which other salmonids can eat (Beckman, 1952).

Table 18 shows use/occurrence time periods for game/fish species in the Gulkana River system.

Table 18. Fish Use/Occurrence Chart.

Species	J	F	M	A	M	J	J	A	S	O	N	D
CHINOOK												
spawn								■	■			
migrate						■	■	■				
juvenile	■	■	■	■	■	■	■	■	■	■	■	■
SOCKEYE												
spawn								■	■			
migrate							■	■				
juvenile	■	■	■	■	■	■	■	■	■	■	■	■
STEELHEAD												
spawn					■	■						
migrate									■	■		
juvenile	■	■	■	■	■	■	■	■	■	■	■	■
overwinter	■	■	■	■								
RAINBOW TROUT												
spawn					■	■						
juvenile/adult	■	■	■	■	■	■	■	■	■	■	■	■
GRAYLING												
spawn				■	■	■						
juvenile/adult	■	■	■	■	■	■	■	■	■	■	■	■

HYDROLOGY AND CHANNEL MORPHOLOGY

The objectives of the Gulkana River hydrology assessment were to:

1. Quantify the natural flow regime within the National Wild River corridor, and
2. Develop relationships between discharge and flow hydraulic attributes (width, depth, velocity, cross-section area, and wetted perimeter).

The natural flow regime is quantified so that instream flow recommendations can be expressed as a percentage of normally occurring discharges. Relationships between discharge and flow hydraulic attributes are developed to assist in evaluating the effects of alternative discharge rates on resource values.

Background

The Gulkana River Basin is 2,140 mi^2 in area and is located mostly within the Copper River Plateau. The river drains 1,759 mi^2 of watershed area above the USGS gauging station at Sourdough. The Gulkana flows generally south to its confluence with the Copper River. Two major tributaries, the Middle Fork and the West Fork, flow generally east to their confluences with the Main Stem (see Figure 1). Unlike other rivers in the Copper River Basin, there is no runoff in the Gulkana River originating from glacier melt. The hydrology of the river is controlled by precipitation, basin physiography, lake storage, and the presence of permafrost. Many of the river's resource attributes, including clear water, fisheries habitat, and channel character, can be attributed, in part, to its unique hydrologic character within the region.

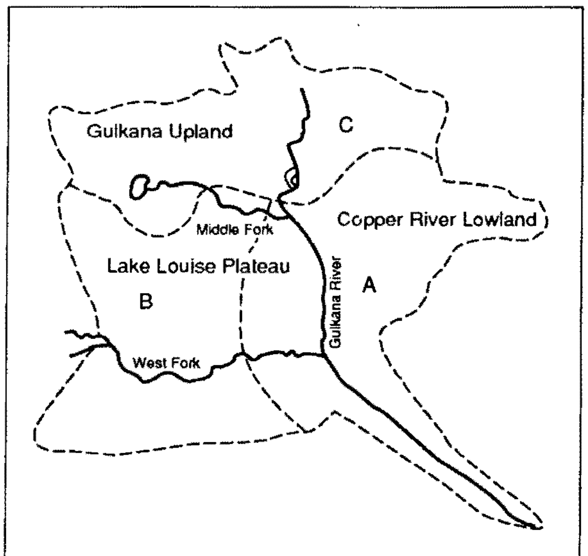

Figure 27. Physiographic regions of the Gulkana River Basin (adapted from Wahrhaftig, 1965, and Lyle, 1980).

The climate of the Gulkana River Basin is characterized as subarctic continental, with mild to warm summers, long cold winters, low rainfall, and moderate snowfall (USDI, Bureau of Land Management, 1983). Average summertime high temperatures range from 60 to 75 °F; average winter lows range from -15 to -30 °F. Annual rainfall at Paxson averages 17.4 inches with 109.5 inches of snow; average rainfall at Glennallen is 11 inches with 47 inches of snow. Most precipitation is from summer rains. July is normally the wettest month. The river generally freezes in October, and becomes ice-free in early to mid-May.

The Gulkana River Basin consists of three main physiographic regions (Figure 27) as described by Wahrhaftig (1965) and further reported on by Lyle (1980), Huntsinger (1983), and Inghram and Carrick (1983). The three regions are the Gulkana Uplands, the Lake Louise Plateau, and the Copper River Lowlands.

The Gulkana Upland physiographic region is characterized by rolling topography and rounded ridges ranging in elevation from 3,500 to 5,500 feet. Surface geology is predominantly glacial moraine and drift deposits.

Permafrost is discontinuous. Numerous lakes occupy glacier-scoured basins and morainal depressions. Tundra vegetation dominates higher elevations, and spruce-hardwood forests dominate lower elevations.

The Lake Louise Plateau occupies a large portion of the drainage area of the West Fork. This physiographic region is characterized as a rolling upland with stagnant ice-controlled topography (Wahrhaftig, 1965). The area has numerous kettle lakes occupying glacial depressions—some of which are not part of a surface drainage network and, as such, are not directly connected, hydrologically, to the Gulkana River.[1] The region is underlain by very shallow permafrost which may extend to depths of several hundred feet (Lyle, 1980). As such, soils are poorly drained, boggy, and have high organic matter contents. Lowland spruce and hardwood forests cover much of the Lake Louise Plateau physiographic region.

The Copper River Lowland physiographic region influences the Gulkana River downstream from its confluence with the West Fork. The region is a smooth plain entrenched by the Copper and Gulkana Rivers. Soils are fine-grained, poorly drained, and boggy. Organic matter contents are high. Shallow permafrost underlies the region. There is considerably less influence of glacier ice in this region than either the Lake Louise Plateau or the Gulkana Uplands. The lakes are very small, generally of permafrost-thaw origin. Spruce and hardwood forests, intermixed with bog and musky areas, are the dominant vegetation types.

Both the Lake Louise and Copper River Lowland physiographic regions were strongly influenced by thick deposits of pleistocene lacustrine sediments, the origin of which was a large glacier-dammed lake extending from approximately Glennallen to the confluence of the Middle Fork. Lakebed sediments are fine grained, and bluish-gray in color. Where present, the river has easily entrenched into the lacustrine sediments. At some river meanders, active bank cutting has resulted in impressive cliffs or exposed blue-gray sediments (Figure 28).

The influence of climate, physiography, and permafrost on the hydrology of the Gulkana River is summarized by Inghram and Carrick (1983). In general, the poorly drained (saturated) character of the watershed results in river flows responding readily to rainfall. Thus, the Gulkana River exhibits considerably more variation in annual streamflow than rivers influenced by glacier melt. However, peak flows tend to be moderated to a significant extent. This is because (1) tributary drainage networks are poorly developed, (2) many lakes in the watershed are not part of integrated drainage networks, and (3) several large lakes (e.g., Crosswind, Summit, and Paxson Lakes) are part of the drainage system. All of these factors serve to buffer the river, somewhat, from extreme runoff events.

Continuous discharge records for the Gulkana River are available from the U.S. Geological Survey at Sourdough for the 1972-1979, 1982 period. The Bureau of Land Management maintained a continuous stage recorder at Sourdough for the 1988 water year.

Natural Flow Regime

The average annual hydrograph for the Gulkana River at Sourdough is characterized by low flows (average discharge approximately 300 ft^3/s) during the November-April winter period, followed by an annual snowmelt dominated peak flow (average discharge somewhat greater than 5000 ft^3/s) in May or early June, which then tapers off to a mid-July to October summer/fall low-flow period where discharges range between roughly 1000-1500 ft^3/s (Figure 29). River discharges increase in response to rainfall during the summer/fall period. July is normally the month of highest precipitation.

Discharge summaries for the Gulkana River at Sourdough and at the six locations on the National Wild River are provided in Table 19. Mean annual discharge varies from 1,063 ft^3/s at the Sourdough gauge to only 42 ft^3/s at the Dickey Lake outlet on the Middle Fork. Mean annual tributary discharges are 136, 151, and 611 ft^3/s for the outlet of Paxson Lake, and the confluences of the Middle Fork and West Fork, respectively.

Mean monthly discharges (Table 19) for the July-September period range from roughly 1,400 ft^3/s at the Sourdough gauge to approximately 65 ft^3/s at the Dickey Lake outlet. Summer period tributary discharges average roughly 180, 190, and 800 ft^3/s for the Paxson Lake outlet, and the Middle Fork and West Fork confluences, respectively.

Thirty-day, 10-year, nonwinter period low flows range from 198 ft^3/s at the Sourdough gauge to only 8 ft^3/s at the Dickey Lake outlet.

Flood magnitude and frequency data for the Sourdough gauge and six locations on the National Wild River are provided in Table 20. One hundred-year return period floods average between only 3-4 times the mean annual peak discharge. This reflects both the buffered nature of the watershed as discussed above, and the importance of snowmelt contributions to flood peaks.

The average median daily flow (50 percentile flow) ranges from 1,811 ft^3/s at the Sourdough gauge to 72 ft^3/s at the Dickey Lake outlet (Table 21).

[1] Although there is no surface-flow connection between many of the Lake Louise Province lakes and the Gulkana River, the role of interflow in this region may be significant.

Figure 28. Photograph of high cutbank comprised of fine-grained lacustrine sediments deposited in a pleistocene glacier-dammed lake.

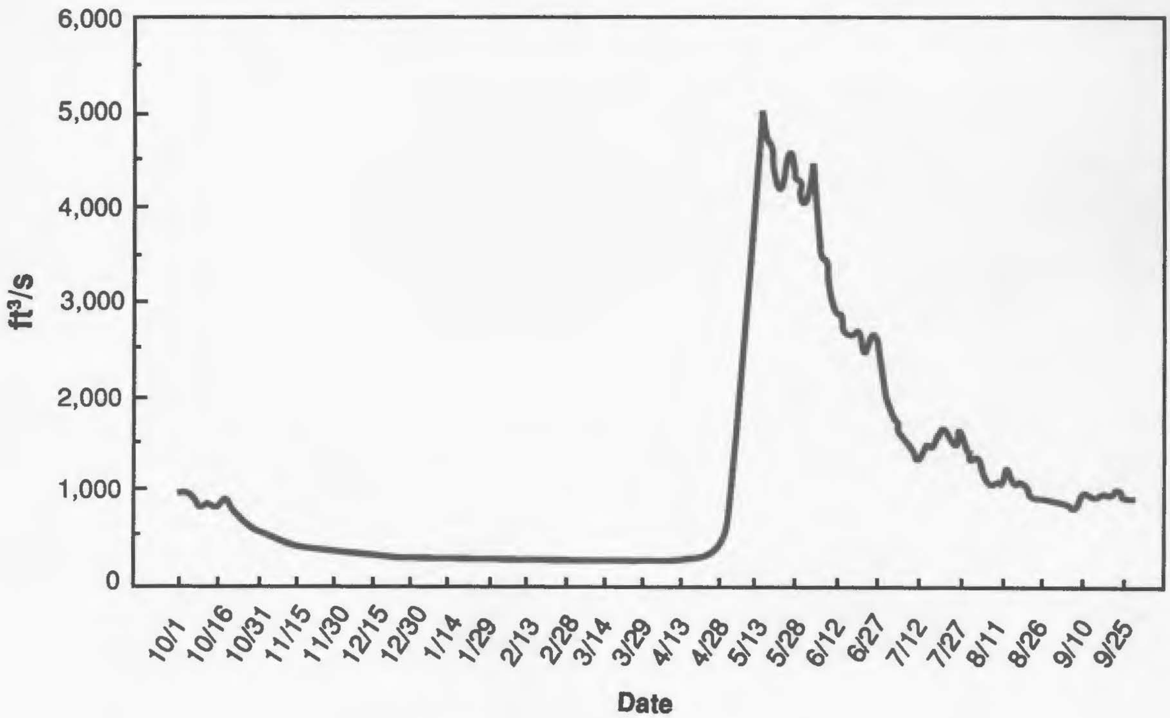

Figure 29. Average Annual Hydrograph, Gulkana River at Sourdough. USGS Station #15200280.

Table 19. Mean Monthly Discharges — Gulkana River, Alaska.

	Dickey Lake Outlet	Paxson Lake Outlet	Middle Fork Confluence	West Fork Confluence	S. Branch West Fork	N. Branch West Fork	Sourdough Gauge
October	33	107	119	480	109	88	835
November	17	56	62	250	57	46	435
December	12	39	44	177	40	32	307
January	11	33	40	162	37	30	281
February	10	33	36	147	33	27	255
March	10	33	37	150	34	27	260
April	12	39	43	176	40	32	306
May	192	552	609	2,158	570	463	3,561
June	172	495	546	1,934	511	415	3,191
July	71	227	252	1,018	231	186	1,776
August	53	171	161	767	173	140	1,335
September	43	137	152	617	139	113	1,073
Mean Annual	42	136	151	611	142	111	1,063
30-Day, 10-Year Low Flow	8	28	28	114	27	21	198

Hydraulic Geometry Relationships

Given information on the river's natural flow regime, the next task was to describe the hydraulic character of flows within selected channel reaches. This was accomplished using single transect methods (USDI, 1979) anddeveloping relationships between discharge at a cross section and the width, average depth, wetted perimeter, cross-section area, and average velocity of flows within the cross section (Parsons and Hudson, 1985). All field cross-section data and derived hydraulic geometry relationships (in graphical form) are provided in Appendix D. Pertinent information provided by those data relevant to this study are discussed below.

Discharge-maximum depth relationships are useful in assessing a river's navigability—both for fisheries passage and recreational boating. Summaries of discharge and maximum depth data are provided in Table 22. Discharges corresponding to maximum depths of 0.5 feet, 1.0 feet, and 2.0 feet are provided.

Discharge versus wetted perimeter relationships are often used to identify critical flow levels for fisheries habitat (Alaska Dept. of Natural Resources, 1985). Discharges corresponding to the inflection point in a plot of discharge versus wetted perimeter are considered critical minimum flows for fisheries. Table 23 identifies flows which correspond to the discharge-wetted perimeter inflection point for selected Gulkana National Wild River cross sections.

Discharge versus velocity data are useful in evaluating several factors, including recreational float trip times, and certain sediment transport/ channel stability issues. Average flow velocities corresponding to the mean August discharge are summarized in Table 24.

Discharge versus cross-sectional area data may be useful in evaluating water column habitat available for fisheries. Cross-section areas corresponding to the mean August discharge are summarized in Tables 23 and 24.

Table 20. Flood Frequencies for the Gulkana River, Alaska.*

	2 Yr. Flow	10 Yr. Flow	25 Yr. Flow	50 Yr. Flow	100 Yr. Flow
Dickey Lake Outlet	381	768	1,026	1,247	1,503
Paxson Lake Outlet	1,104	2,067	2,693	3,196	3,757
Middle Fork Confluence	1,214	2,260	2,937	3,477	4,079
West Fork Confluence	4,302	7,339	9,264	10,655	12,142
S. Branch West Fork	1,150	2,148	2,795	3,314	3,893
N. Branch West Fork	920	1,746	2,283	2,721	3,213
Sourdough Gauge	7,100	11,700	14,600	16,600	18,700

* *All values in* ft^3/s

Table 21. Average Daily FLow Durations for Gulkana River, Alaska.*

	10 Percent Exceeded	25 Percent Exceeded	50 Percent Exceeded	75 Percent Exceeded	90 Percent Exceeded
Dickey Lake Outlet	168	110	72	52	46
Paxson Lake Outlet	542	355	232	167	149
Middle Fork Confluence	602	395	258	186	166
West Fork Confluence	2,433	1,595	1,042	751	669
S. Branch West Fork	567	372	243	175	156
N. Branch West Fork	443	290	190	137	122
Sourdough Gauge	4,228	2,772	1,811	1,305	1,163

* *All values in* ft^3/s

Flow widths may be factors in navigability, aesthetics, and the utility or availability of gravel/ sand bar sites for recreation (or other) uses. Flow width corresponding to both the 1.5-year return period peak flow and the mean August flow are summarized for selected National Wild River cross sections (Tables 24 and 25).

Channel Morphology

Streamflows also influence sedimentation processes and related stream channel morphological features. These flow-dependent morphological features in turn are components of certain stream corridor values. The purpose of this chapter is to describe the flow-dependent morphological attributes of the Gulkana River and discuss the way in which certain features are dependent upon instream flows.

Overall, the Gulkana River is a meandering, single-thread channel, entrenched in predominantly fine-grained lacustrine sediments. Gradients are mild. The river has achieved a firm bed of coarse material or bedrock. Primary adjustment modes are lateral migrations associated with meandering (Figure 30). Adjustment rates are low, however, due to the river's hydrologic nature, its incised status, and the stability produced by vegetation and frozen soils.

The amount of sediment and water discharged by the Gulkana River is determined by climate and watershed characteristics. Within the constraints imposed by local geology, the river has developed a combination of gradient, pattern, shape, and hydrau-

Table 22. Discharges for Selected Maximum Depths.

Location	Maximum Depth, in feet		
	0.5	1.0	2.0
Main Stem			
Outlet Paxson Lake	20	55	220
RM 2.5	14	115	590
RM 3	10	50	300
RM 5	14	30	60
RM 7	17	35	120
RM 10	10	15	25
RM 18	10	20	125
RM 25	20	45	390
RM 33.5	10	20	75
RM 38	20	50	180
RM 40	40	80	125
Sourdough	N/A	50	285
Middle Fork			
RM 0	12	40	140
RM 2.5	5	18	80
RM 3	3	10	45
RM 6	8	30	120
RM 10	5	15	50
RM 16	2	10	60
RM 22.5	5	10	20
RM 24	15	30	80
West Fork			
RM 83	25	50	300
RM 63	5	10	40
RM 37	10	20	70
South Branch confluence with North Branch	5	10	25
South Branch Upstream from confluence	.5	1.1	20
South Branch			
RM 20	10	20	150
RM 0	1	2	5
North Branch			
At confluence with South Branch	5	15	50
RM 9	20	50	230
RM 2	5	10	45

Table 23. Discharge at Inflection Point from Discharge vs. Wetted Perimeter Chart.

Location	Wetted Perimeter (feet)	Discharge
Main Stem		
RM 0	2.5	50
RM 2.5	70	40
RM 3	75	30
RM 5	100	180
RM 7	70	170
RM 18	125	180
RM 25	2.0	360
RM 33.5	130	750
Sourdough	205	1,300
Middle Fork		
RM 0	50	30
Below Dickey Lake Outlet	15	30
RM 2.5	20	10
RM 6	45	50
RM 10	40	50
RM 24	90	250
South Branch, West Fork		
RM 0	35	5
Confluence with North Branch	25	25
West Fork		
RM 37	100	270
RM 63	75	310
RM 83	115	220

lic variables which allows it to transport water and sediment loads efficiently, i.e., with a minimum time-rate expenditure of potential energy or stream power (Ritter, 1978). Thus, all major morphological features of the river dependent upon erosion or sediment deposition processes are interrelated, and both control and respond to the expenditure of stream energy. Important flow-dependent features include channel gradient, channel pattern, cross-section shape, pools, bars, banks, and substrate characteristics. Channel features dependent upon large organic debris loading (trees, branches) may also be controlled by channel erosion processes.

River morphological features are naturally dynamic and permanent morphological changes are the mechanisms by which rivers respond to changes in discharge and/or sediment regimes. Several concepts and descriptive models are available which may aid in an assessment of probable responses to the Gulkana River changes in flow regimes.

Lane (1955) presented a qualitative relationship between bed-material load, Qs, water discharge Q, sediment size d_{50}, and channel gradient S:

$$Qs \cdot d_{50} \approx Q \cdot S \qquad (1)$$

That proportionality states that water discharge changes will be compensated for by changes in sediment size and bedload sediment transport.

Schumm (1971) developed a proportional relationship between water discharge and the hydraulic geometry variables width W, depth D, meander wavelength L, and gradient:

$$Q \approx \frac{W, D, L}{S} \qquad (2)$$

Table 24. Velocities and Cross-Sectional Areas Corresponding to Mean August Discharge.

Location	Mean August Discharge (ft /s)	Mean Velocity (ft /s)	Cross-Sectional Area (ft)
Outlet of Paxson Lake	170	2.4	70
Main Stem			
R 3	330	2.4	140
RM 25	470	3.0	155
RM 40	1,300	2.2	600
Sourdough	1,330	3.5	380
Middle Fork			
RM 0	50	1.4	35
RM 22.5	160	.5	325
West Fork			
RM 37	310	1.7	180
RM 83	770	1.8	430
North Branch at confluence with South Branch	140	2.0	70
South Branch at confluence with North Branch	170	1.7	100

Table 25. Flow Top-Widths Corresponding to Both the Mean Annual Peak Discharge and the Mean August Discharge for Selected Gulkana National Wild River Cross Sections.

Location	2 Year Peak Flow (ft^3/s)	Top Width (ft)	Mean August Discharge (ft^3/s)	Top Width Discharge (ft)
Outlet of Paxson Lake	1,100	93	170	63
Main Stem				
RM 3	2,310	107*	330	94
RM 25	2,720	268*	470	210
RM 40	6,900	206*	1,300	142
Sourdough	7,100	225*	1,330	207
Middle Fork				
RM 0	380	77*	50	45
RM 22.5	1,210	128*	160	102
West Fork				
RM 37	2,070	142*	310	102
RM 83	4,300	181*	770	128
North Branch at confluence with South Branch	920	82*	140	48
South Branch at confluence with North Branch	1,150	73*	170	36

* *Calculated from graphical methods*

Figure 30. Overall, the Gulkana River is a meandering, single-threaded channel entrenched in lacustrine sediments. Primary adjustment modes are lateral migration associated with meandering.

Schumm (1971) also developed a proportional relationship between the same hydraulic geometry variables and bed-material load:

$$Qs \approx \frac{W, L, S}{D, P} \qquad (3)$$

where P is channel sinuosity.

Equations 1-3 represent a framework within which channel responses to changes in instream flows can be determined. Heede (1976) expands upon these proportionalities by discussing channel adjustments in terms of the energy expending roles of morphological features. He hypothesizes that channel response will occur in a predictable hierarchy—with responses requiring the shortest times and lowest energy inputs occurring first. Thus, he suggests that streams will adjust morphological features in the following order: bed form, bed material size (armor), width, pattern, and longitudinal profile. The direction of adjustment will be in the direction of increased or decreased flow efficiency (i.e., increased or decreased stream power) depending upon the change in equilibrium condition.

Gradients

Average channel gradients for key reaches on the Gulkana River are depicted in Figure 31. A relevant discussion of river gradients as excerpted from the Gulkana River Management Plan (USDI, 1983) follows:

> "For the first 3 miles from the outlet of Paxson Lake, the Gulkana River has a gradient of 38 feet per mile with Class II rapids. The next 16 miles have a gradient of seven to eight feet per mile with gentle meanders. More riffles are encountered as Canyon Rapids is approached. The one-quarter-mile long Canyon Rapids are Class III/IV. The river drops the following 8 miles at a rate of 50 feet per mile with many stretches of Class II rapids. For the

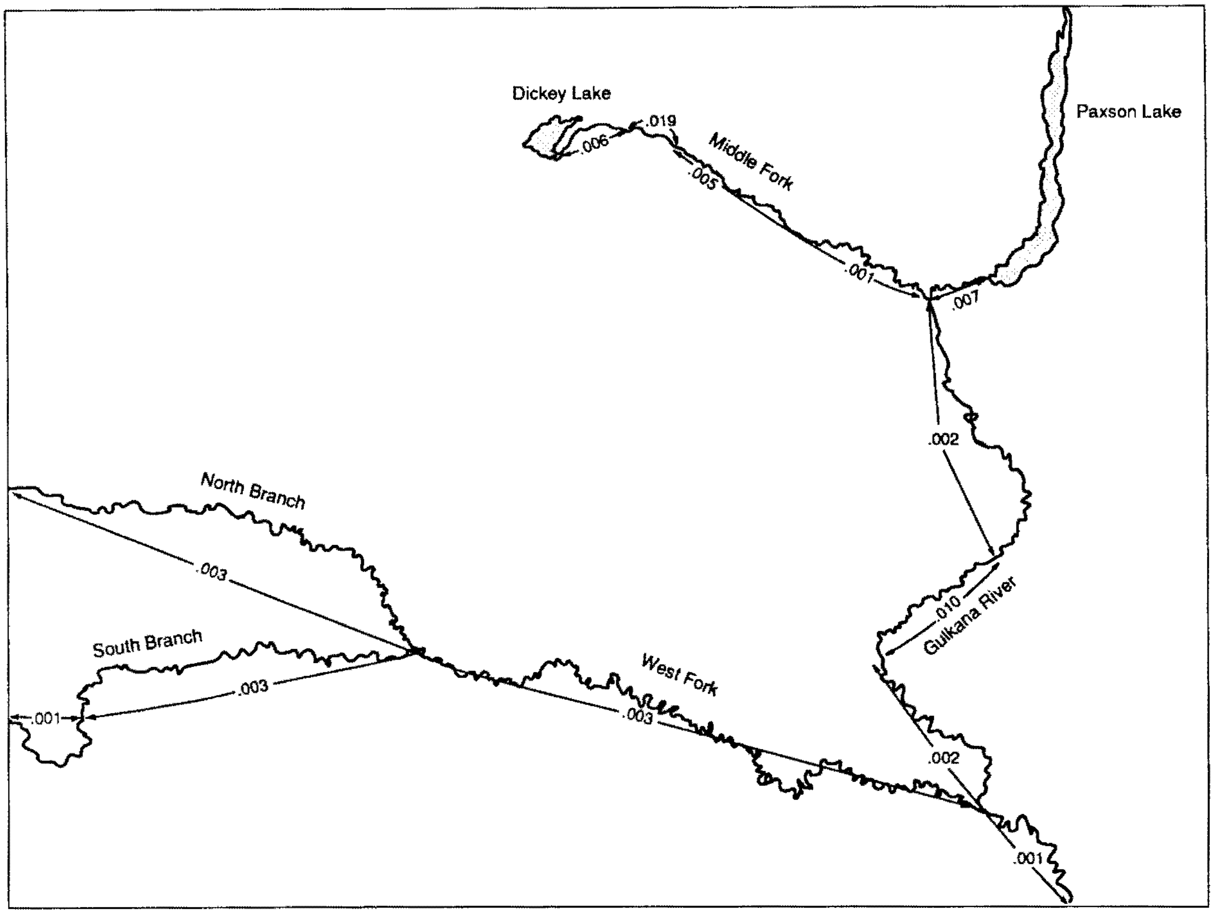

Figure 31. Average stream gradients for selected reaches, Gulkana National Wild River.

remaining distance to the confluence of the West Fork, the gradient is 10 feet per mile. Over the remaining distance to Sourdough Creek, the river drops 5 feet per mile.

"The Middle Fork Gulkana River, for a distance of about 3 miles below Dickey Lake, flows through riffles and rocky runs at a gradient of 30 feet per mile. A gradient of over 100 feet per mile and boulders of up to 8 feet in diameter characterize the next river mile and result in Class III and IV rapids. The river then has riffles and rocky runs with a gradient of 25 feet per mile for the next 6 miles. The remainder of the Middle Fork slowly meanders to the main Gulkana River at a gradient of about 1 foot per mile.

"The south branch of the West Fork Gulkana River meanders through lake-dotted country for 8 miles with a gradient of about 2 feet per mile. The river then flows with a perceptible current through a very shallow mile-long lake. The first 5 miles below this lake are slow, with river depths up to 8 feet. From this point to its confluence with the north branch of the West Fork Gulkana River, the south branch has a gradient of about 15 feet per mile with several riffles and rocky runs.

"The north branch of the West Fork Gulkana River has a varied gradient from 3 to 60 feet per mile along its 30-mile length. From the confluence of the north and south branches, the West Fork Gulkana River flows slowly for 4 miles. It then enters a canyon where it speeds through riffles and around large boulders up to 4 feet in diameter. The remainder of the West Fork flows in a series of riffles and slow runs. West Fork gradients average 16 feet per mile."

As discussed above, a stream would typically respond to decreased flows or increased sediment loads by increasing its gradient, that is, reducing the amount of energy expended in meandering (Lane, 1955; Schumm, 1971), and possibly by aggrading (or filling) certain reaches. Heede (1976) suggests, however, that other features would likely be more responsive than longitudinal profile to changes in flow regime. The Gulkana River has several key geologic base level controls and is well imprinted in the landscape. It is unlikely that major changes in longitudinal profile, beyond those caused by changes in channel pattern (see following discussion), would result from reductions in flow regime.

Channel Pattern

Channel pattern is a plane-form channel descriptor. Channel patterns include straight, meandering, and braided. When channel sinuosity (the ratio of channel length to down-valley distance) is less than 1.5, a channel is considered straight or sinuous. When sinuosities are greater than 1.5, channels may be classified as meandering (Leopold et al., 1964). Braided channels have multiple channels which continue to divide and rejoin. Meandering and braiding are modes of stream energy dissipation and are related to channel gradient, valley width, discharge, and sediment load.

Sinuosities

Average sinuosities for selected reaches of the Gulkana National Wild River are depicted in Figure 32. In general, the Gulkana River Main Stem from the Paxson Lake outlet to the West Fork confluence would be classified as straight or sinuous. The rest of the National Wild River, including the Middle Fork, the West Fork, and the Main Stem downstream from the West Fork confluence, would be classified as meandering (although several short rapids reaches would be excluded from the "meandering" classification). In particular, the lower half of both the West Fork and Middle Fork are tortuous, with sinuosities in excess of 2.0.

The meandering character of the two main tributaries (West Fork and Middle Fork) has important implications for the overall character of the National Wild River: banks, point bars, riffle-pool features, and sloughs are all influenced strongly by the meandering process.

Meandering involves both the lateral and downstream migration of channel bends (Figure 33). Helical flow patterns contribute to the scouring of cutbanks on the outside of meanders, and the deposition of sediment on the large point bars which form on the inside of meanders. Point bars further function as floodplains, and when vegetation becomes established, they may be particularly effective in dissipating stream energy and inducing sedimentation during floodflows. In their early successionary stages, point bars make excellent recreational campsites and provide water access for wildlife. When a point bar is forming, or when it is being encroached upon by an upstream meander, it may be susceptible to the formation of secondary or floodflow channels. These channels may eventually lead to a meander "cutoff" resulting in the formation of oxbows and sloughs. Oxbows and sloughs, in turn, are important habitat components for fish and wildlife. The process of point bar formation in a meandering river is depicted in Figure 34.

A stream would typically respond to decreased flows or increased sediment loads by decreasing its sinuosity, and reducing the amount of energy expended on the meander process (Lane, 1955; Schumm, 1971). Gulkana River meander processes and related features are probably very susceptible to changes (reductions) in flow regime. This is because (1) meandering is a principal mode of energy dissipation in many reaches—especially on the West and Middle Forks, and (2) channel materials, generally consisting of coarse nonerosive beds and fine-grained erosive banks, tend to favor meandering (lateral migrations) as an important channel adjustment process.

Although sinuosities are high and meandering is a very important factor influencing the National Wild River character, meander adjustment *rates* are retarded to a great extent due to the hydrologic character of the basin (discussed above) which tends to moderate flood peaks. Also contributing to low meander adjustment rates is the fact that frozen cutbanks in the springtime may add a degree of lateral stability during early-season high flows. However, this stability may be offset by ice-scouring effects. Finally, the generally incised character of the stream means that considerable sediment inputs result from small lateral movements—requiring large expenditures of stream energy for small movements laterally.

Important expressions of meandering—including bars, pools, and sloughs—tend to be small, because

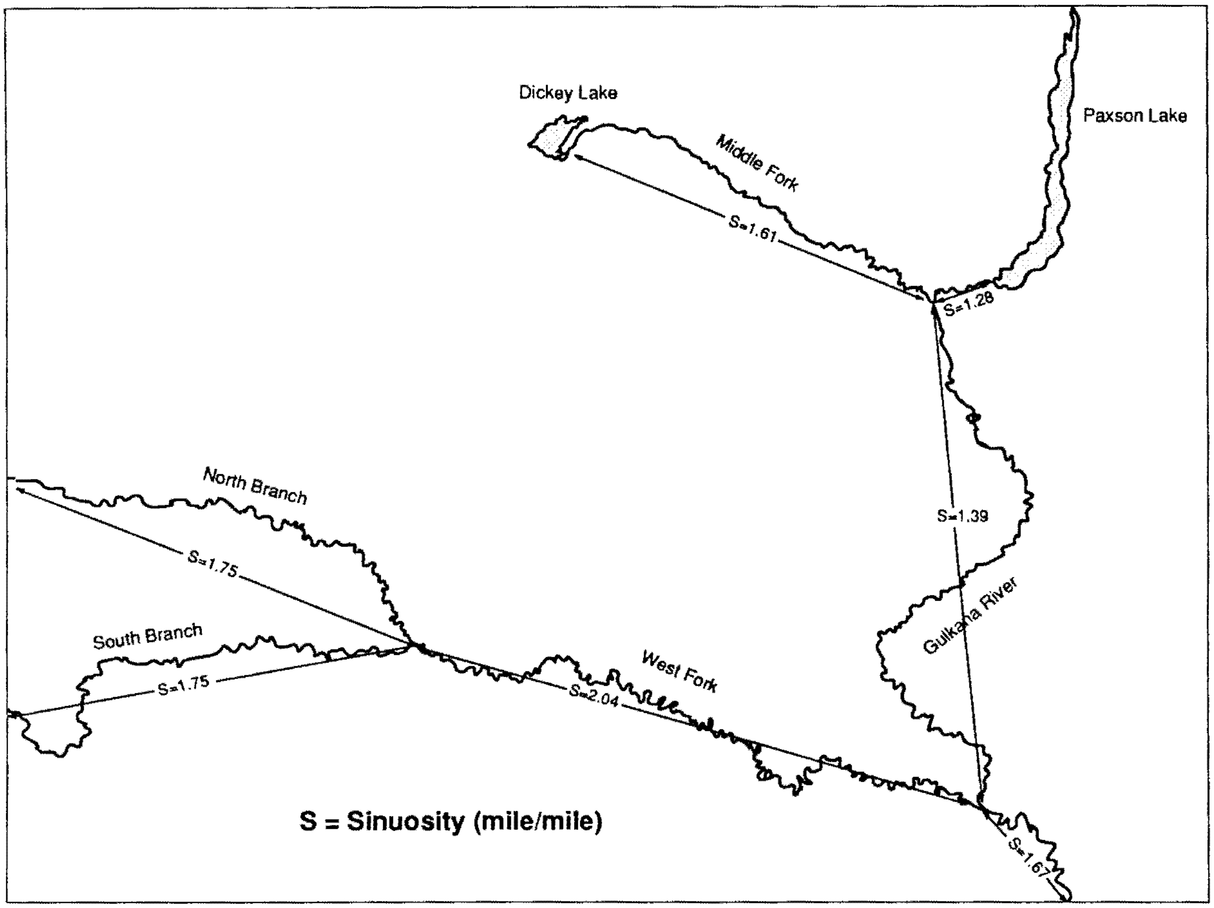

Figure 32. Average sinuosities for selected reaches of the Gulkana National Wild River.

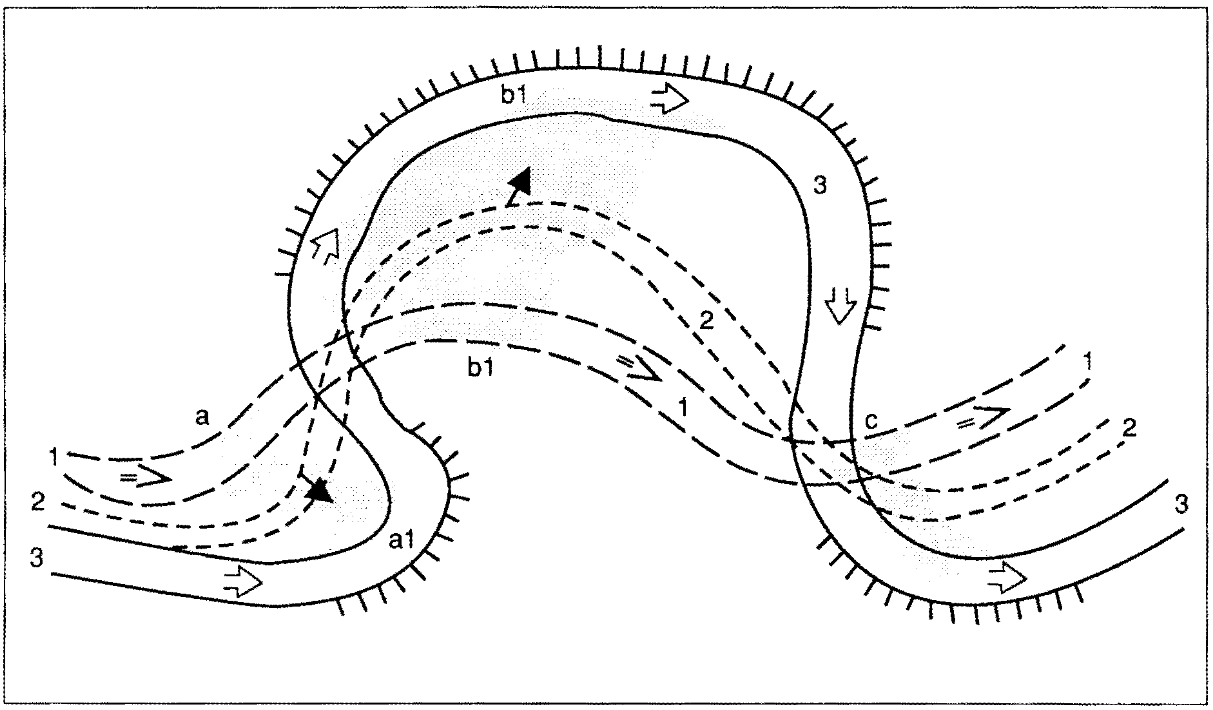

Figure 33. Lateral and downstream migration of meander bends (from Schumm, 1977).

meandering rates are low (even though sinuosities are high). Reductions in flows—particularly floodflows—would likely be felt in further reductions in meandering, and the subsequent reduction or loss of features dependent upon meander processes.

Pools and Riffles

Pools are commonly defined as the relatively deep portions of channels. They are areas of converging flows or large secondary currents. Primary pools are typically found at meander bends and are associated with helical flow patterns and eddies around point bars. Secondary pools may be associated with plunging flows downstream from boulders or large logs/trees. Primary pool expression on the Gulkana River is generally moderate to weak. Pool depths typically approach 6-8 feet, and less frequently are as great as 8-12 feet. A region of very deep pools (<12 ft) occurred along the reach between the Middle Fork Confluence and Canyon Rapids.

Riffles—or shallows—occur in zones of diverging flow, often where flow paths "cross over" from one channel bank to the other between successive meander bends. Riffles tend to be depositional features, prone to periodic scouring and filling. (Conversely, "rapids" tend to be more geologically controlled, and are areas of steeper gradient and very coarse or boulder-sized bed materials). Again, true riffle expression on the Gulkana River is moderate to weak. Riffle depths commonly range between 2-5 feet. Most ephemeral depositional features in the Gulkana River are not true riffles, but rather are small zones of deposition along banks, or in association with rocks or tree debris. The shallowest reaches in the river are most commonly associated with rapids, not riffles.

In association, pools and riffles are elements of "form roughness" and contribute (as does meandering) to the dissipation of stream energy. In the Gulkana River, this process is most evident as large eddy currents associated with meandering. Typically, reductions in flow or increases in sediment transport would tend to reduce or smooth a stream's riffle-pool expression (Lane, 1955; Schumm, 1971; Jackson and Beschta, 1984). It is likely that flow reductions would influence pool/riffle features in the Gulkana River. In particular, pools might become susceptible to some degree of filling.

However, the sensitivity of pools (and riffles) to flow reductions may not be high. This is because the river's sediment loads originate to a large extent as lacustrine deposits and tend to be fine-grained and relatively transportable in relation to channel bed materials. Most sediment inputs are fairly readily transported downstream by even modest high flows. If all high flows were eliminated, eventual reductions in pool size would likely occur.

To quantify the effect of flows on pool depths, a relationship was developed between maximum cross-

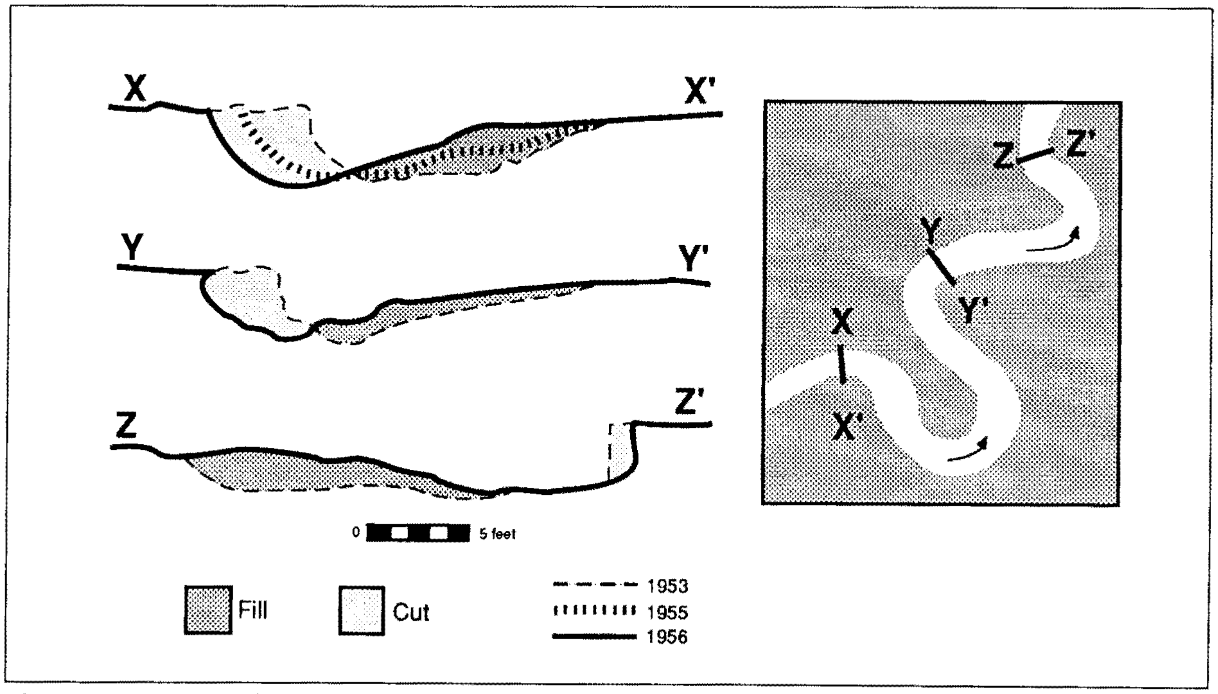

Figure 34. Process of point bar formation in a meandering river (from Ritter, 1978).

section depth, D, and bank-full flow, Q_{bf}, using data from deep (nonriffle, nonrapid) cross sections:

$$D = a\,Q_{bf}^{x} \qquad (4)$$

$$(r^2 = 0.45)$$

where a and x are regression coefficients, equal to 1.13 and 0.28, respectively. The relationship is shown graphically in Figure 35.

Channel Widths

Channel width is commonly a parameter sensitive to changes in flow regime (Heede, 1976; Schumm, 1971). Similarly, active (bank-full) channel width may influence both channel navigability and aesthetic factors, such as viewshed. This can be an instream flow issue, particularly on upstream portions of the West Fork and Middle Fork, where narrow channels and frequent "sweepers" can be impediments to boating. Similarly, it has been found elsewhere that active flood channel features, such as floodplain widths and gravel point bar widths, are related to active channel widths (Van Haveren et al., 1987).

In its headwaters, the Gulkana River is very narrow, with active channel widths as small as 10 feet (West Fork) to 30 feet (Middle Fork). Downstream, main channel widths can exceed 250 feet and the width issue is less acute.

Bank-full widths, W, on the Gulkana River are related to bank-full flow, Q_{bf}, by equation 5,

$$W = b\,Q_{bf}^{y} \qquad (5)$$

$$(r^2 = .99)$$

where b and y are regression coefficients equal to and, respectively.

Side channel and point bar widths are highly dependent upon river stage. These features may be largely inundated at higher (bank-full) flows, and may approach 150 feet in width under mean August flow conditions on the main channel. Widths of major Gulkana side channel bars, including point bars (W_{bar}) were related to mean annual flow (Q_{ma}) by equation (6),

$$W_{bar} = cQ_{ma}^{z} \qquad (6)$$

$$(r^2 = 0.45)$$

where c and z are regression coefficients equal to 1.736 and 0.496, respectively. As indicated by equations 5 and 6, both Gulkana River channel and floodplain widths would decrease with decreased river flows. In fact, the magnitude of the decrease

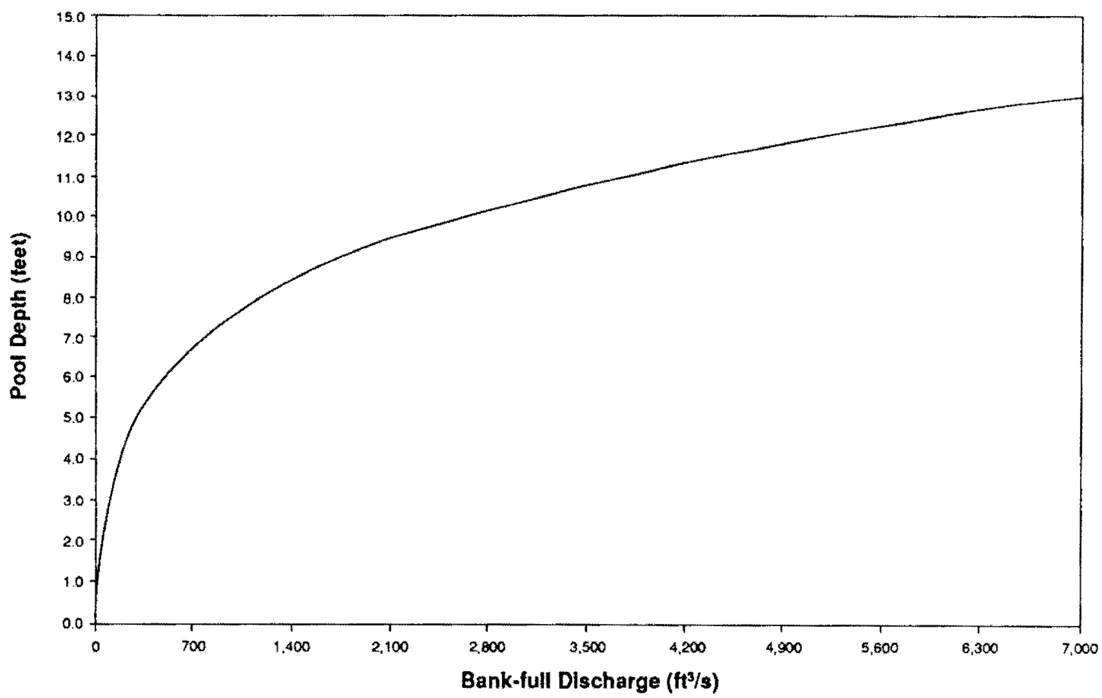

Figure 35. Relationship between pool cross-section maximum depth and bank-full discharge.

may be underestimated by equations 5 and 6 if reducing high (flood) flows were the main factor influencing reductions in mean annual flow. Under this scenario, vegetation encroachment might contribute to even greater reductions in channel and side bar widths.

Substrate

Substrate sediments provide a form of flow resistance referred to as skin friction. Particle sizes respond to changes in both flow and sediment transport rates (Schumm, 1971). In general, flow reductions or sediment transport increases will result in a reduction in substrate particle size.

While Gulkana River bed material sizes ranged from sand and gravel up to large cobbles, and even boulders (boulders were especially common in rapids), the predominant bed material size was probably cobble.

Flow conditions made it impossible for this project to quantify substrate sizes, or to develop relationships with streamflow. However, it is not thought that substrate character would be altered drastically by small or even moderate reductions in streamflow. This is because sediment transport loads tend to be fairly fine-grained and are efficiently flushed through the system by even modest high-flow events. Large reductions in high (flood) flows, however, could eventually lead to substantial fine sediment deposition and the reduction of substrate particle sizes.

Channel Morphology - Flow Relationship

While most major Gulkana National Wild River morphological attributes can be expected to respond to changes in flow regime, the two characteristics expected to be most sensitive to reductions in streamflow (especially high flows) are channel (and side bar/point bar) widths, and the lateral migration rates associated with meandering. High-flow reductions would eventually result in vegetation encroachment on the main channel (and a more advanced vegetation successionary status), and the reduction in features such as sloughs which are dependent upon meander migration processes.

Gravel Bar Maintenance

Channel side and point bar material is deposited during decreasing flows on the falling limb of the spring snowmelt hydrograph or a storm hydrograph. In response to declining flow velocities, the stream simply loses its ability to transport gravel. Since the size of particles capable of being transported varies directly with flow velocity, depositional bars are usually constructed of well-sorted material of uniform size.

As flow velocities increase in response to increasing discharge from spring snowmelt or storms, bar material is picked up and transported downstream. In this way, gravel bars are rejuvenated during high-flow events and their size maintained as a function of mean annual discharge. High flows are also responsible for scouring debris and vegetation from bars. Without this scouring action, vegetation would encroach, debris would accumulate, and camping remnants such as fire rings would persist.

The study team developed a method for predicting the effect on gravel bar width of reduced high flows. Based on visual analysis of 1:12,000-scale aerial photographs, the team selected all of the largest gravel bars on the Gulkana Main Stem above the West Fork confluence, the Gulkana Main Stem below the West Fork confluence, the West Fork, and the Middle Fork channels. The team assumed that the largest bars were of interest to boaters for overnight camping sites. All bars selected were "point" bars, that is the inside, aggrading portion of a meander bend.

Using the 1:12,000-scale aerial photographs, the team measured the width of the open or unvegetated area of each gravel bar and the width of the active channel at a stable reach (little or no aggradation or degradation) between meander bends. The team determined the average gravel bar width and the average ratio of bar width to active channel width for each of the four reaches. Finally, the team determined for each reach the relationship between active channel width and the 2-year peak discharge. The relationship is of the form, Channel Width = aQ_2^b, with a and b being constants determined from regression analysis.

The 2-year flow is selected here primarily because it can be administered from a water rights management standpoint. However, in reality, randomly occurring floods, including extreme events, are periodically required to maintain the river's character.

INSTREAM FLOW RECOMMENDATIONS TO PROTECT CRITICAL RESOURCE VALUES

Previous chapters discuss the relationships between resource value attributes and flow levels. This chapter will define, both analytically and evaluatively, specific flows necessary to maintain wild river values in the Gulkana and its tributaries at a level consistent with legislative and administrative mandates.

Flows for Recreational Boating

The recreation assessment reported earlier suggests three different types of boating opportunities. The Gulkana is a relatively accessible river of only moderate difficulty, so it offers an excellent opportunity for *"family/novice boating."* For a quality experience, this group requires flow levels that minimize the necessity for dragging boats over rocks. The required flow level for this is 2,100 ft^3/s at Sourdough. This type of boating is available on the Gulkana following the high flows of breakup (June-July), and after periods of heavy rain in August. It appears that family/novice boating is a primary opportunity offered by the Gulkana, so this flow should be retained whenever natural conditions permit (i.e., after rains in August).

The Gulkana is still "boatable" at lower flows, but considerably greater skill and effort is required. For the hard-core boater who is willing to spend considerable time pulling boats across shallows and over rocks, the river offers *"drag boating"* opportunities. The required flow for this type of experience is 1,400 ft^3/s at Sourdough. This kind of experience is available during the lower flow periods of late summer and early autumn (August-September), except when heavy rains bring flows up to novice/family boating levels.

At certain higher flows, the Canyon Rapids section of the Gulkana produces challenging hydraulics, offering the opportunities for *"whitewater boating."* High quality whitewater requires flows of 3,000 ft^3/s at Sourdough. This kind of experience is available during high flow periods following breakup (generally late May and June), or after exceptionally high rainfall.

It is important to understand that boaters watch flow levels closely, and they often take trips on short notice to take advantage of higher flows. For example, the average August flow at Sourdough is 1,334 ft^3/s, which means that on average the river meets the requirements only for drag boating. However, heavy rainfall during August could easily bring the river up to 2,000-3,000 ft^3/s at Sourdough, allowing family/novice boating for opportunistic floaters. Instream flow reservations should preserve such opportunities.

Flow Depths and Velocities for Salmon Spawning

Chinook salmon require a depth of ≥ 0.2 m to spawn. Certain velocities are important for maintenance of redds. Optimal velocities are 0.30 to 0.90 m/s with a range of 0.20 to 1.15 m/s being acceptable. At lower velocities, redds will accumulate silt. Higher flow velocities will scour and disrupt the gravels in redds. Chinook salmon also require a depth ≥ 0.24 m for migration to redds.

Sockeye salmon will spawn in depths of 15 to 32 cm with depths 0.24 m needed to ensure migration. For redds to be productive, velocities of 0.35 to 0.70 m/s are necessary.

Winter Flows for Overwinter Survival of Fish

Naturally-occurring winter flows are lower than that required for normal fish passage in the system. Fish generally overwinter in the deeper pools, the water levels of which are dependent on river flows. High flow velocities are required to minimize the buildup of channel ice, which also reduces pool depths. Since salmonid redds are subject to desiccation or freezing under low flow conditions, late fall and winter flows must be sufficient to prevent this condition from occurring in the Gulkana River system.

Floodflows for Gravel Bar Maintenance

Average channel widths, average bar widths, and the average ratios of channel width to bar width are given in Table 26. Based on the regression relationships established between bar width and 2-year peak discharge, the effect on bar width of reducing 2-year flows can be predicted (Table 27).

For the Middle Fork, the gravel bars reduce in direct proportion to reductions in high flows. The average existing gravel bar width is 89.4 feet. A 20 percent reduction in flows results in an average width of 71.3 feet; a 40 percent reduction in flows results in an average width of 53.3 feet. To maintain acceptable camping sites, bar width should not decrease by more than 10 percent. This translates to a Q_2 reduction of approximately 10 percent or a required flow of 1,093 ft^3/s.

For the West Fork, the relationship between bar width and floodflows was poor, but like the Middle Fork, the exponent for the power relationship was approximately 1.0. Therefore, bar width reduction is probably proportional to floodflow reductions. To maintain acceptable campsites, bar widths should not decrease by more than 10 percent and, consequently, the Q_2 should not reduce below 10 percent or 3,872 ft^3/s.

For the Main Stem between Paxson Lake and West Fork confluence, there are few bars and no discernible relationships between bar widths and flows. In this reach, camping values will be keyed to other (nonbar) nonflow dependent features, such as upper banks and islands.

For the Main Stem below West Fork confluence, bar width is very sensitive to high flows. The exponent b was 3.0. The average gravel bar width is 76.3 feet. A 20 percent reduction in floods results in an average width of 38.7 feet. A 40 percent reduction in floods results in an average width of 16.2 feet. To maintain acceptable camping sites, bar widths should not decrease by more than 10 percent. This translates to a Q_2 reduction of approximately 3 percent or a required flow of 6,887 ft^3/s.

Although the 2-year floodflow was emphasized as being required to maintain bars, a random series of floodflows of varying magnitudes is actually required for channel maintenance. If, at any time in the future, proposals are made to store water and reduce flood peaks in the Gulkana River watershed, these flow requirements should be reevaluated.

The above discussion points out differences between the instream flow requirements of the various river resource values. Recreational boating, for example, generally requires higher flows than those required for fish habitat maintenance during the summer months. Floodflows required for annual gravel bar maintenance far exceed the magnitude of flows required for either fish habitat or boating.

The team's instream flow recommendations are based on a cross-comparison of these flow requirements and on a consideration of the season of use (Tables 3 and 18). A summary of instream flow needs is presented in Table 28. Recommended flows for any given period satisfy the flow requirements of all the resource values for the indicated river reach. Annual hydrographs comparing recommended flows with natural flows are shown by river reach in Figures 36 through 42. A discussion of instream flow requirements by individual reach follows.

Table 26. Channel and Gravel Bar Width Data.

	Middle Fork	West Fork	Main Stem Above West Fork	Main Stem Below Confluence
Average Channel Width (ft)	48.9	91.3	84.5	148.3
Average Bar Width (ft)	89.4	87.4	64.0	76.3
Standard Deviation	26.7	20.6	22.3	17.5
Average Ratio, Channel Width/Bar Width	1.8	1.0	.8	.5
Standard Deviation	.5	.2	.3	.1
Q2 (ft^3/s)	1,214	4,302	2,798	7,100

Table 27. Predicted Bar Widths Corresponding to Both 20 Percent and 40 Percent Reductions in 2-Year Flow.

	Middle Fork	West Fork	Main Stem Above West Fork	Main Stem Below Confluence
Predicted Bar Width, 20% Flow Reduction (ft)	71.3	70.0	NA	38.7
Predicted Bar Width, 40% Flow Reduction (ft)	53.3	52.6	NA	16.2

Table 28. Flow Levels (ft^3/s) Recommended for Instream Flow Reservation, Gulkana River.

	Sourdough	Main Stem at Paxson Lake Outlet	Canyon Rapids	West Fork at Confl.	North Branch West Fork at Confl.	South Branch West Fork at Confl.	Middle Fork at Dickey Lake Outlet	Middle Fork at Confl.
October	835	107	—	480	88	109	33	119
November	435	56	—	250	46	57	17	62
December	307	39	—	177	32	40	12	44
January	281	36	—	162	30	37	11	40
February	255	33	—	147	27	33	10	36
March	260	33	—	150	27	34	10	37
April	306	39	—	176	32	40	12	43
May	198 (7,100)*	100 (1,104)*	—	114 (4,302)*	21 (920)*	27 (1,150)*	30 (381)*	28 (1,093)*
June	2,100	240	3,000**	767	140	173	40	161
July	2,100	240	2,100**	767	140	173	40	161
August	1,334	240	1,400**	767	140	173	40	161
September	1,073	240	1,400**	617	113	139	40	152

* *Peak discharge plus normal associated rising and falling limb flows to be maintained on a 2-year return period basis*

** *as measured at Sourdough gauge*

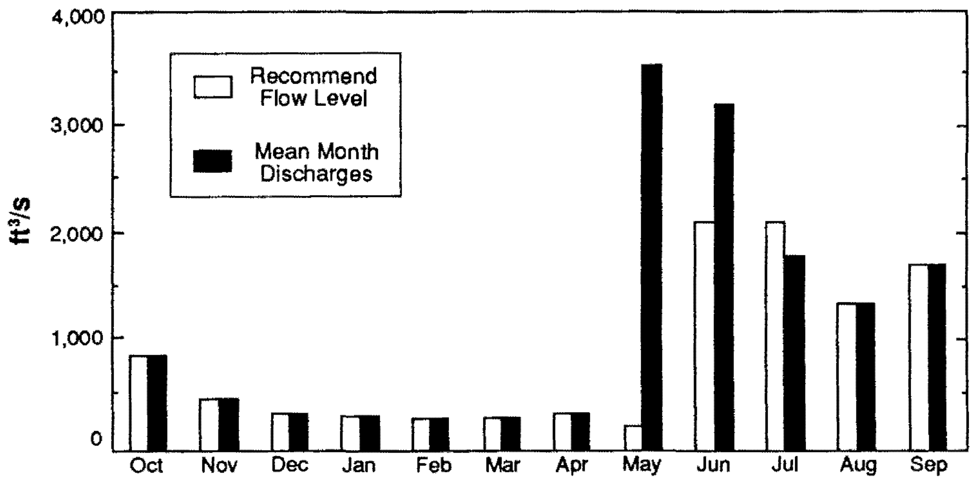

Figure 36. Recommended instream flows and mean monthly discharge for Sourdough.

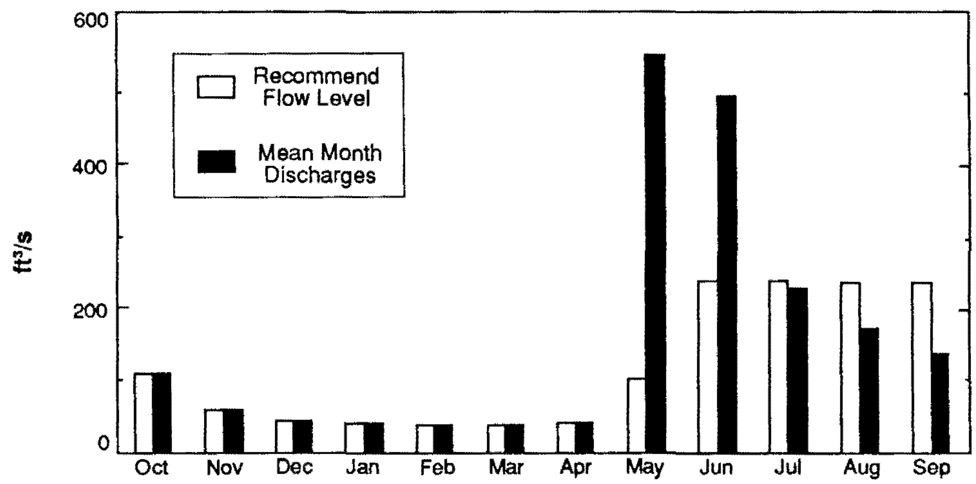

Figure 37. Recommended instream flows and mean monthly discharge for Paxson Lake Outlet.

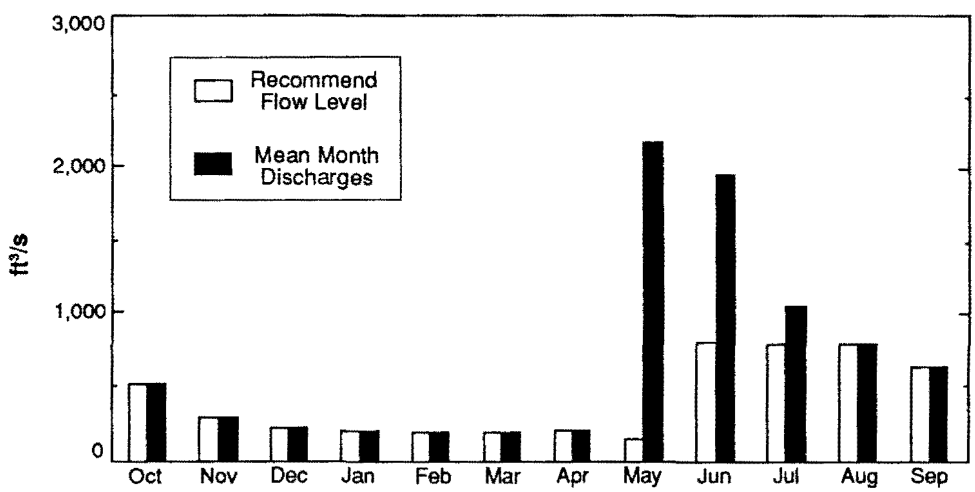

Figure 38. Recommended instream flows and mean monthly discharge for West Fork at confluence with Main Stem.

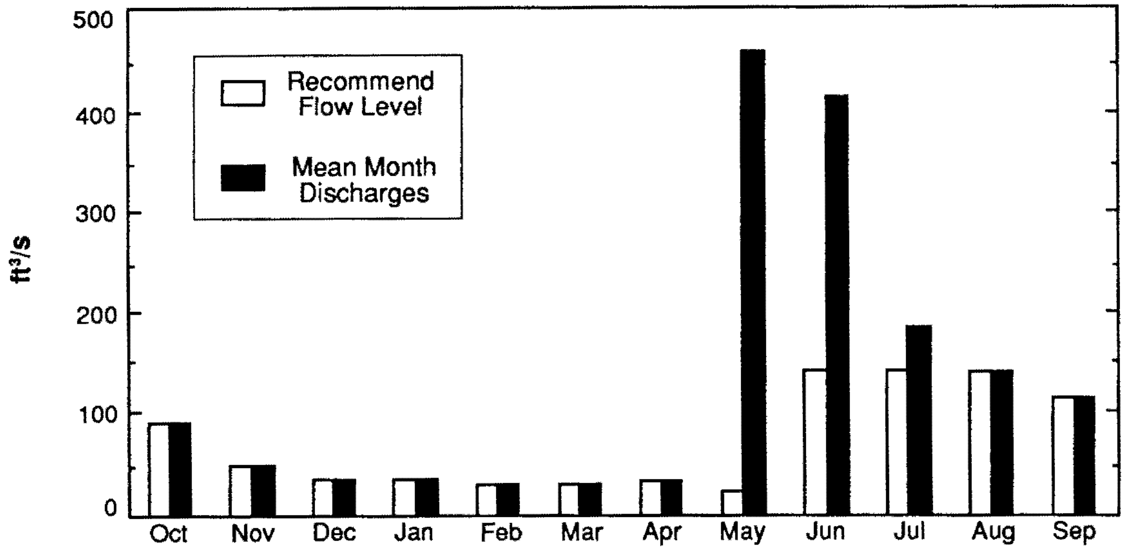

Figure 39. Recommended instream flows and mean monthly discharge for North Branch, at confluence with South Branch.

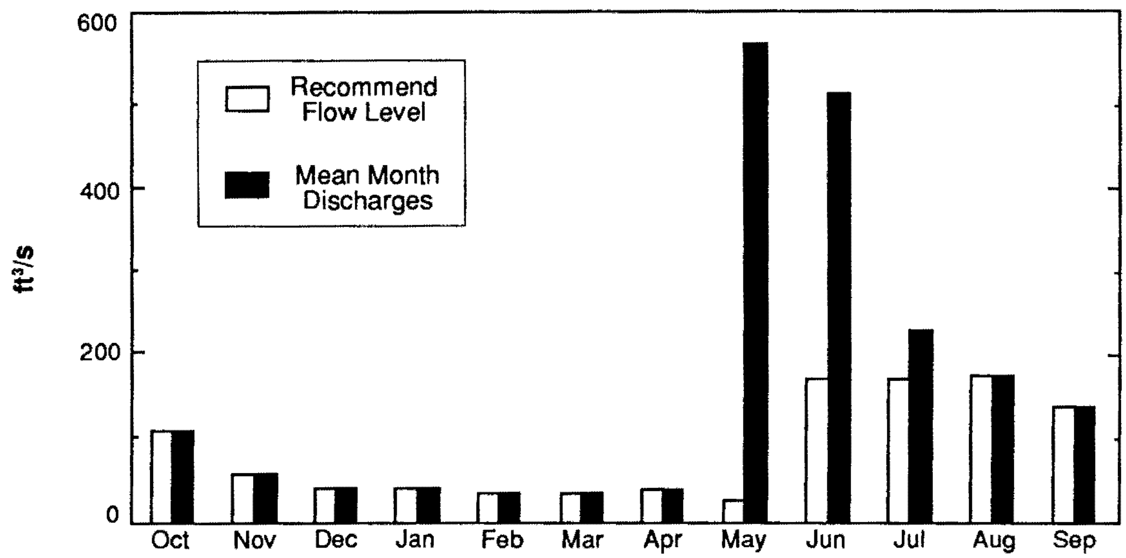

Figure 40. Recommended instream flows and mean monthly discharge for South Branch, West Fork confluence with South Branch.

Middle Fork, Gulkana River

Instream flows on the Middle Fork are required to protect recreational boating (floating), salmon and steelhead spawning and migration, and gravel bar maintenance for boater camping. Since the boating season is generally June through September, a flow of 40 ft^3/s below the Dickey Lake outlet is recommended for those 4 months. Steelhead spawning occurs from mid-April through the end of June. Salmon spawning occurs from mid-July through the end of August. Migration and spawning of these species require a flow of 30 ft^3/s below the Dickey Lake outlet during the 4-month period, May-August. Bank-full flows are required to maintain and rejuvenate gravel bars on the Middle Fork. The mean annual flood normally occurs between mid-May and early June in response to snowmelt runoff. Based on

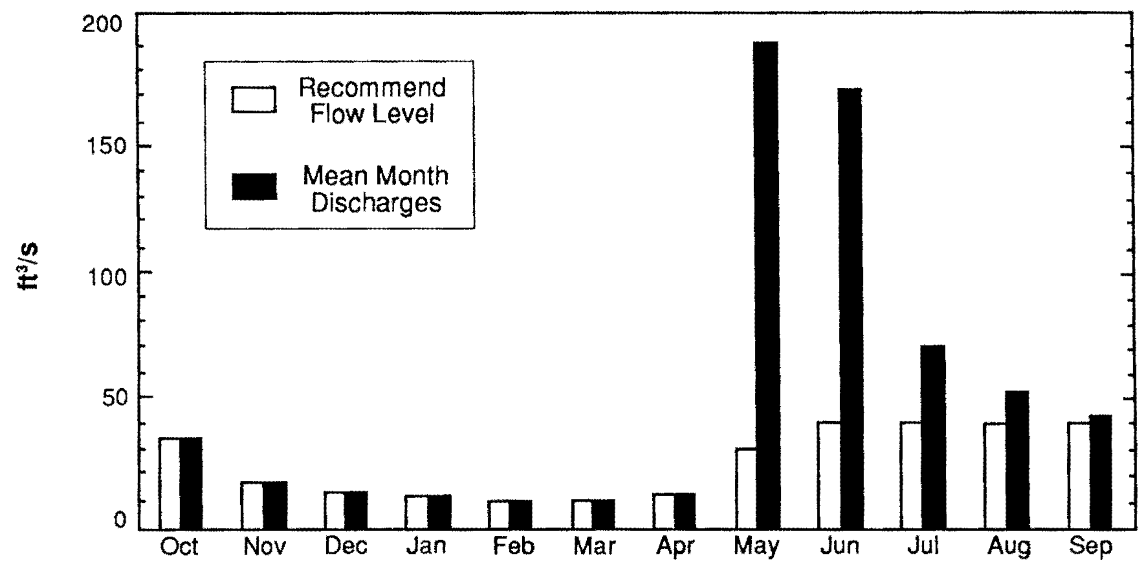

Figure 41. Recommended instream flows and mean monthly discharge for Dickey Lake Outlet.

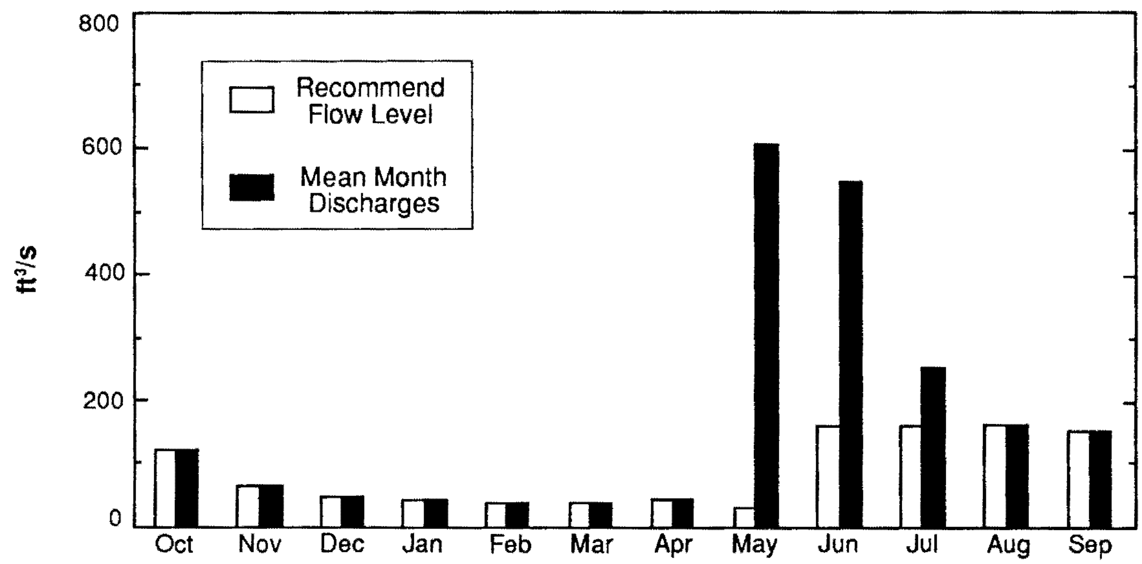

Figure 42. Recommended instream flows and mean monthly discharge for Middle Fork, Main Stem confluence.

the team's analysis of flows required for bar maintenance, the 2-year peak discharge of 1,093 ft^3/s at the fork's mouth, including the associated flow-duration relationships on both the rising and falling limbs of the flood hydrograph, is necessary to protect the quality of gravel bar camping on the Middle Fork.

West Fork, Gulkana River

Flow maintenance issues on the West Fork include recreational boating (floating), jet boat navigability for fall hunting access, boater camping on gravel bars, and wildlife viewing from the river corridor. Recreational boating is an issue on both the North and South Branches of the West Fork during the period June-September. These channels are small, quite narrow in places, and low flows increase the necessity for boat dragging. For June- August, the required flows are 140 and 173 ft^3/s for the North and South Branches, respectively, immediately above their confluence and are equivalent to their mean

August flows. For September, the recommendation is for the naturally occurring flows (mean September flows are 113 and 139 ft^3/s, respectively) if they are less than the equivalent of the respective mean August flows.

Jet boat navigability up to the confluence with the Fish Lake Tributary is an issue in September, primarily during moose season. Flows are required during this time to support jet boat use by hunters. The team's instream flow recommendation for September on the West Fork is for the naturally occurring mean September flow of 617 ft^3/s.

Gravel bars on the West Fork provide for boater camping sites and wildlife viewing. Due to the entrenched nature of the West Fork channel, wildlife are best viewed from the river corridor while they are occupying bars. Flows required to maintain and rejuvenate gravel bars are the 2-year peak discharge and associated flow-duration relationship occurring on both the rising and falling limbs of the flood hydrograph. The 2-year flow event most commonly occurs in May or June in response to snowmelt runoff. On the West Fork, the 2-year peak discharges of the North and South Branches are 920 and 1,150 ft^3/s, respectively, and 4,302 ft^3/s for the West Fork main channel.

Gulkana River Main Stem - Paxson Lake to Middle Fork Confluence

The Main Stem of the Gulkana River between Paxson Lake and the confluence with the Middle Fork supports recreational boating (floating) and salmon spawning and migration. The normal boating season is June through September. Boating concerns on this reach include boat dragging due to low water levels. A flow of 240 ft^3/s is recommended to provide a minimally acceptable boating experience during the 4-month boating season. Spawning and migration of chinook and sockeye salmon during the period June-August requires a flow of 100 ft^3/s immediately below the lake.

Gulkana River from Canyon Rapids to Sourdough

The boating season, specifically where river users anticipate a quality whitewater experience, is mid-June through mid-July. The required flow at Canyon Rapids necessary to support a user-perceived optimum whitewater experience is 3,000 ft^3/s. This flow level should be protected at the infrequent times it occurs.

Family/novice boating, from a floatability perspective, requires a certain flow level to minimize boat dragging. The required flow for this reach is 2,100 ft^3/s during the normal boating season of June through September.

Boaters use gravel bars for camping below Canyon Rapids. Again, the 2-year peak discharge, and its associated flow-duration relationships on either side of the flood hydrograph, is recommended for maintaining and rejuvenating gravel bars. For this reach of the Gulkana River, the 2-year peak flow is 2,800 ft^3/s and normally occurs in May or early June.

Jet boats are used for fishing access during the salmon runs in June and July. Jet boat navigability is a concern during this period from Sourdough to the confluence with the West Fork and approximately 2 miles above the confluence on both the Main Stem and the West Fork. Recommended flow levels for the Main Stem are 2,100 ft^3/s at Sourdough and 1,400 ft^3/s above the confluence, and 617 ft^3/s for the West Fork.

ADDITIONAL RECOMMENDATIONS

The following river corridor management and water resource management recommendations are offered in addition to the instream flow recommendations:

1. The additional 15 miles on the South Branch of the West Fork should be added to the National Wild River designation. Such designation, and the river corridor protection it affords, will help to preserve the hydrologic integrity of the South Branch and West Fork river systems.

2. The U.S. Geological Survey gauge at Sourdough should be reactivated. A continuous period of record from 1973 to 1978 was established. This is not a sufficient period of record to adequately assess extreme events on the Gulkana River. The gauge site location is excellent. Costs required to activate and maintain the gauge are small in comparison to the costs of the original installation. Costs might be shared by USGS, BLM, and National Weather Service.

3. BLM should monitor river use impacts in order to adjust river management strategies. River use is considerably lighter on the upper West Fork and Middle Fork than on the main Gulkana River. A different management strategy may be necessary for the more remote tributaries of the Gulkana National Wild River System.

4. A water-quality analysis should be completed for the upper West Fork and North Branch to determine if there are water quality factors currently limiting salmon habitat in those reaches.

RECOMMENDED LEGAL AND MANAGEMENT STRATEGY FOR INSTREAM FLOW RESERVATION

BLM was successful in obtaining an instream flow reservation on Beaver Creek National Wild River. The Beaver Creek water right assessment included a thorough analysis of legal mechanisms available for protecting instream flows. Van Haveren et al. (1987) concluded that a Federal reserved water right is created upon designation of a National Wild River and that flows implied by that right can be adequately protected and administered under Alaskan law. The legal mechanism selected for Beaver Creek was the State of Alaska Application for Reservation of Water. Based on the success of that mechanism for Beaver Creek, the team recommends that an *Application for Reservation of Water* (Appendix E) be submitted to the Alaska Department of Natural Resources, Division of Land and Water Management, specifying the water flow amounts as recommended in this report.

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APPENDICES

Appendix A
Recreation Survey Sample, Format, and Results

Survey Format and Results

(I = Instructions by Interviewer)

I: This survey is part of what is called a water rights assessment study being conducted by the BLM, the managing agency on the river. The purpose of the study is to determine how much water is in the Gulkana at various times during the year, as well as determine how much water should be in the river in order to maintain its outstanding recreational, aesthetic, fishery, and wildlife values. While the BLM obviously can't control flows by manipulating the weather etc., it may be able to influence how much water will be taken out of the river for other uses such as mining, irrigation, or other hydro projects.

Although no one is currently seeking to take water out of the Gulkana, which has been designated a National Wild River by Congress, our goal is to reserve a water right with the state before someone asks. This will ensure that the Gulkana remains "wild"—as far as instream flow is concerned—into the foreseeable future.

In order to do this job right, we need to know about you, why you come to the Gulkana, and what you think about different instream flow levels. The following questions are designed to get that information.

First, we'd like to ask some questions about your trip.

	Percent Upstream	Percent Downstream
1. What kind of boat were you using?		
a. inflatable rafts	0	69
b. canoes/kayaks	0	22
c. combo of canoes and rafts	0	9
d. motorized boat with jet unit	73	0
e. motorized boat with prop	25	0
f. airboats	2	0
2. Where did you go/come from on the river?		
a. Paxson-Sourdough floaters	0	100
b. Middle Fork floaters	0	0
c. West Fork floaters	0	0
d. Motorized upstream	100	0
3. Did you camp at Sourdough?		
a. no, on river	66	100
b. no, day user	13	0
c. yes	21	0
4. Where are you from?		
a. Anchorage (includes Eagle River)	7	33
b. Mat-Su valley	2	4
c. Kenai Peninsula	0	0
d. Delta/Paxson/ AK towns North	13	7
e. Fairbanks (includes North Pole)	61	36
f. Glennallen/ Copper Basin/Valdez	5	7
g. Southeast Alaska	0	0
h. Lower 48 and Canada	7	11
i. Outside No. America	0	2
5. How many days were you on the river?		
Mean number of days:	2.9	3.7
Median:	3.0	4.0
6. How many trips have you taken on the Gulkana?		
Mean number of trips:	19.6	7.5
Median:	7.0	3.0

7. How many years have you been boating?

Mean number of years:	9.3	9.5
Median:	5.0	9.0

8. How many people in your group?

Mean number in party:	3.6	4.7
Median:	3.0	4.0

I: Next we want to find out why you come to the Gulkana. I'm going to give you a list of different reasons for taking trips on the river and I want you to tell me how important each one is to you in regard to THIS TRIP. These are reasons other users have given on a variety of different trips; some may not be important for you on this trip.

In answering these questions, I want you to give me a number on a scale between 1 and 5: 1 = not at all important/does not enhance your trip and 5 = extremely important/enhances trip.

	Mean Score	
	Upstream	**Downstream**
9. Fishing	4.9	4.1
10. Seeing wildlife	3.8	3.8
11. Scenery and scenic views	3.6	3.7
12. Photographic opportunities	3.0	3.2
13. Hiking along the river	1.3	1.3
14. Camping	3.6	4.2
15. Running rapids	1.5	4.3
16. Navigability or floatability	4.5	4.6
17. Hunting	1.1	1.0
18. Seeing historical sites (cabins)	1.7	1.8
19. Experiencing solitude	4.0	4.1
20. Meeting other users	2.5	1.9
21. Being with friends and family	4.8	4.7
22. Being in a natural or wild place	4.5	4.9
23. Having good weather	4.3	3.7

24. What were you fishing for on this trip?

	Percent	
a. kings only	2	0
b. reds only	0	2
c. grayling only	0	24
d. rainbows and steelhead only	2	4
e. kings and reds only	25	0
f. all the fish species	46	69

25. Which wildlife, if any, were you interested in seeing, or which would have enhanced your trip (you didn't have to see them; however, these can be the things you wanted to see)?

	Percent Naming	
a. bears	48	69
b. eagles	57	64
c. moose	50	69
d. caribou	50	69
e. wolves	9	4
f. small mammals	18	31
g. birds other than eagles	16	22

I: Now I'd like to ask a series of questions about flow levels on THIS TRIP.

26. Did you check water levels before taking this trip?

	Percent	
	Upstream	**Downstream**
a. no	29	40
b. yes	71	60

27. If you did, where did you call or check?

a. BLM office in Glennallen	0	7
b. Nat. Weather Service	13	11
c. Sourdough Lodge	15	11
d. Word of mouth	30	52
e. Gulkana Bridge	3	7
f. Rocks at Sourdough	13	0
g. Fish and Wildlife/ Fairbanks	20	0
h. Fish and Wildlife/ Glennallen	7	8

28. How many times did you hit or drag bottom?

Mean number of times:	1.9	11.2
Median:	1.0	5.0

29. Where?

30. What did you do at the Falls or the drop in Canyon Rapids (downstream users only)?

a.	ran Falls with all gear in boats	25
b.	ran Falls without gear or passengers	45
c.	lined Falls	0
d.	portaged all gear, passengers, and boats	30

31. Did you fish from gravel or sand bars on this trip?

a.	no	5	4
b.	yes	95	96

32. Did you camp on a gravel or sand bar on this trip?

a.	no	48	20
b.	yes	52	80

33. If the river were even lower than it is now and it took longer for you to get downstream, would you spend another night or two on the river or would you simply paddle longer each day (downstream users only)?

a.	spend more nights on river	35
b.	work harder each day; same number of nights	64

I: Finally, we want you to rate the instream flow level you experienced on this trip. We want you to tell us if the river was too low, way too low, too high, or just right (optimum) with regard to a list of different aspects of the trip.

34. For finding places to fish from?
35. For catching salmon?
36. For catching other fish?
37. For finding places to camp?
38. For a thrilling ride in rapids?
39. For a safe ride in rapids?
40. For hiking along the bank?
41. For river aesthetics?
42. For speed of the trip?

43. For floatability/navigability?

[NOTE: These results have been presented and discussed in the text of the report.]

Aside from asking these questions, the interviewer also noted the date and the flow level at Sourdough (converted from Gulkana Bridge stage levels using a correlation with Sourdough flow levels).

Date	Flow Level ft^3/s	Upstream Users	Downstream Users
Users Trips			
6/21	3,835	0	1
6/30	2,925	10	13
7/3	2,370	11	6
7/4	2,225	13	13
7/5	2,150	3	4
7/9	2,005	6	5
7/10	2,100	9	4
7/11	2,140	3	5
7/31	2,590	0	1
8/1	2,430	1	2
8/2	2,225	0	1
8/13	1,950	0	1
8/15	2,140	0	1
Team Trips			
7/20	1,535	Trip 1 (Middle/Main Stem: put-in)	
7/27	3,835	Trip 1 (Middle/Main Stem: take-out)	
8/10	2,280	Trip 2 (Main Stem)	
8/15	2,140	Trip 3 (Main Stem)	

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service

Floatability Report

DATE__________ FLOATER(S)__________

RIVER __________

TYPE OF BOAT __________

PUT IN POINT	TAKE OUT POINT
Location __________	Location __________
Date __________	Date __________
Time __________	Time __________
*River Stage __________	*River Stage __________

Check River condition(s)

- Flooding ☐
- Hazardous ☐
- Ideal ☐
- Satisfactory ☐
- Minimum ☐

Check one based on "International Scale of River difficulty"

- CLASS I ☐
- CLASS II ☐
- CLASS III ☐
- CLASS IV ☐
- CLASS V ☐
- CLASS VI ☐

Name of Rapid(s):

REMARKS:

Appendix B
National Weather Service River Floatability Reports

Table B-1. Summary of National Weather Service Floatability Cards

Date	Avg. Flow* ft^3/s	Rating	Type of Boat (size)
Low water conditions: many hits; some dragging required			
July 1979	1,525?	satisfactory	rafts (15')
Aug. 1979	1,420?	minimum	rafts
July 1982	2,140	satisfactory	rafts
July 1982	1,875	satisfactory	rafts
Aug. 1982	2,590	minimum	rafts
July 1983	2,280	minimum	rafts
Sept 1986	1,070	minimum	rafts
July 1987	1,330	minimum	canoes
July 1987	1,255	ideal	rafts (14')
July 1988	2,280	satisf./min.alumin	canoes
Average	1,854		
Ideal water conditions: few hits; no dragging required			
June 1979	1,875?	satisfactory	rafts
June 1982	4,140	ideal	rafts
May 1983	3,105	satisfactory	canoes
July 1985	2,755	ideal	canoes
July 1985	4,142	satisfactory	rafts (12')
Sept 1985	2,280	ideal	canoes (17')
Average	3,284		
High water conditions: no hits; Class IV rapids; camps flooded			
July 1979	2,280?	ideal	rafts
May 1982	5,470	satisfactory	rafts
June 1982	5,470	ideal	canoes/kayaks
June 1982	5,470	ideal	rafts
June 1985	7,860	flooding	rafts
July 1988	2,755	satisfactory	rafts (14')
Average	5,405		

* Flows converted from stage readings using correlation with Sourdough ft^3/s readings. See hydrology methods for further details.

? 1979 figures may have been on different scales; they were not used in calculations of averages.

Appendix C
Aquatic Habitat Observations and Maps

Field Observations

July 20 - Day One

The overall habitat in the first 2 miles below Dickey Lake was excellent. The pool/riffle ratio was ideal with abundant substrate of suitable size for spawning for chinook, sockeye, and rainbow-steelhead trout. Streambanks were totally stable, with good overhangs providing quality habitat. Woody riparian vegetation was in excellent condition, providing bank stability as well as cover. The vegetation was predominantly willow. Kick samples showed a diverse macroinvertebrate community.

Eight pairs of chinook salmon were observed, as well as several sockeyes. Chinook salmon were active on two redds, with the sockeyes migrating into Dickey Lake. Hook and line samples produced 25 grayling and 1 rainbow trout. The largest grayling caught was 34 cm long and weighed .34 kg. The rainbow trout was 40 cm long and weighed .5 kg.

July 21 - Day Two

Habitat observed day two can be placed into one of three habitat types: multiple-channel, cascades, or a meandering channel. The multiple-channel section provided very little fish habitat and was a struggle for migrating salmon to move through. Any reduction in existing flows would severely hamper salmon and steelhead trout migration. The cascade areas provided very little habitat due to increased gradients and velocities. These reaches appeared to present no problem for trout or salmon migration. The meandering channel type provided excellent habitat. The pool/riffle ratio was close to 50/50 with many high quality pools. Streambanks were totally stable with woody vegetation providing excellent cover. Vegetation was predominantly willows with some spruce trees. Substrate of suitable size for trout and salmon spawning was common. We did observe spawning activity by chinook salmon on three different redds.

Twelve pairs of chinook salmon were observed on day two. Two that were captured were between 115 and 130 cm in total length and weighed between 20 and 23 kg. Hook and line samples also produced numerous grayling between 30 and 40 cm in total length. The largest grayling caught weighed .8 kg. We also captured two small fry, less than 5 cm in total length, that appeared to be chinook salmon.

July 22 - Day Three

The first half of day three was a continuation of the last part of day two. Observations included excellent fish habitat, good pool/riffle ratio, totally stable banks, excellent woody riparian vegetation, abundant substrate of appropriate size for trout and salmon spawning, and high quality pools. After passing the confluence of Hungry Hollow, the Middle Fork habitat changed. Its gradient decreased, sinuosity increased, and velocities became more constant with no well defined pool/riffle structure. The streambanks were not as stable and the bottom substrate was composed of more sands and fines, but still was dominated by cobble. Riparian vegetation was predominately spruce trees.

The habitat through this reach could be described almost as one continuous run. Pools that were present were of low quality.

Upstream of the unnamed tributary that enters the Middle Fork at the Winter Trail, 12 pairs of chinook salmon and a few sockeye salmon were observed. Hook and line samples produced numerous grayling, one chinook, one sockeye, and one rainbow trout. The chinook salmon weighed approximately 23 kg and was 114 cm in total length; the sockeye salmon weighed 2.5 kg and was 74 cm in total length; and the rainbow trout weighed 1.2 kg and was 43 cm in total length. No fish were caught in the Middle Fork below the unnamed tributary. Sampling conducted on tributaries to the Middle Fork produced a few grayling. We did not observe any migrating salmon in this reach, but this was probably due to the increased turbidity from recent rains.

July 23 - Day Four

Habitat observed in day four was a continuation of the habitat recorded the previous day below Hungry Hollow Creek. It did not change until approximately 1 mile above the confluence of the Middle Fork and the Gulkana River. At that point the gradient increased and again the river began to display a pool/riffle structure. The Gulkana River above the confluence provided excellent habitat. There was a good pool/riffle ratio with high quality pools. The streambanks were totally stable and well vegetated by willows that provided good cover for the stream. Useable substrate of appropriate size was present for trout and salmon spawning.

No fish were captured or observed in the Middle Fork, but again this was the result of increased turbidity from recent rains. A few grayling were caught and released in tributaries to the Middle Fork. They were between 25 and 33 cm long and weighed .2 to .3 kg. At the confluence, we did observe a school of sockeye salmon, estimated at 50 fish, moving up the Gulkana River towards Paxson Lake. Hook and line sampling did produce one sockeye and a few grayling at the confluence.

July 24 - Day Five

After the confluence the river becomes a big river system. Three homogeneous reaches were observed on day five. The first reach was from the confluence of the Middle Fork and the Gulkana River downstream for approximately 3 miles. The river channel had frequent braiding and side sloughs that provided excellent trout and grayling habitat as well as seasonal habitat for salmon. The streambanks were stable, with riparian vegetation being a combination of willows and spruce trees. Due to turbidity from recent rains, no observations were made of substrate, and this was true for the remainder of the trip. The next 3 to 4 miles had a low gradient and a very high sinuosity with numerous oxbows. Pool depths were measured up to 376 cm and probably provide important winter habitat for trout and salmon. The streambanks in this area were stable for the most part, but the process of forming more oxbows and straightening of the river channel was an active ongoing process. The remainder of day five was in habitat that could be described as one continuous run broken up partially by large boulders that provided minimal pool habitat.

The streambanks were totally stable and showed a three-tier vegetation community that appeared to be influenced by ice breakup in the spring.

Few salmon were observed migrating and the only fish caught were grayling in some of the sloughs, again the result of high turbidity from recent rains. Grayling that were caught were of a much smaller size than what we experienced in the Middle Fork. Most of them were under 25 cm in total length and weighed less than .2 kg.

July 25 - Day Six

The first 2 miles of day six were a continuation of the habitat that existed at the end of day five. This changed at Canyon Rapids and continued for approximately the next 8 miles. The habitat in this area displayed a good pool/riffle structure, stable streambanks, and excellent woody riparian vegetation. The riparian community was composed of aspen, willow, and spruce, with cottonwoods making their first appearance on the river. In places there was braiding of the river which produced a good diversity of habitat that should be ideal for rainbow trout.

A few salmon were observed this day but only small graylings were caught by hook and line sampling, a result of high turbidity.

July 26 - Day Seven

Habitat observed on day seven was a continuation of day six, for the first couple of miles. At that point, the gradient decreased, the sinuosity increased, and the habitat type changed. This stretch of river had a pool/riffle ratio approaching 50/50 and stable streambanks. Woody vegetation was a continuation of day six, although cottonwoods were becoming more common in the community. On the 26th, the West Fork and an unnamed tributary to the Gulkana River were discharging high amounts of sediment to the Gulkana River. No fish were observed and only two small chinook salmon (less than 10 cm) were caught by hook and line sampling.

July 27 - Day Eight

Habitat observed on day eight was a continuation of the second part of day seven. No hook and line sampling was done.

July 28 - Day Nine

Day nine we boated across Paxson Lake to its outlet. We then walked downstream approximately one quarter of a mile to evaluate the habitat and complete a transect. The habitat observed was excellent. The system had a good pool/riffle ratio and high quality pools. It was a repeat of what we observed at the confluence with the Middle Fork on day four. Substrate of the appropriate size for successful salmon spawning was common. Streambanks were totally stable and woody vegetation was predominately willows. No hook and line sampling was done, but numerous sockeye salmon were observed migrating into Paxson Lake.

Gulkana Mile Conversion Chart

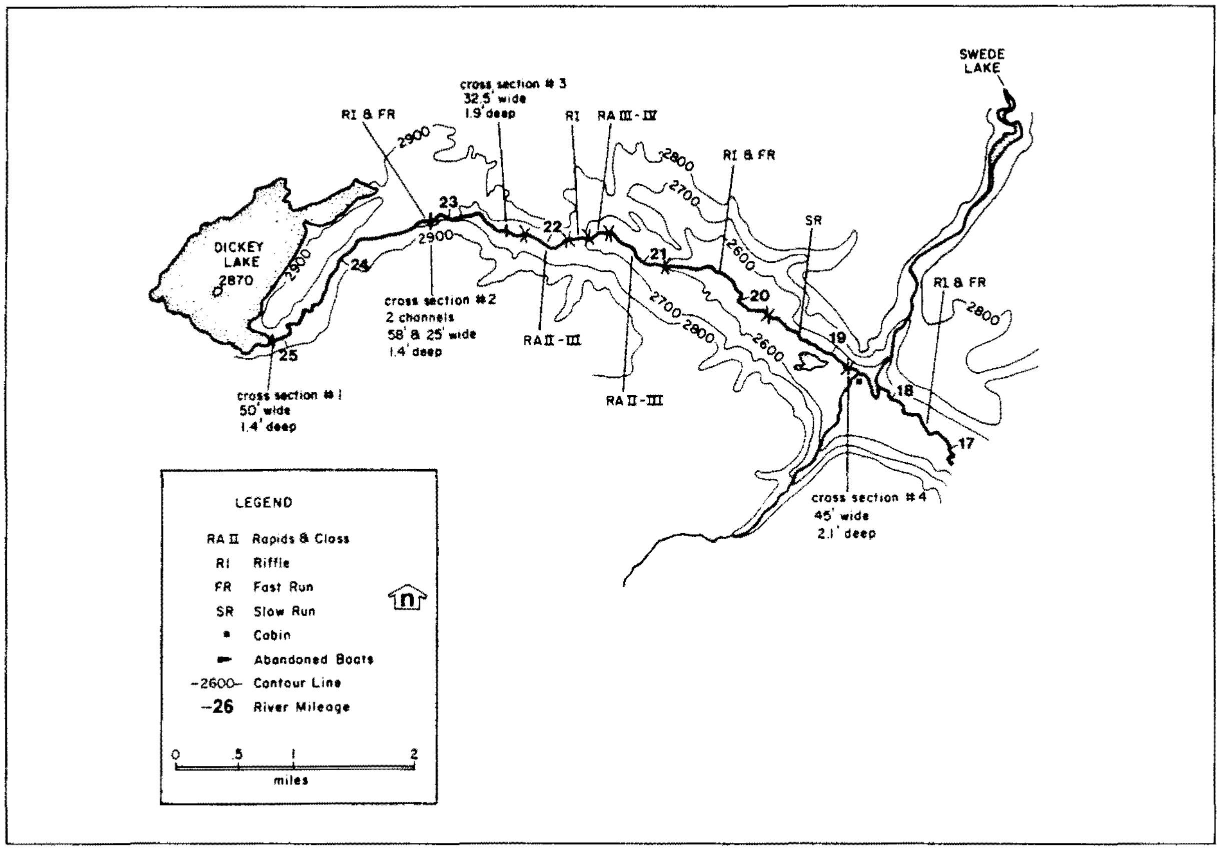
Main Stem		Main Stem	
Map Mile	BLM River Mile	Map Mile	BLM River Mile
81	0	55	26
80	1	54	27
79	2	53	28
78	3	52	29
77	4	51	30
76	5	50	31
75	6	49	32
74	7	48	33
73	8	47	34
72	9	46	35
71	10	45	36
70	11	44	37
69	12	43	38
68	13	42	39
67	14	41	40
66	15	40	41
65	16	39	42
64	17	38	43
63	18	37	44
62	19	36	45
61	20	35	46
60	21	34	47
59	22	33	48
58	23	32	49
57	24	31	50
56	25	30	51

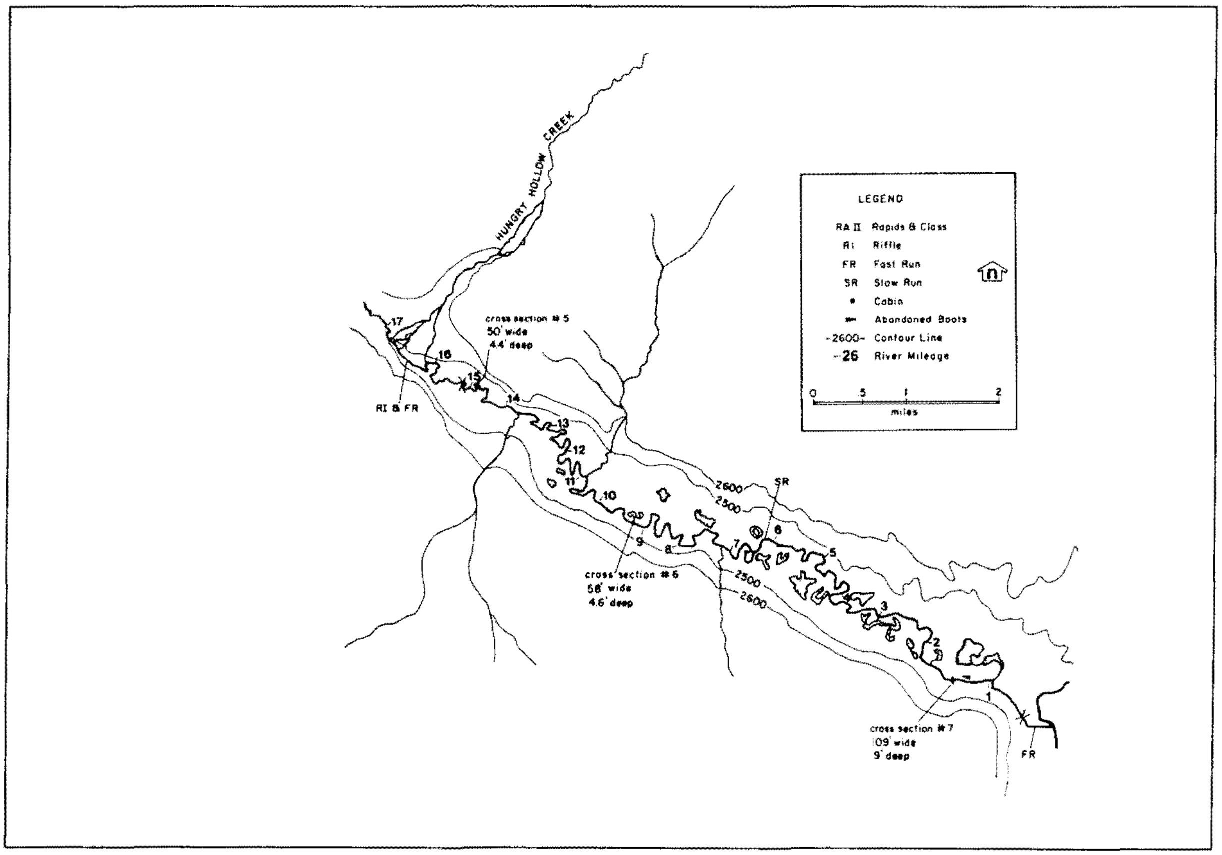
Middle Fork	
Map Mile	BLM River Mile
25	0
24	1
23	2
22	3
21	4
20	5
19	6
18	7
17	8
16	9
15	10
14	11
13	12
12	13
11	14
10	15
9	16
8	17
7	18
6	19
5	20
4	21
3	22
2	23
1	24
0	25

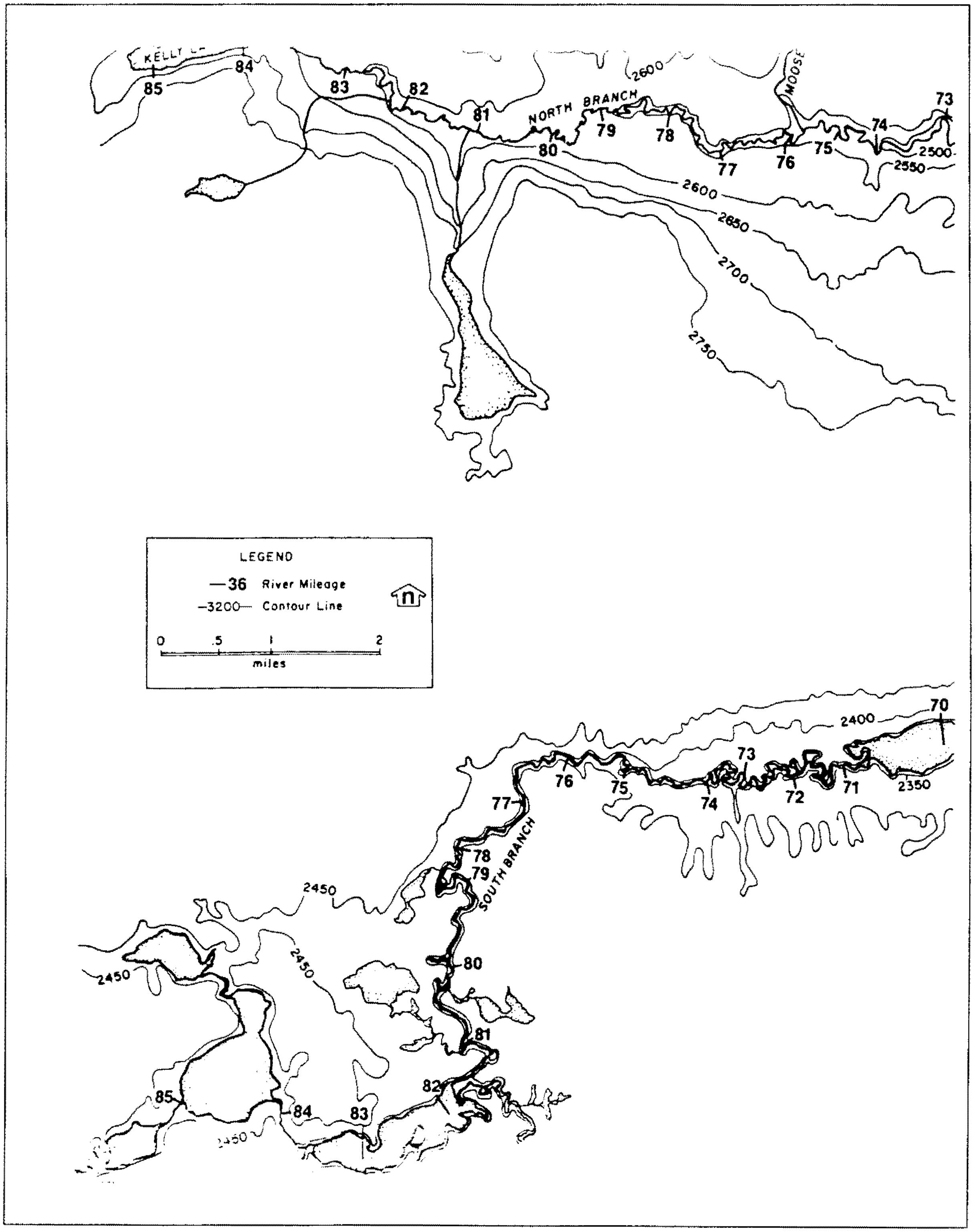
West Fork	
Map Mile	BLM River Mile
84	0
83	1
82	2
81	3
80	4
79	5
78	6
77	7
76	8
75	9
74	10
73	11
72	12
71	13
70	14
69	15
68	16
67	17
66	18
65	19
64	20
63	21
62	22
61	23
60	24
59	25
58	26
57	27
56	28
55	29
54	30
53	31

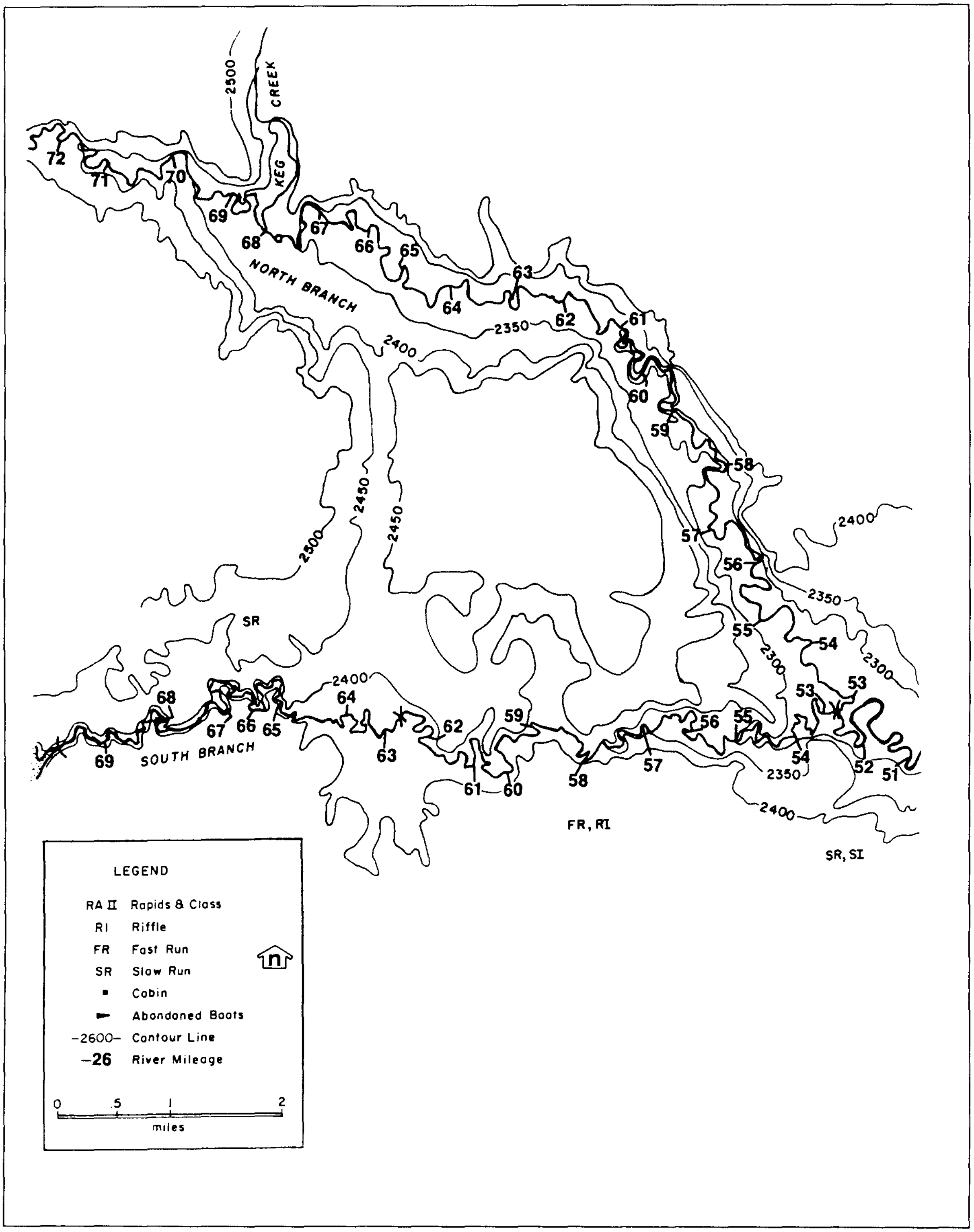
West Fork	
Map Mile	**BLM River Mile**
52	32
51	33
50	34
49	35
48	36
47	37
46	38
45	39
44	40
43	41
42	42
41	43
40	44
39	45
38	46
37	47
36	48
35	49
34	50
33	51
32	52
31	53
30	54
29	55
28	56
27	57
26	58
25	59
24	60
23	61
22	62
21	63

West Fork	
Map Mile	**BLM River Mile**
20	64
19	65
18	66
17	67
16	68
15	69
14	70
13	71
12	72
11	73
10	74
9	75
8	76
7	77
6	78
5	79
4	80
3	81
2	82
1	83
0	84
4	21
3	22
2	23
1	24
0	25

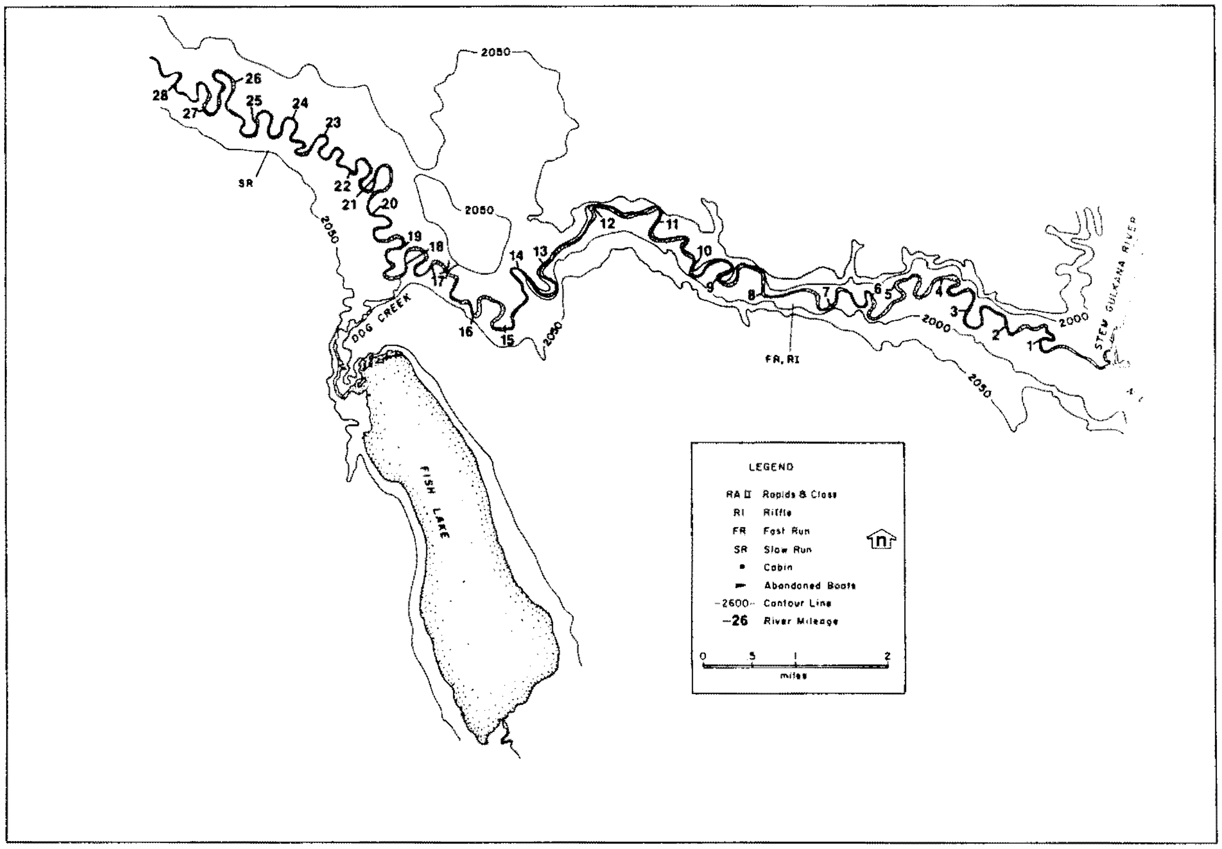

SWEDE LAKE
cross section # 3
32.5' wide
1.9' deep
RI & FR
RI
RA III - IV
RI & FR
SR
RI & FR
DICKEY LAKE
2870
2900
2800
2700
2600
23
22
21
20
19
18
17
24
25
cross section # 2
2 channels
58' & 25' wide
1.4' deep
RA II - III
RA II - III
cross section # 1
50' wide
1.4' deep
cross section # 4
45' wide
2.1' deep
LEGEND
RA II Rapids & Class
RI Riffle
FR Fast Run
SR Slow Run
Cabin
Abandoned Boats
-2600- Contour Line
-26 River Mileage
0 .5 1 2
miles

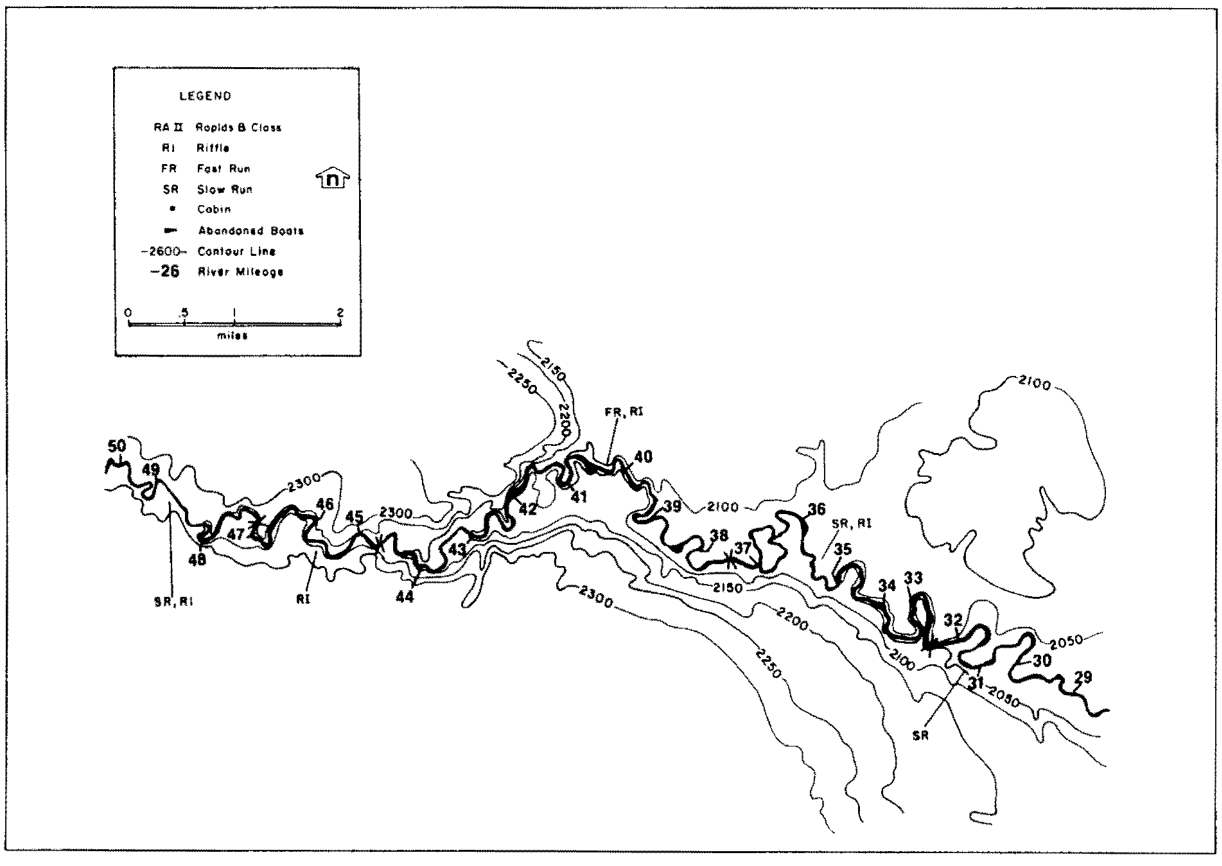

HUNGRY HOLLOW CREEK
17
16
15
14
13
12
11
10
9
8
7
6
5
3
2
1
RI & FR
cross section # 5
50' wide
4.4' deep
cross section # 6
58' wide
4.6' deep
cross section # 7
109' wide
9' deep
SR
FR
2600
2500
LEGEND
RA II Rapids & Class
RI Riffle
FR Fast Run
SR Slow Run
Cabin
Abandoned Boats
-2600- Contour Line
-26 River Mileage
0 .5 1 2
miles

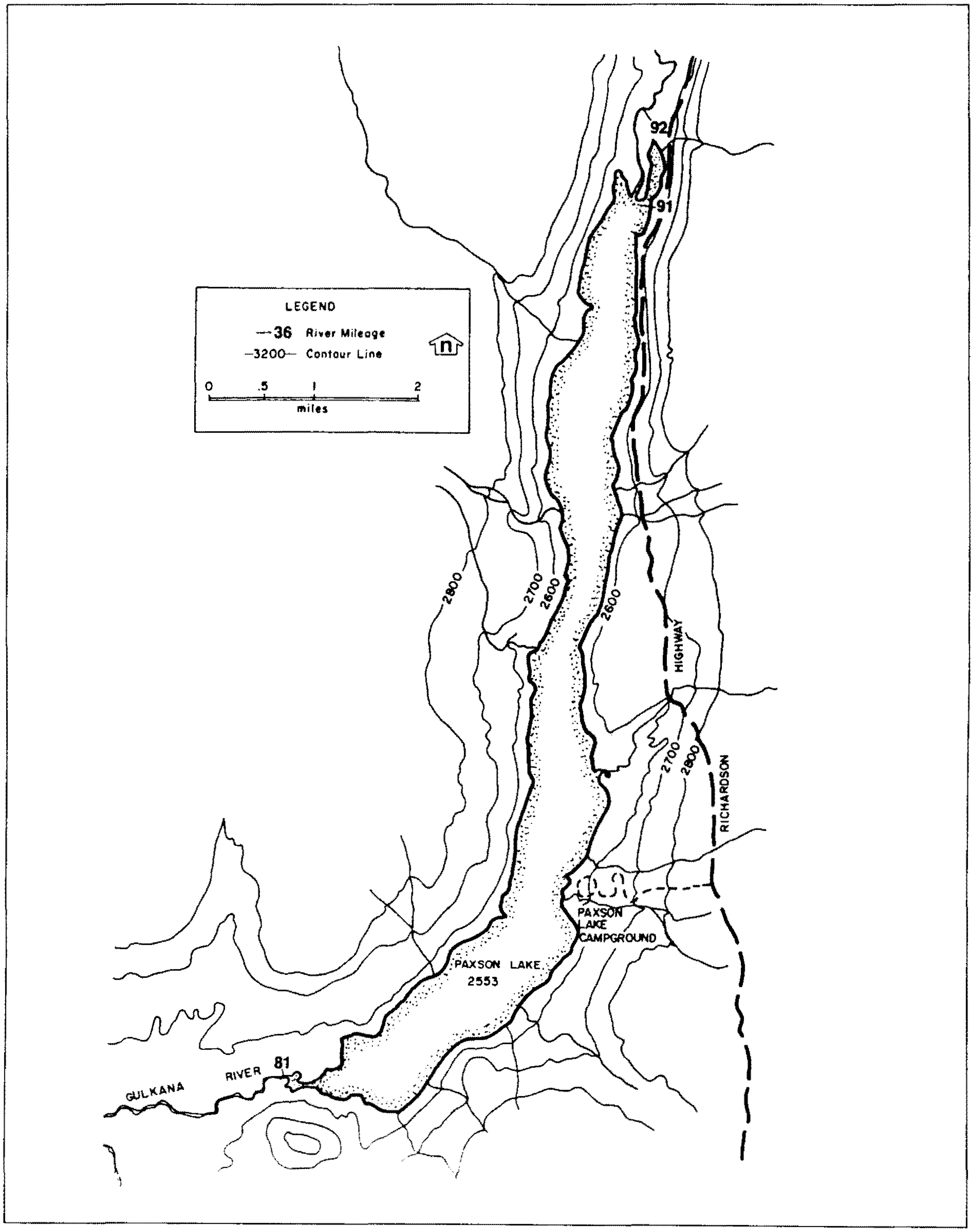

KELLY L.
85
84
83
82
81
NORTH BRANCH
80
79
78
77
76
75
74
73
MOOSE
2600
2500
2550
2650
2700
2750
LEGEND
—36 River Mileage
—3200— Contour Line
0 .5 1 2
miles
70
2400
2350
71
72
73
74
75
76
77
78
79
SOUTH BRANCH
2450
80
81
82
83
84
85

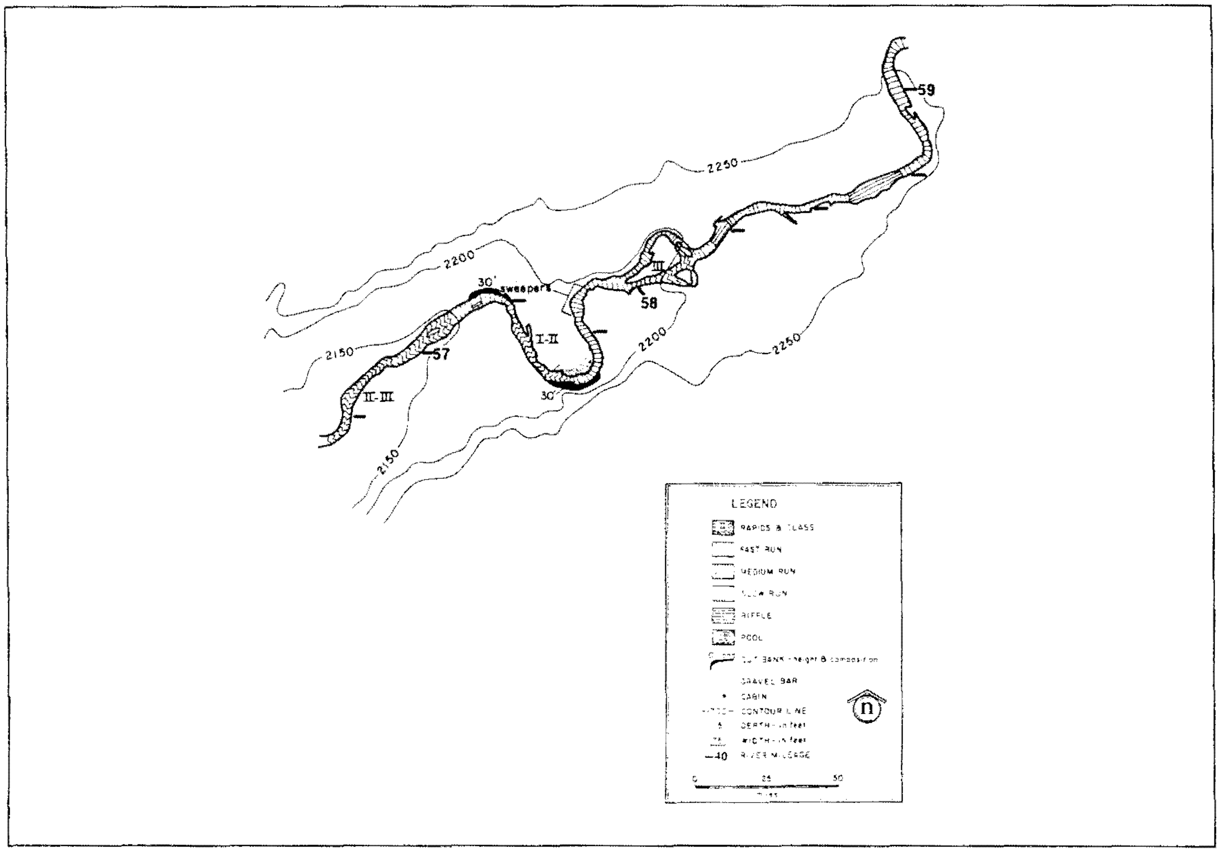


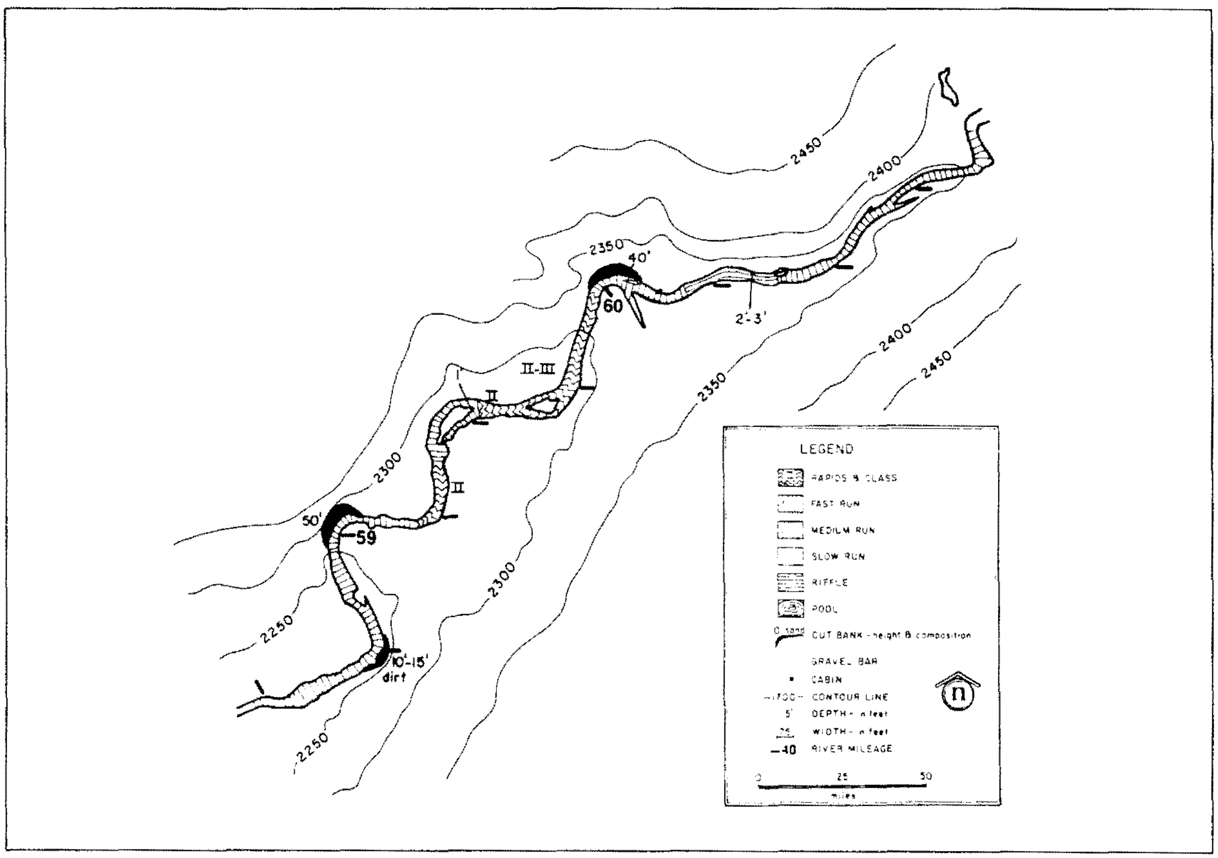
KEG CREEK
NORTH BRANCH
SOUTH BRANCH
2500
2450
2400
2350
2300
SR
FR, RI
SR, SI
LEGEND
RA II Rapids & Class
RI Riffle
FR Fast Run
SR Slow Run
Cabin
Abandoned Boats
-2600- Contour Line
-26 River Mileage
0 .5 1 2
miles

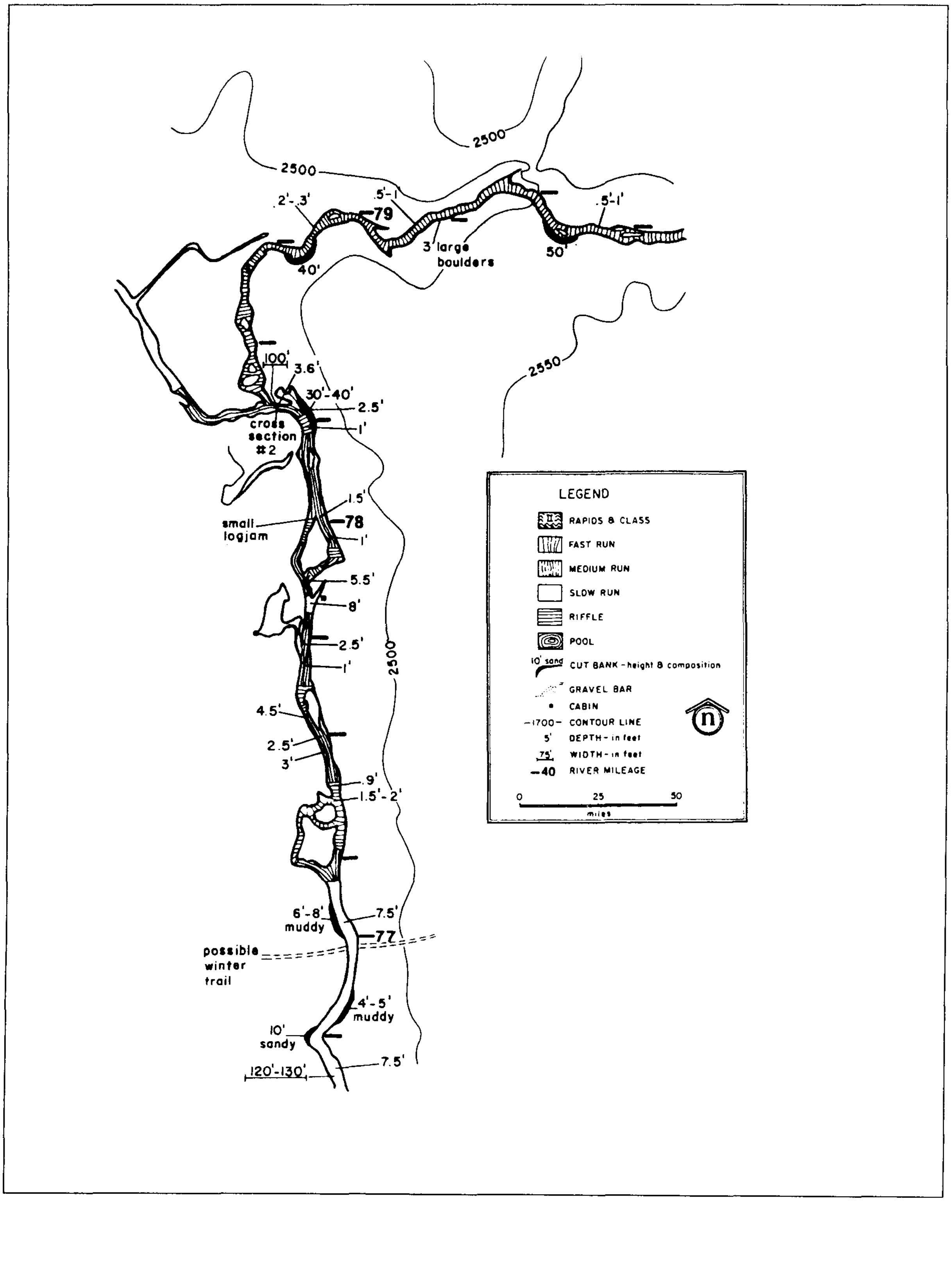

LEGEND
RA II Rapids & Class
RI Riffle
FR Fast Run
SR Slow Run
• Cabin
Abandoned Boats
-2600- Contour Line
-26 River Mileage
0 .5 1 2
miles
FISH LAKE
DOG CREEK
STEM GULKANA RIVER
SR
FR, RI
2050
2000
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28

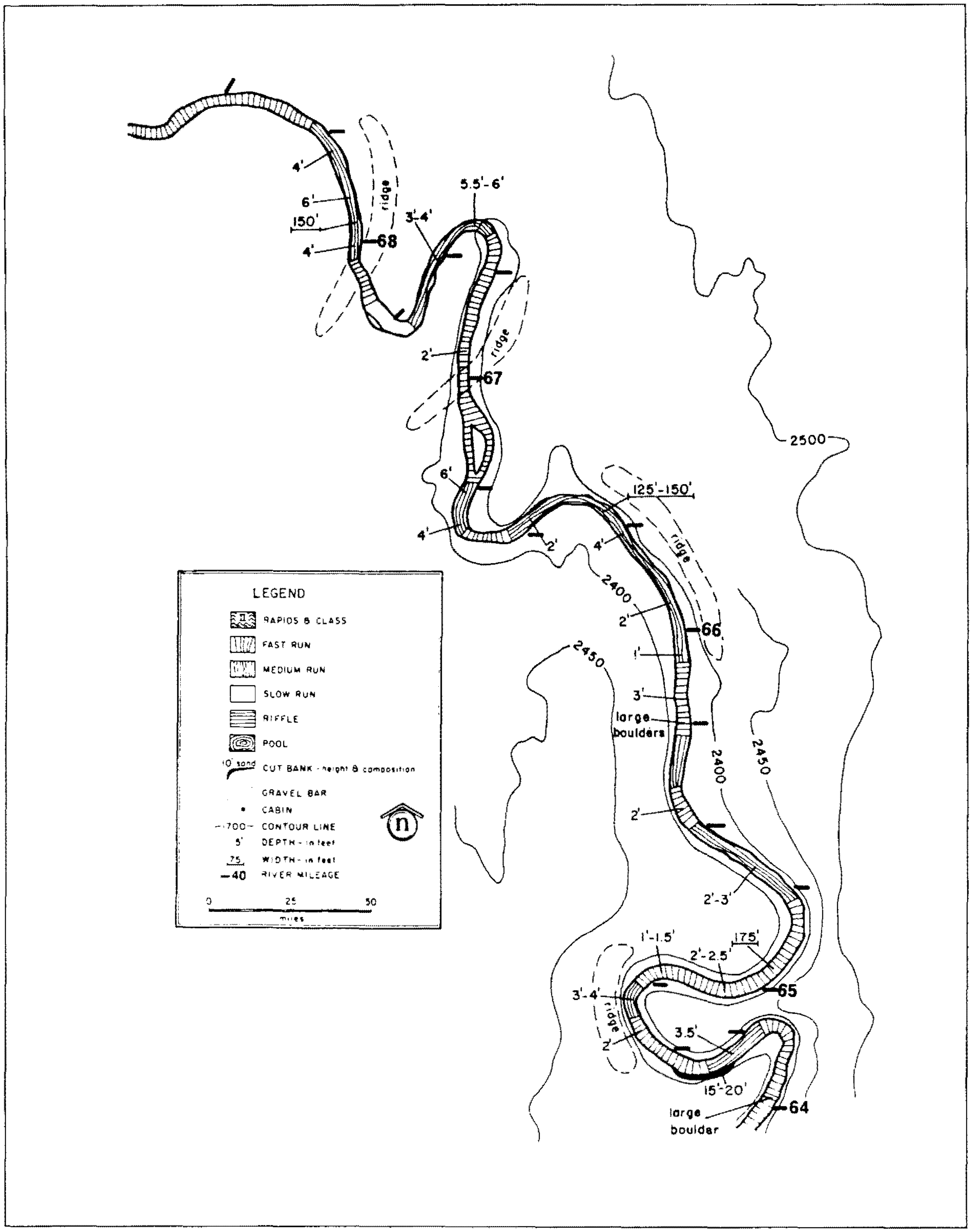

LEGEND
RA II Rapids & Class
RI Riffle
FR Fast Run
SR Slow Run
• Cabin
Abandoned Boats
-2600- Contour Line
-26 River Mileage
0 .5 1 2
miles
FR, RI
SR, RI
SR, RI
RI
SR
2050
2100
2150
2200
2250
2300
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50


LEGEND
36 River Mileage
3200 Contour Line
0 .5 1 2
miles
92
91
2800
2700
2600
2600
HIGHWAY
RICHARDSON
2700
2800
PAXSON LAKE CAMPGROUND
PAXSON LAKE
2553
GULKANA RIVER 81

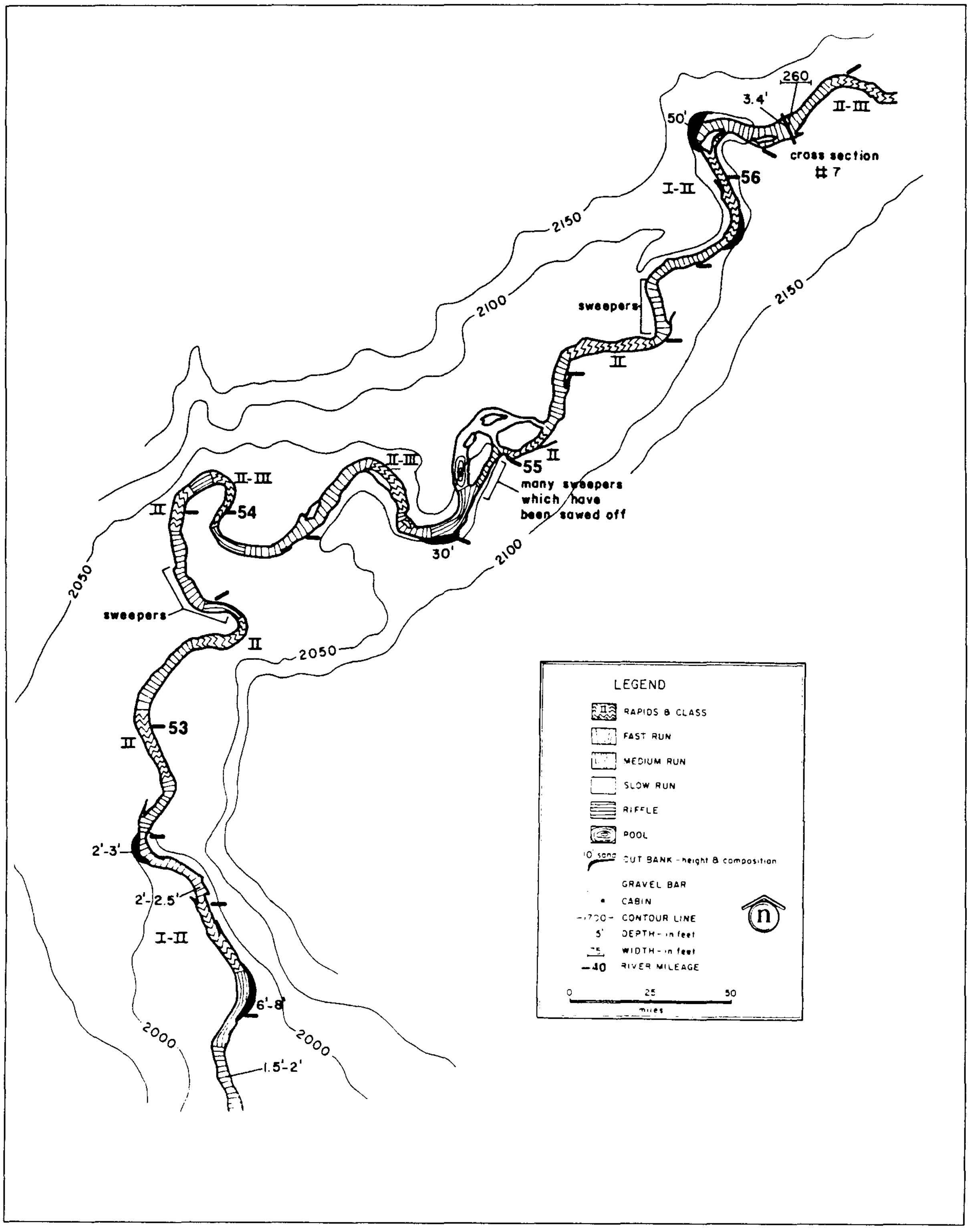

59
2250
2200
30'
sweepers
III
58
I-II
2150
57
II-III
30'
2200
2250
2150
LEGEND
RAPIDS & CLASS
FAST RUN
MEDIUM RUN
SLOW RUN
RIFFLE
POOL
CUT BANK - height & composition
GRAVEL BAR
CABIN
CONTOUR LINE
DEPTH - in feet
WIDTH - in feet
RIVER MILEAGE

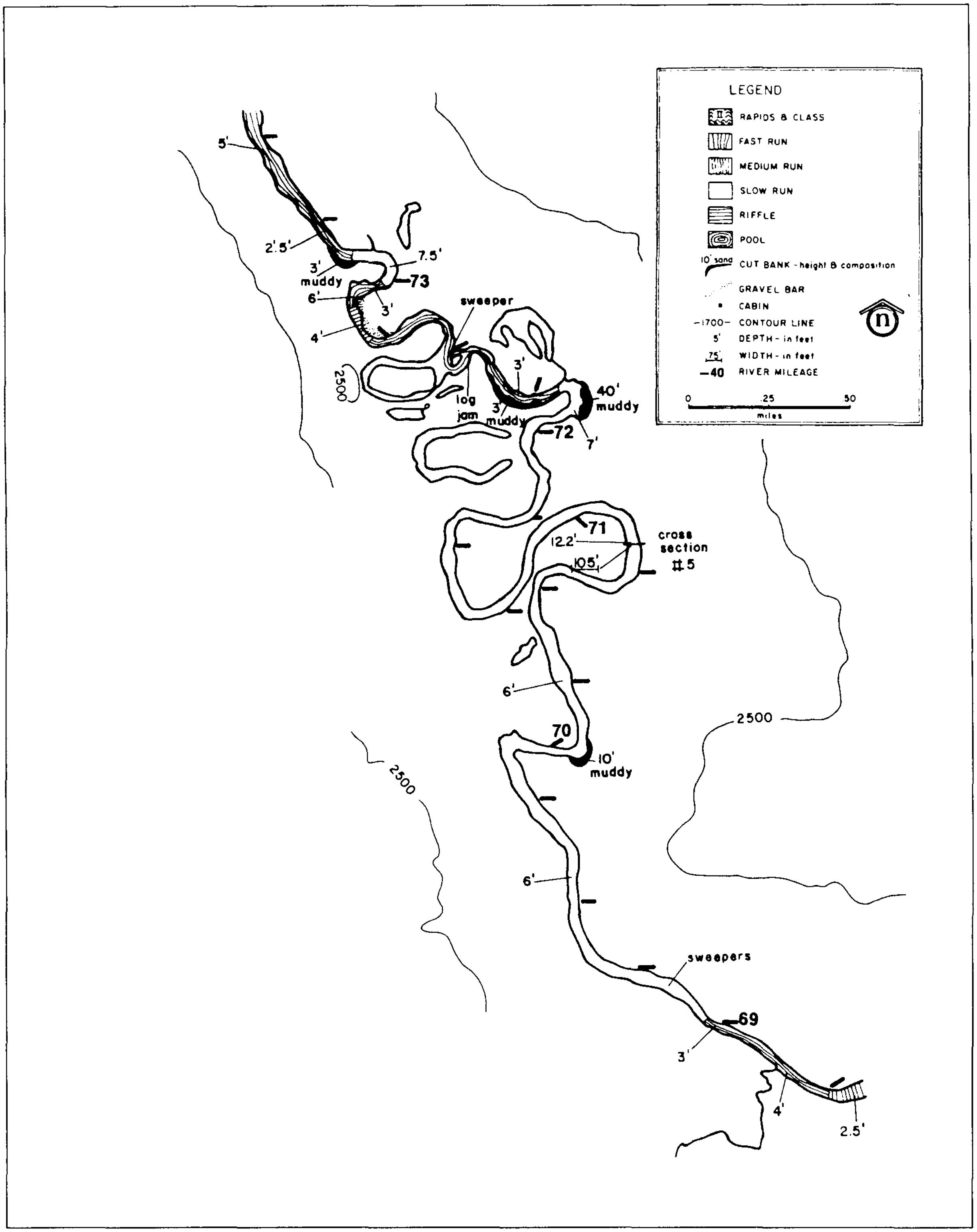

2450
2400
2350
40'
60
2'-3'
II-III
II
2400
2450
2350
2300
II
50'
59
2300
2250
10'-15'
dirt
2250
LEGEND
RAPIDS & CLASS
FAST RUN
MEDIUM RUN
SLOW RUN
RIFFLE
POOL
CUT BANK - height & composition
GRAVEL BAR
CABIN
CONTOUR LINE
DEPTH - in feet
WIDTH - in feet
RIVER MILEAGE
0
25
50
miles

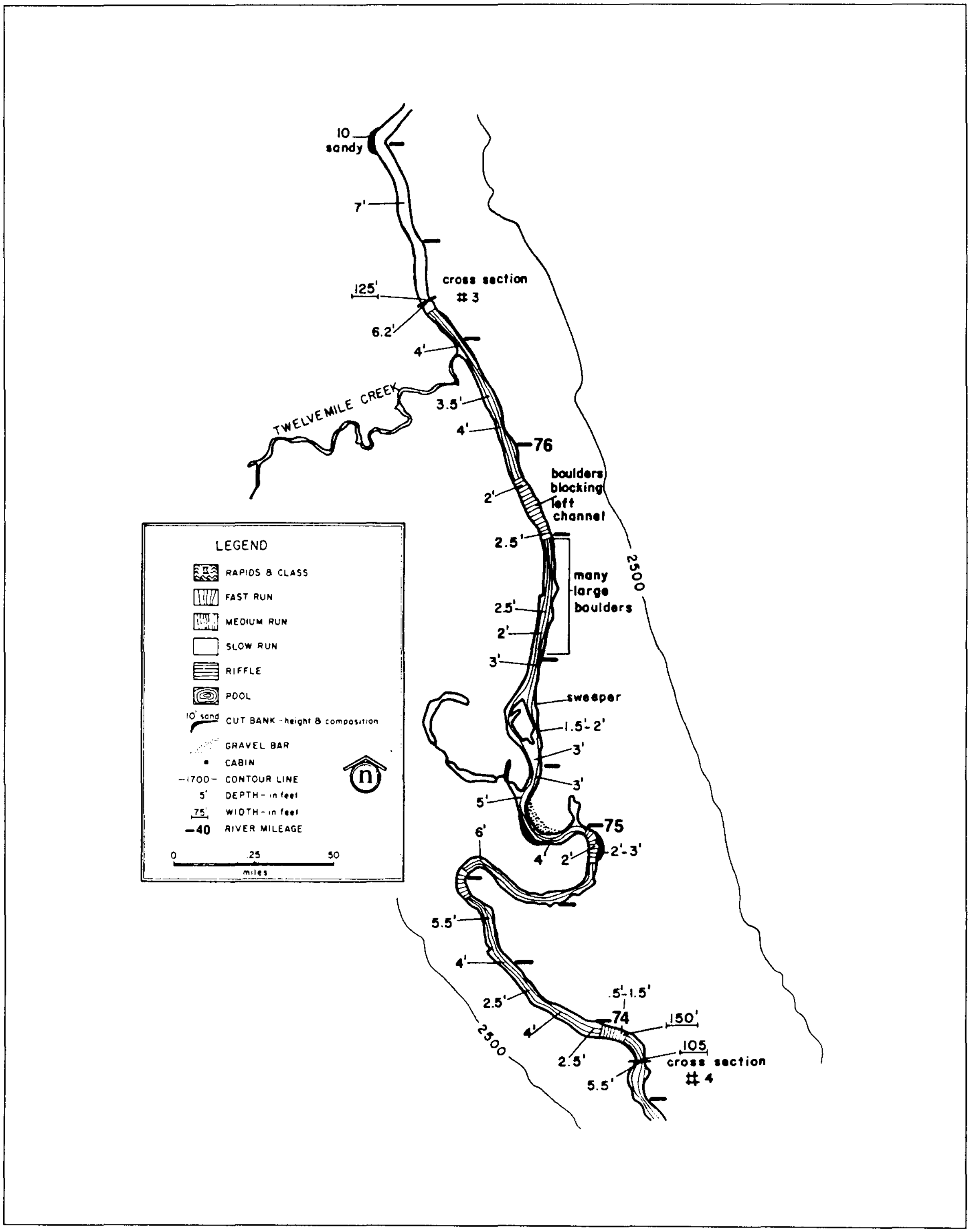

2500
2500
2550
2500
.2'-.3'
.5'-1
79
.5'-1'
40'
3' large
boulders
50'
100'
3.6'
30'-40'
2.5'
cross
section
#2
1'
1.5'
small
logjam
78
1'
5.5'
8'
2.5'
1'
4.5'
2.5'
3'
.9'
1.5'-2'
6'-8'
muddy
7.5'
77
possible
winter
trail
4'-5'
muddy
10'
sandy
7.5'
120'-130'
LEGEND
RAPIDS & CLASS
FAST RUN
MEDIUM RUN
SLOW RUN
RIFFLE
POOL
10' sand
CUT BANK - height & composition
GRAVEL BAR
CABIN
-1700- CONTOUR LINE
5' DEPTH - in feet
75' WIDTH - in feet
-40 RIVER MILEAGE
0
25
50
miles

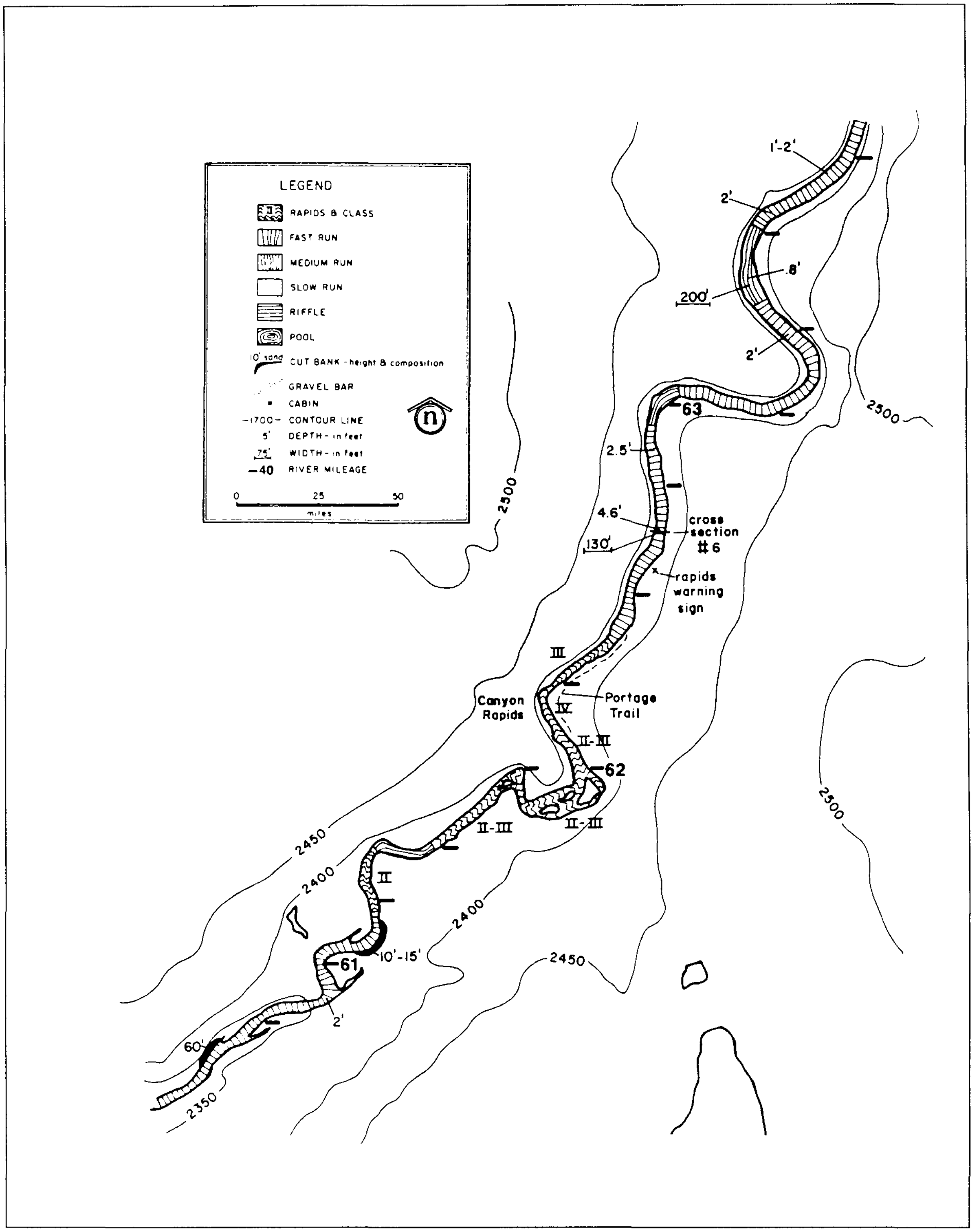


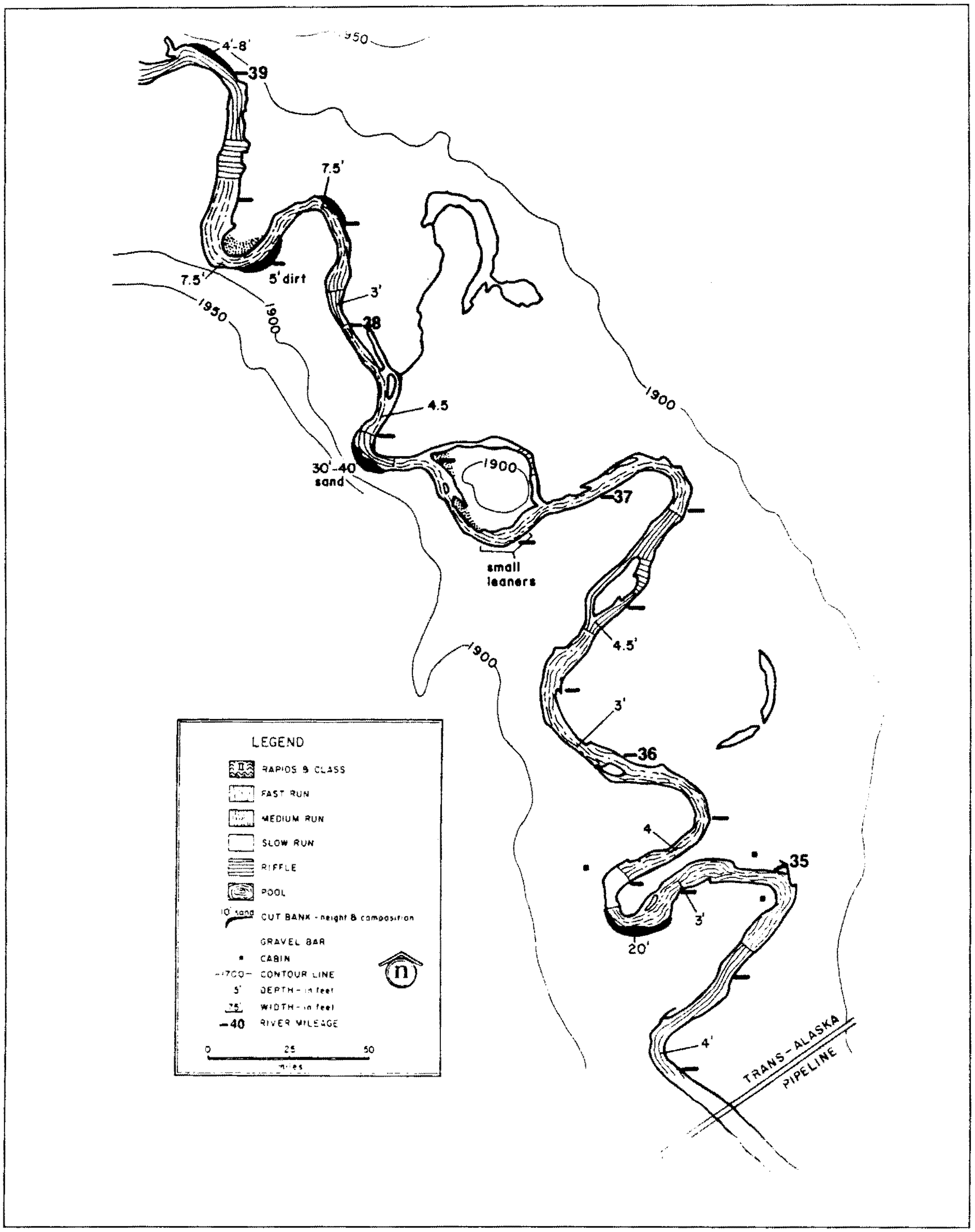
LEGEND
RAPIDS & CLASS
FAST RUN
MEDIUM RUN
SLOW RUN
RIFFLE
POOL
10' sand
CUT BANK - height & composition
GRAVEL BAR
CABIN
-700- CONTOUR LINE
5' DEPTH - in feet
75 WIDTH - in feet
-40 RIVER MILEAGE
0 25 50
miles
n
ridge
4'
6'
150'
68
3'-4'
5.5'-6'
2'
67
6'
4'
125'-150'
2'
4'
2400
2'
66
2450
1'
3'
large boulders
2400
2450
2500
2'
2'-3'
1'-1.5'
2'-2.5'
175'
65
3'-4'
2'
3.5'
15'-20'
large boulder
64


260
3.4'
50'
II-III
cross section
7
56
I-II
2150
2100
sweepers
2150
II
II-III
55
II
many sweepers
which have
been sawed off
II-III
II
54
30'
2100
2050
sweepers
II
2050
53
II
2'-3'
2'-2.5'
I-II
6'-8'
2000
2000
1.5'-2'
LEGEND
RAPIDS & CLASS
FAST RUN
MEDIUM RUN
SLOW RUN
RIFFLE
POOL
CUT BANK - height & composition
GRAVEL BAR
CABIN
CONTOUR LINE
5'
DEPTH - in feet
WIDTH - in feet
—40
RIVER MILEAGE
0
25
50
miles

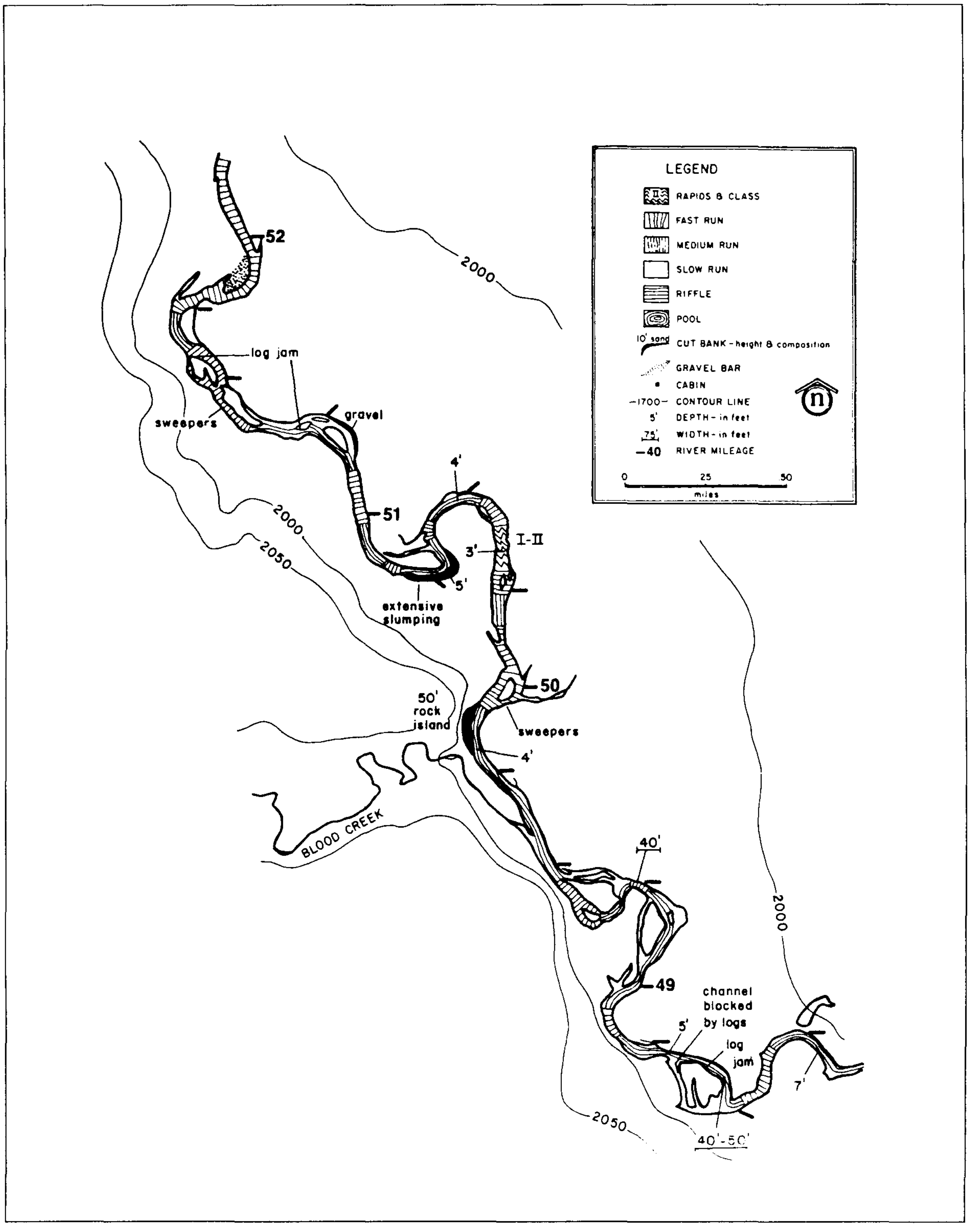

LEGEND
RAPIDS & CLASS
FAST RUN
MEDIUM RUN
SLOW RUN
RIFFLE
POOL
10' sand CUT BANK - height & composition
GRAVEL BAR
CABIN
-1700- CONTOUR LINE
5' DEPTH - in feet
75' WIDTH - in feet
-40 RIVER MILEAGE
0 .25 .50
miles
5'
2.5'
7.5'
3'
muddy
73
6'
3'
4'
sweeper
2500
log
jam
3'
muddy
3'
40'
muddy
72
7'
71
12.2'
105'
cross
section
#5
6'
70
10'
muddy
2500
2500
6'
sweepers
69
3'
4'
2.5'

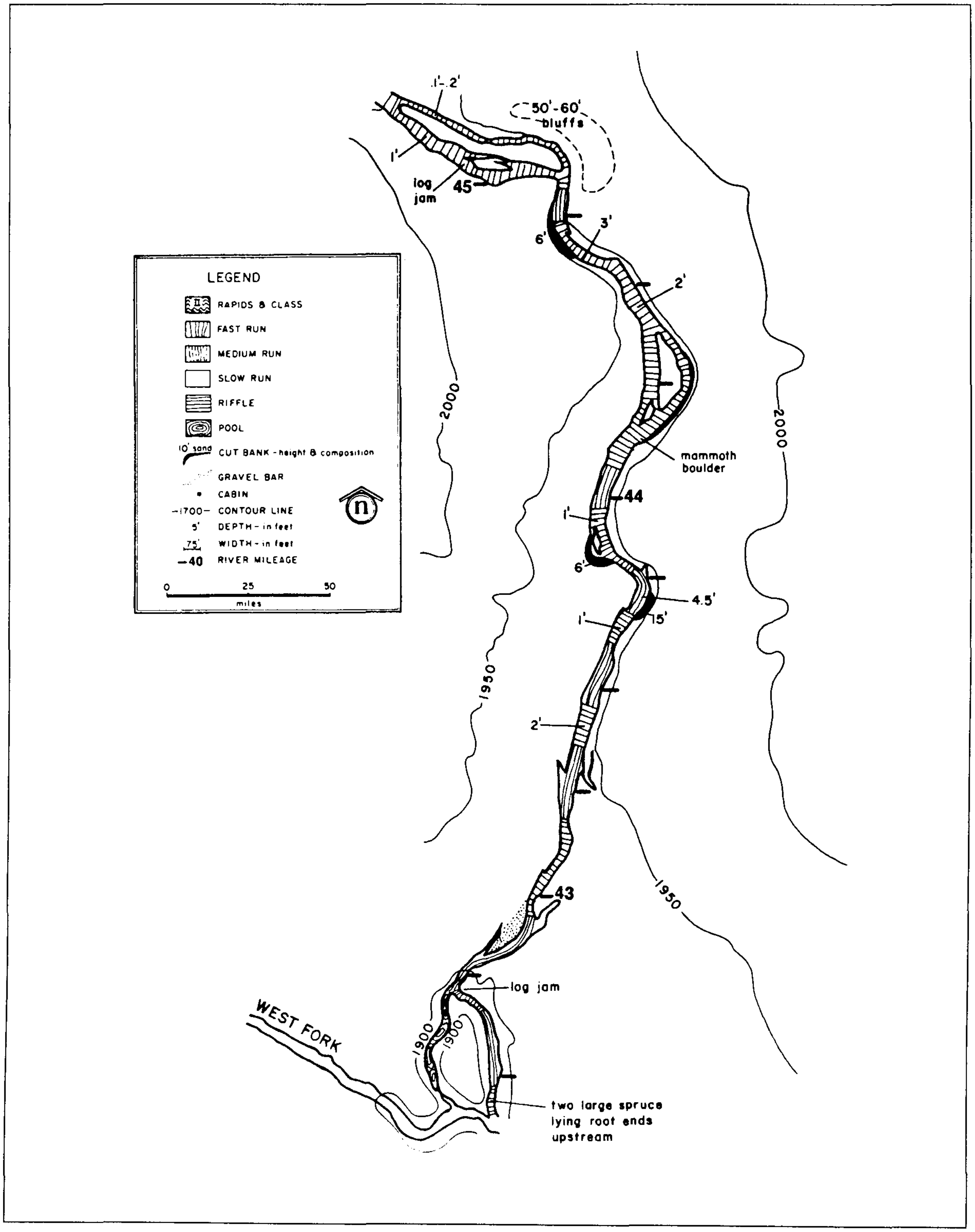

10
sandy
7'
125'
cross section
3
6.2'
4'
TWELVEMILE CREEK
3.5'
4'
76
boulders
blocking
left
channel
2'
2.5'
many
large
boulders
2.5'
2'
3'
2500
sweeper
1.5'-2'
3'
3'
5'
75
6'
4'
2'
2'-3'
5.5'
4'
2.5'
4'
.5'-1.5'
74
150'
105
cross section
4
2.5'
5.5'
2500
LEGEND
RAPIDS & CLASS
FAST RUN
MEDIUM RUN
SLOW RUN
RIFFLE
POOL
10' sand
CUT BANK - height & composition
GRAVEL BAR
CABIN
-1700- CONTOUR LINE
5' DEPTH - in feet
75' WIDTH - in feet
-40 RIVER MILEAGE
0
.25
.50
miles
n


LEGEND
RAPIDS & CLASS
FAST RUN
MEDIUM RUN
SLOW RUN
RIFFLE
POOL
10' sand CUT BANK - height & composition
GRAVEL BAR
CABIN
-1700- CONTOUR LINE
5' DEPTH - in feet
75' WIDTH - in feet
-40 RIVER MILEAGE
0 25 50
miles
1'-2'
2'
.8'
200'
2'
2500
63
2.5'
2500
4.6'
cross section #6
130'
rapids warning sign
III
Canyon Rapids
Portage Trail
IV
II-III
62
2500
2450
II-III
II-III
2400
II
2400
10'-15'
2450
61
2'
60'
2350

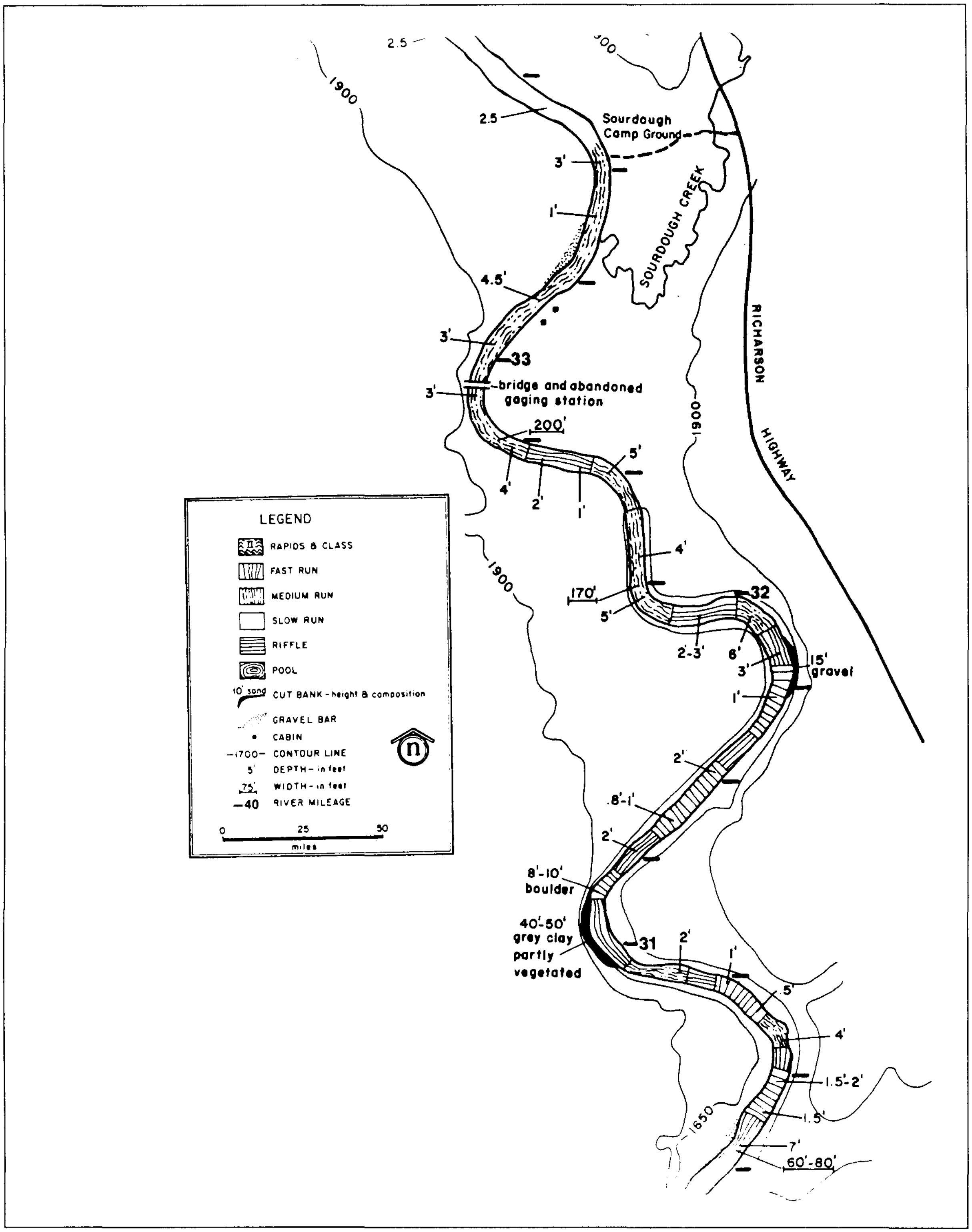


4'-8'
39
7.5'
7.5'
5' dirt
3'
1950
1900
28
4.5
30'-40
sand
1900
37
small
leaners
1900
4.5'
1900
3'
36
4
35
3'
20'
4'
TRANS-ALASKA
PIPELINE
LEGEND
RAPIDS & CLASS
FAST RUN
MEDIUM RUN
SLOW RUN
RIFFLE
POOL
10' sand
CUT BANK - height & composition
GRAVEL BAR
CABIN
CONTOUR LINE
DEPTH - in feet
WIDTH - in feet
RIVER MILEAGE
0
25
50
miles

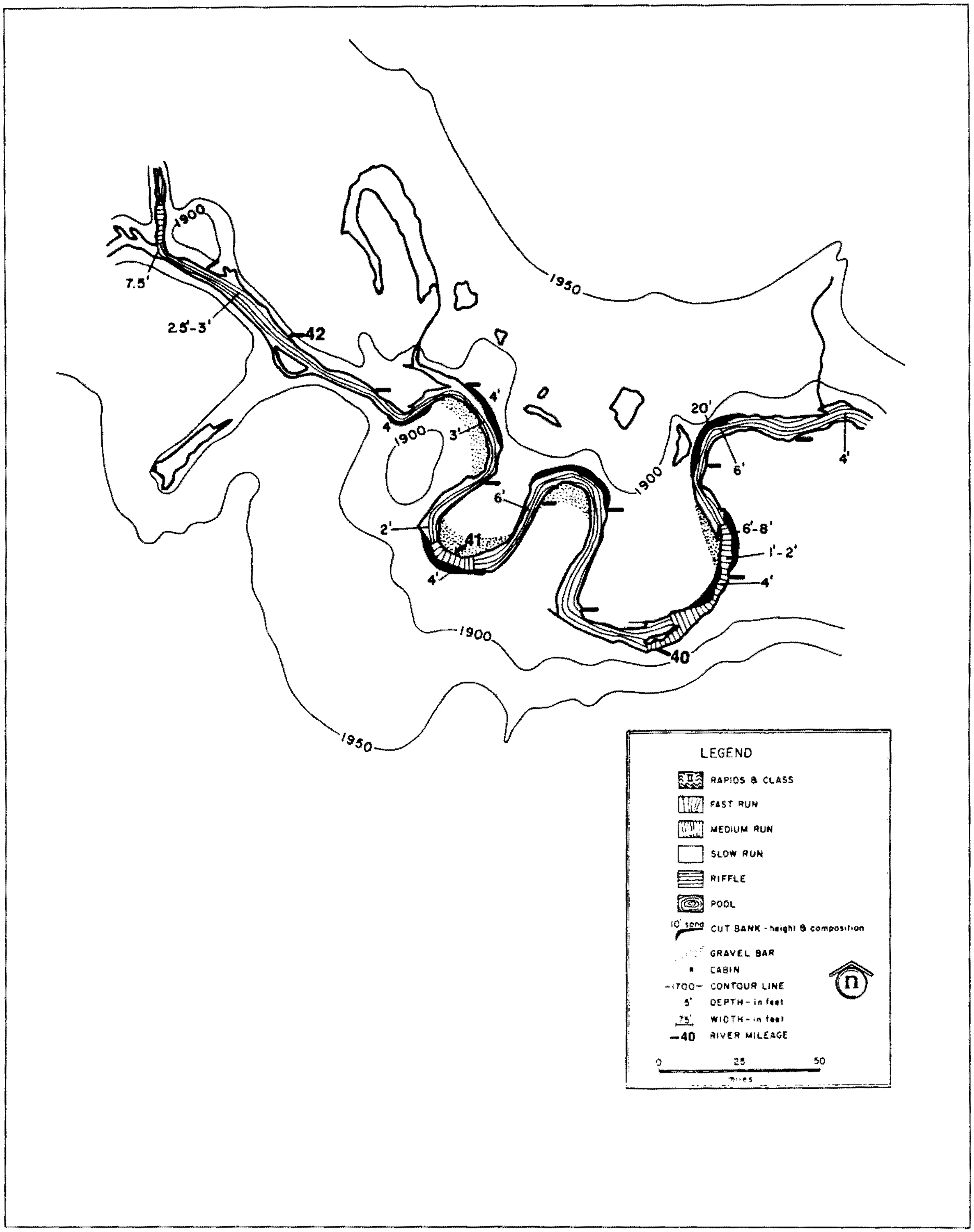

52
log jam
gravel
sweepers
4'
51
I-II
3'
5'
extensive slumping
2000
2050
50
50' rock island
sweepers
4'
BLOOD CREEK
40'
49
channel blocked by logs
5'
log jam
7'
40'-50'
2050
2000
LEGEND
RAPIDS & CLASS
FAST RUN
MEDIUM RUN
SLOW RUN
RIFFLE
POOL
10' sand
CUT BANK - height & composition
GRAVEL BAR
CABIN
-1700- CONTOUR LINE
5' DEPTH - in feet
75' WIDTH - in feet
-40 RIVER MILEAGE
0
25
50
miles

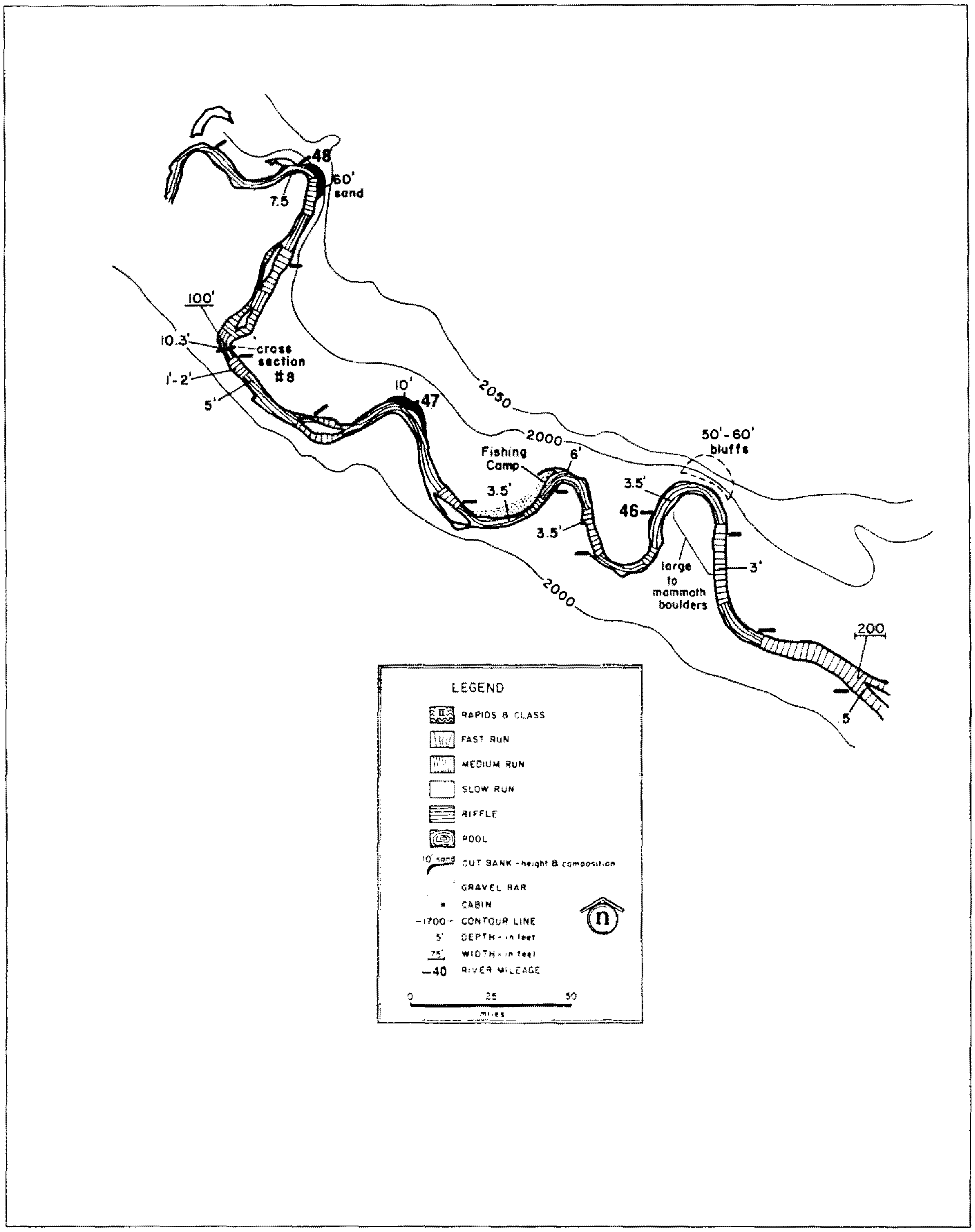


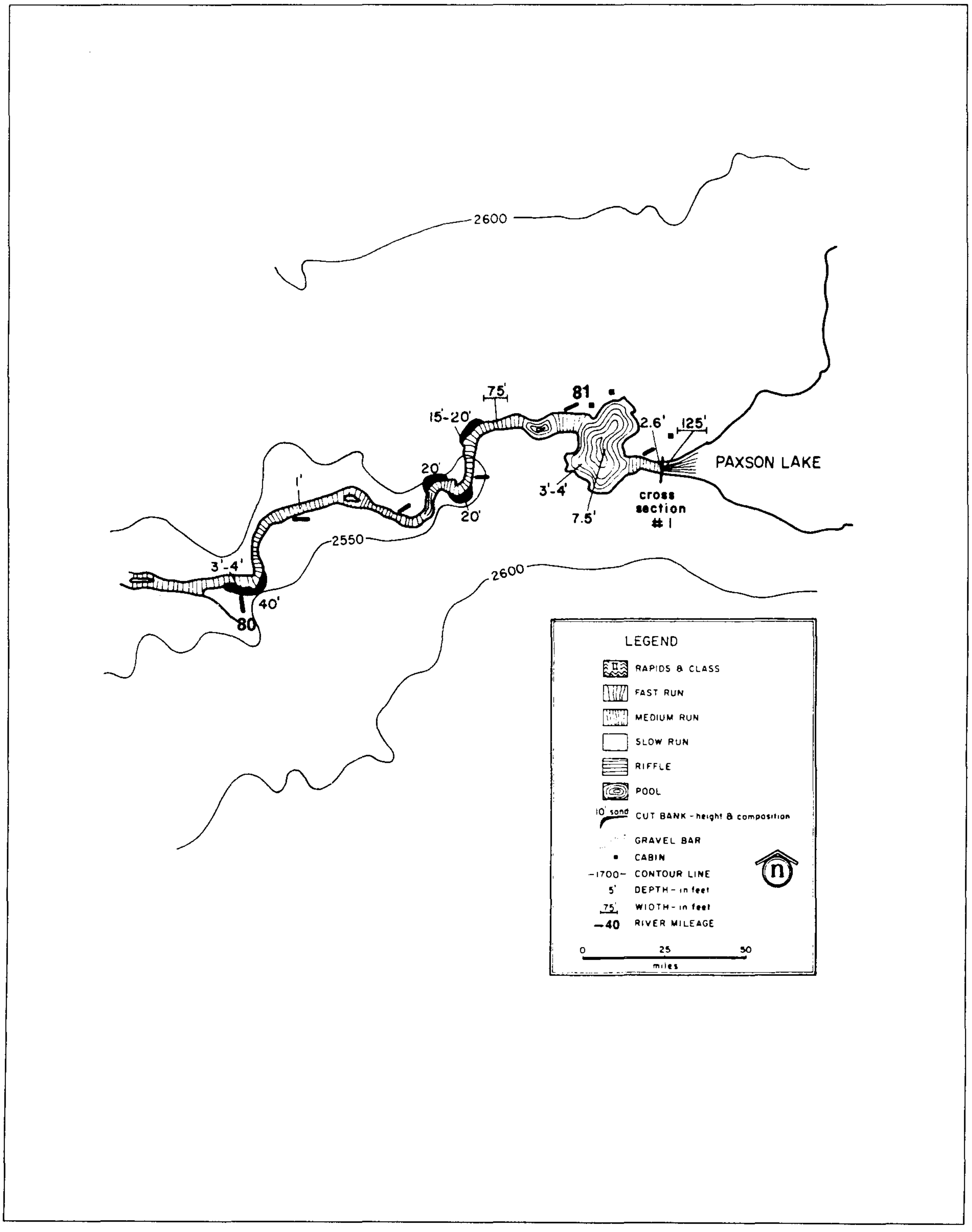
LEGEND
RAPIDS & CLASS
FAST RUN
MEDIUM RUN
SLOW RUN
RIFFLE
POOL
CUT BANK - height & composition
GRAVEL BAR
CABIN
CONTOUR LINE
DEPTH - in feet
WIDTH - in feet
RIVER MILEAGE
miles
50'-60' bluffs
log jam
45
44
43
mammoth boulder
log jam
WEST FORK
two large spruce lying root ends upstream
2000
1950
1900



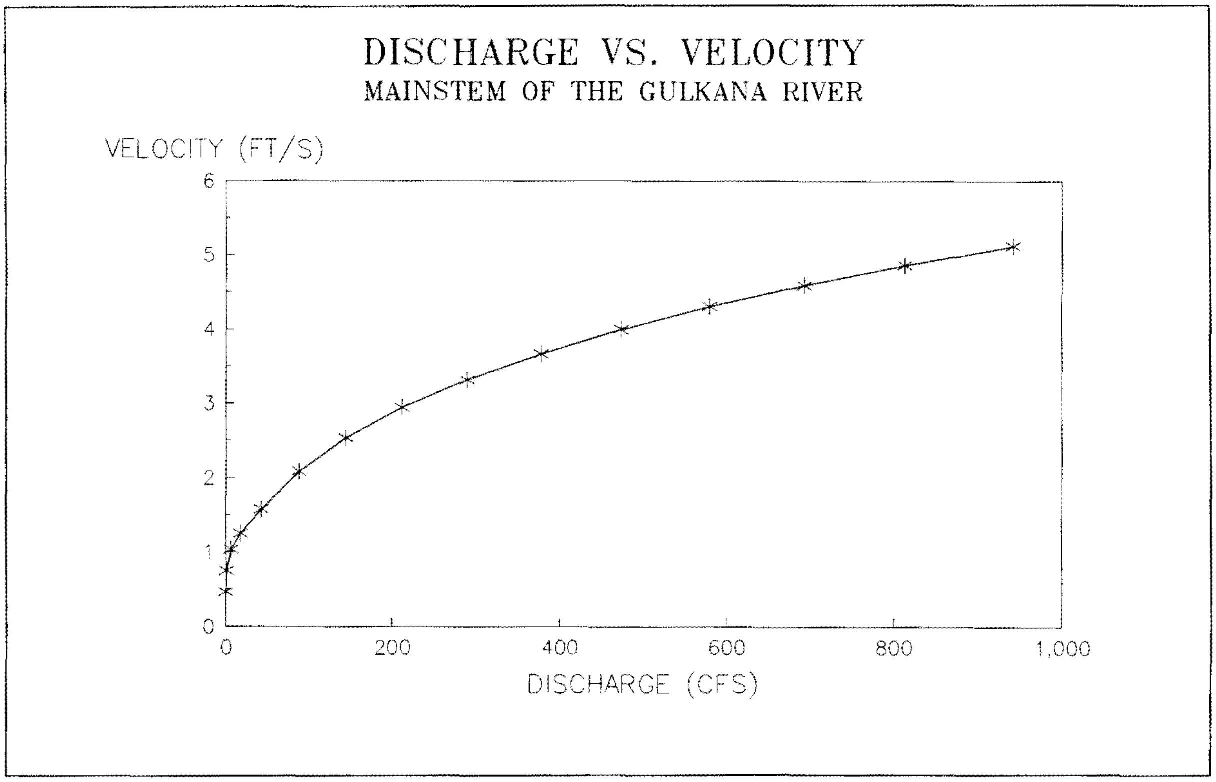
Sourdough Camp Ground
SOURDOUGH CREEK
RICHARSON HIGHWAY
bridge and abandoned gaging station
33
32
31
200'
170'
15' gravel
8'-10' boulder
40'-50' grey clay partly vegetated
60'-80'
1900
1650
LEGEND
RAPIDS & CLASS
FAST RUN
MEDIUM RUN
SLOW RUN
RIFFLE
POOL
CUT BANK - height & composition
GRAVEL BAR
CABIN
CONTOUR LINE
DEPTH - in feet
WIDTH - in feet
RIVER MILEAGE
miles

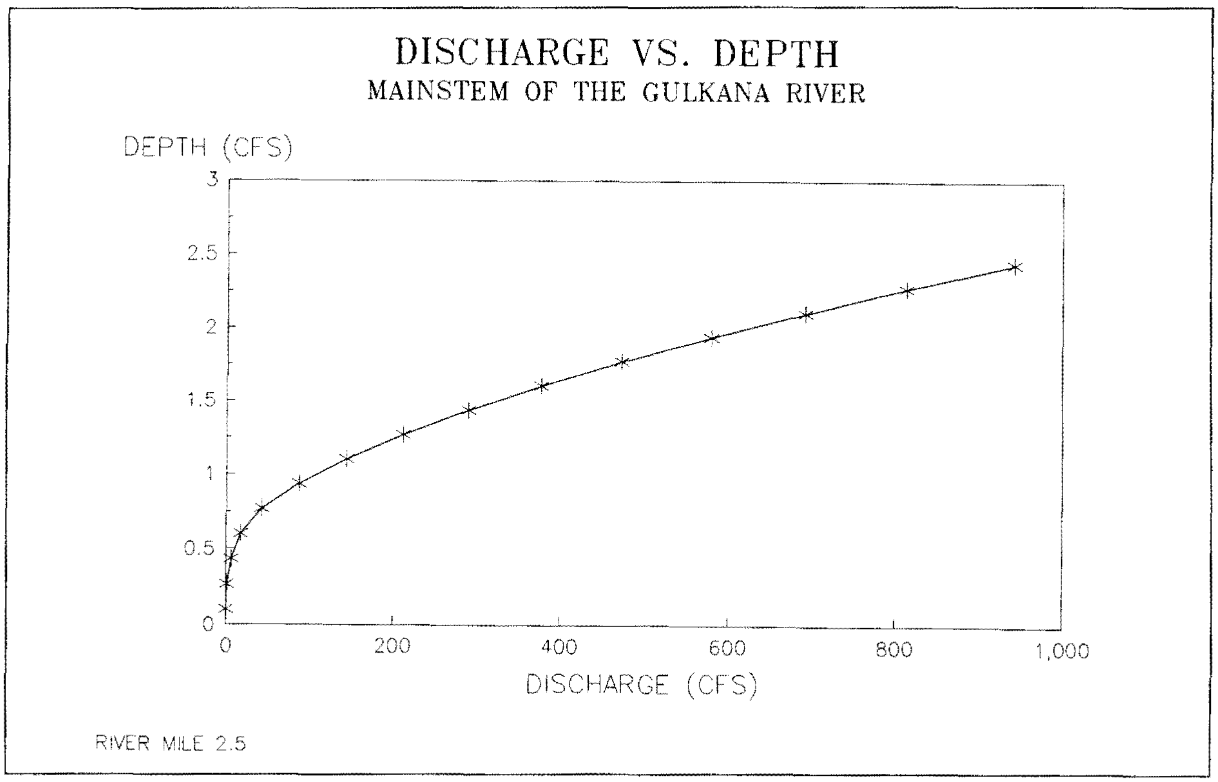

1900
7.5'
2.5'-3'
42
1950
4'
4
1900
3'
20'
6'
4'
6'
1900
2'
41
6'-8'
1'-2'
4'
4'
1900
40
1950
LEGEND
RAPIDS & CLASS
FAST RUN
MEDIUM RUN
SLOW RUN
RIFFLE
POOL
10' sand
CUT BANK - height & composition
GRAVEL BAR
CABIN
1700
CONTOUR LINE
5'
DEPTH - in feet
75'
WIDTH - in feet
40
RIVER MILEAGE
0
25
50

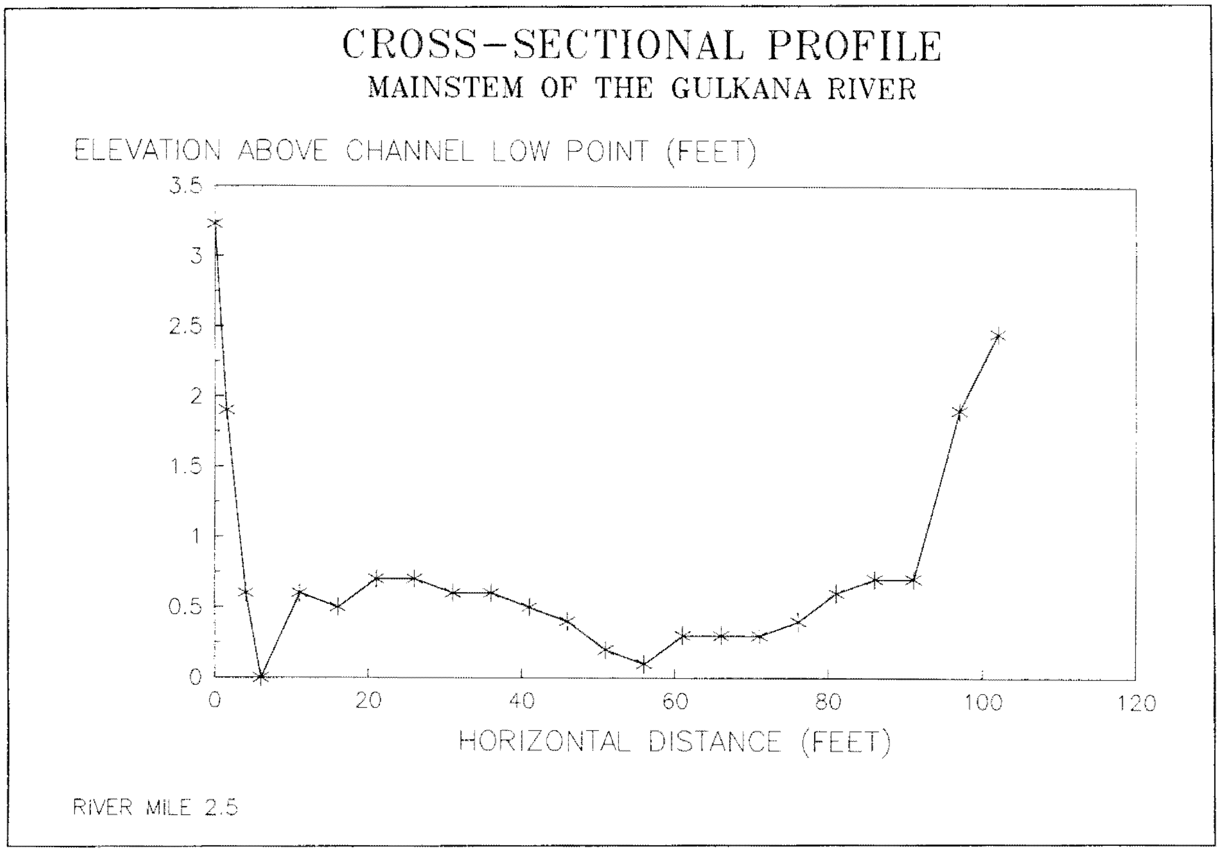

48
60'
sand
7.5
100'
10.3'
cross
section
#8
1'-2'
5'
10'
47
2050
2000
Fishing
Camp
6'
3.5'
3.5'
50'-60'
bluffs
3.5'
46
large
to
mammoth
boulders
3'
2000
200
5
LEGEND
RAPIDS & CLASS
FAST RUN
MEDIUM RUN
SLOW RUN
RIFFLE
POOL
CUT BANK - height & composition
GRAVEL BAR
CABIN
CONTOUR LINE
DEPTH - in feet
WIDTH - in feet
RIVER MILEAGE
0
25
50
miles

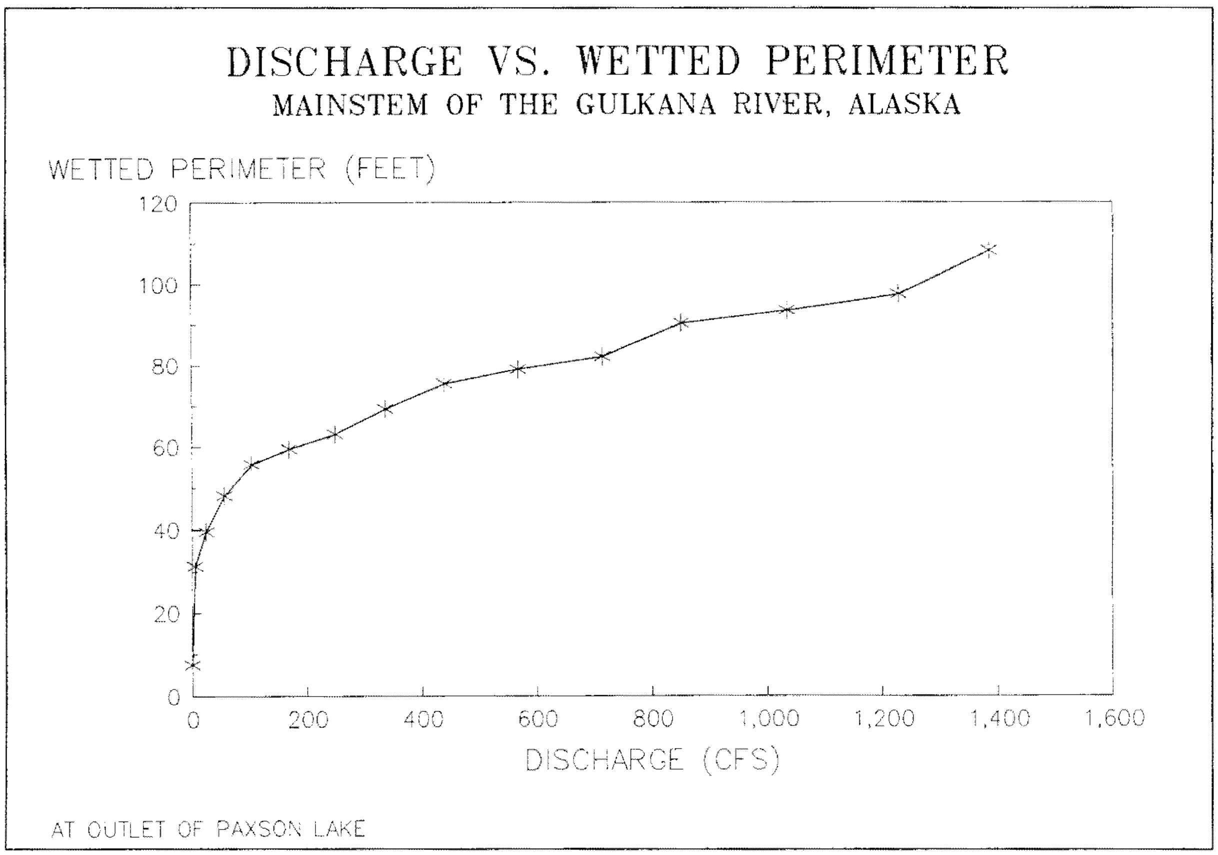

2600
2550
2600
75'
81
15'-20'
20'
20'
1'
3'-4'
40'
80
2.6'
125'
3'-4'
7.5'
cross section #1
PAXSON LAKE
LEGEND
RAPIDS & CLASS
FAST RUN
MEDIUM RUN
SLOW RUN
RIFFLE
POOL
CUT BANK - height & composition
GRAVEL BAR
CABIN
-1700- CONTOUR LINE
5' DEPTH - in feet
75' WIDTH - in feet
-40 RIVER MILEAGE
0 25 50
miles

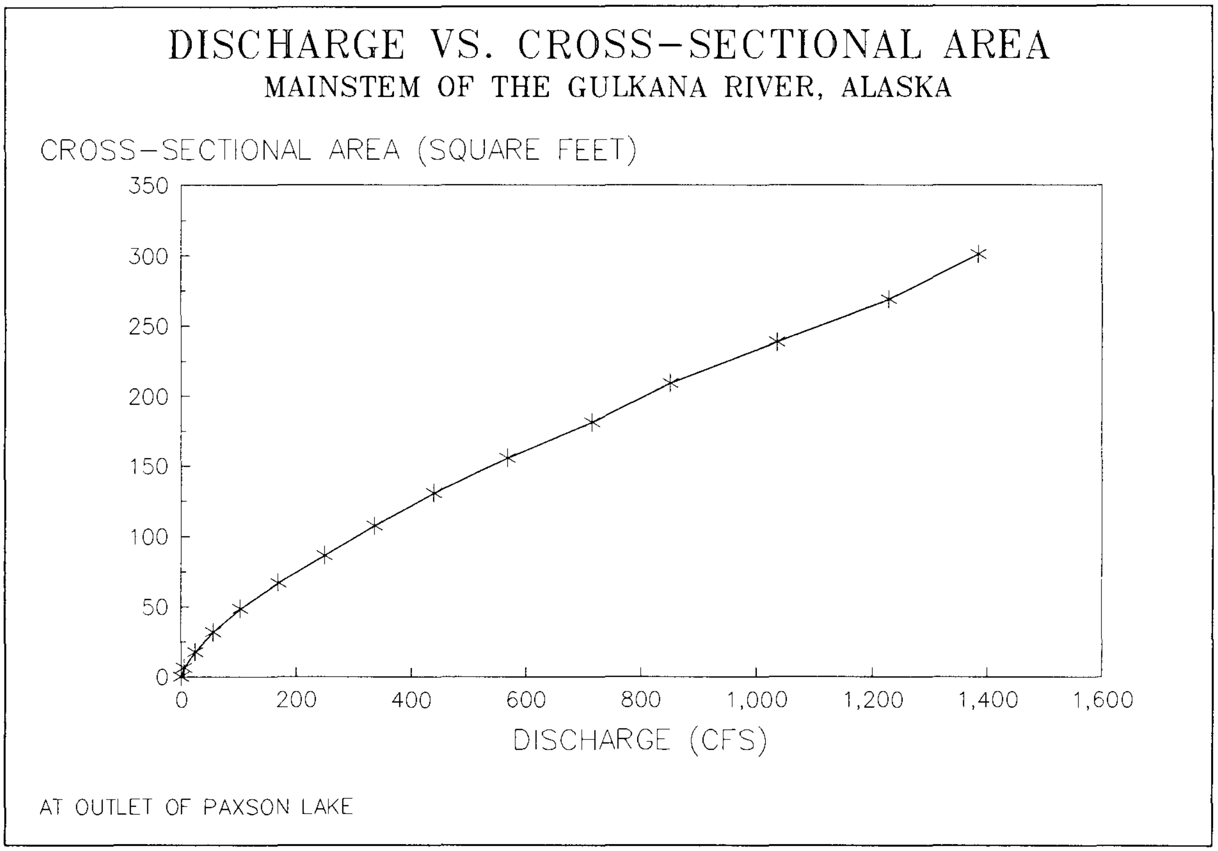
Appendix D
Hydrologic Data

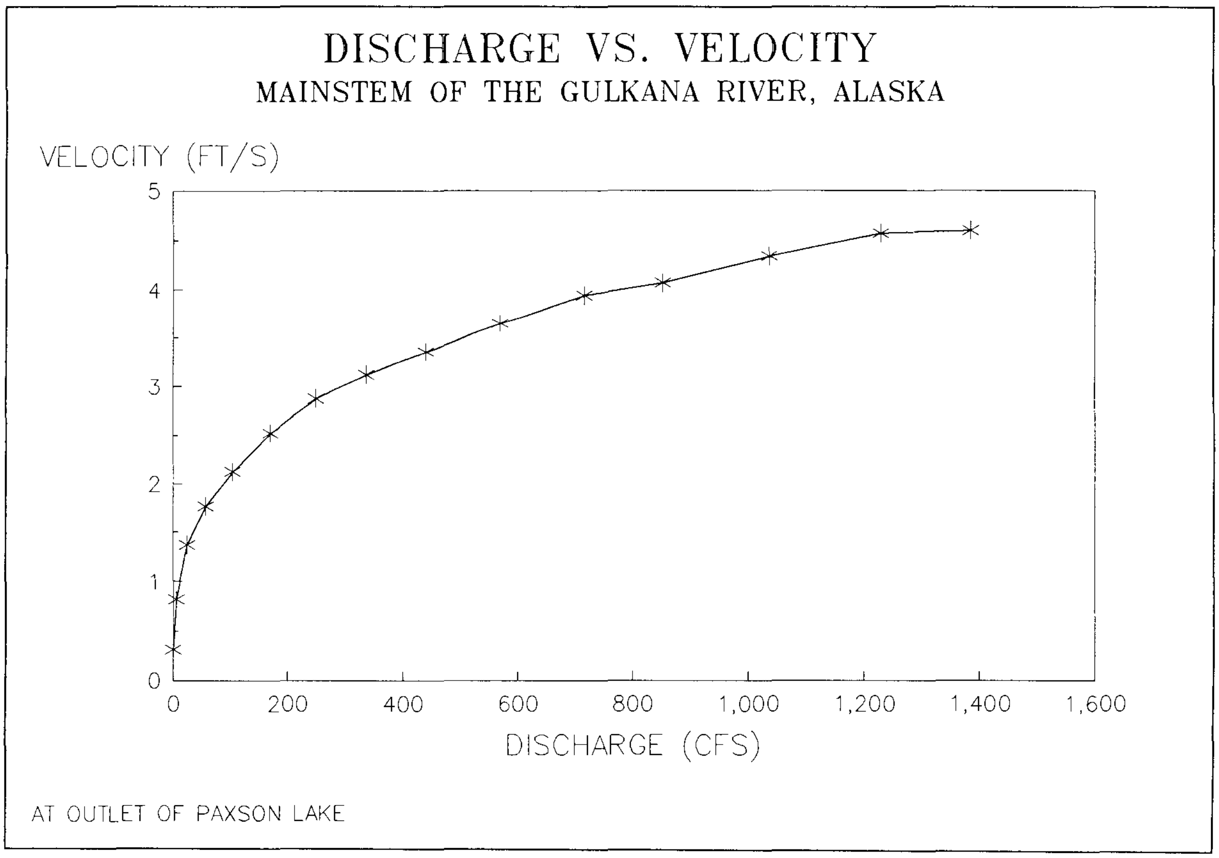


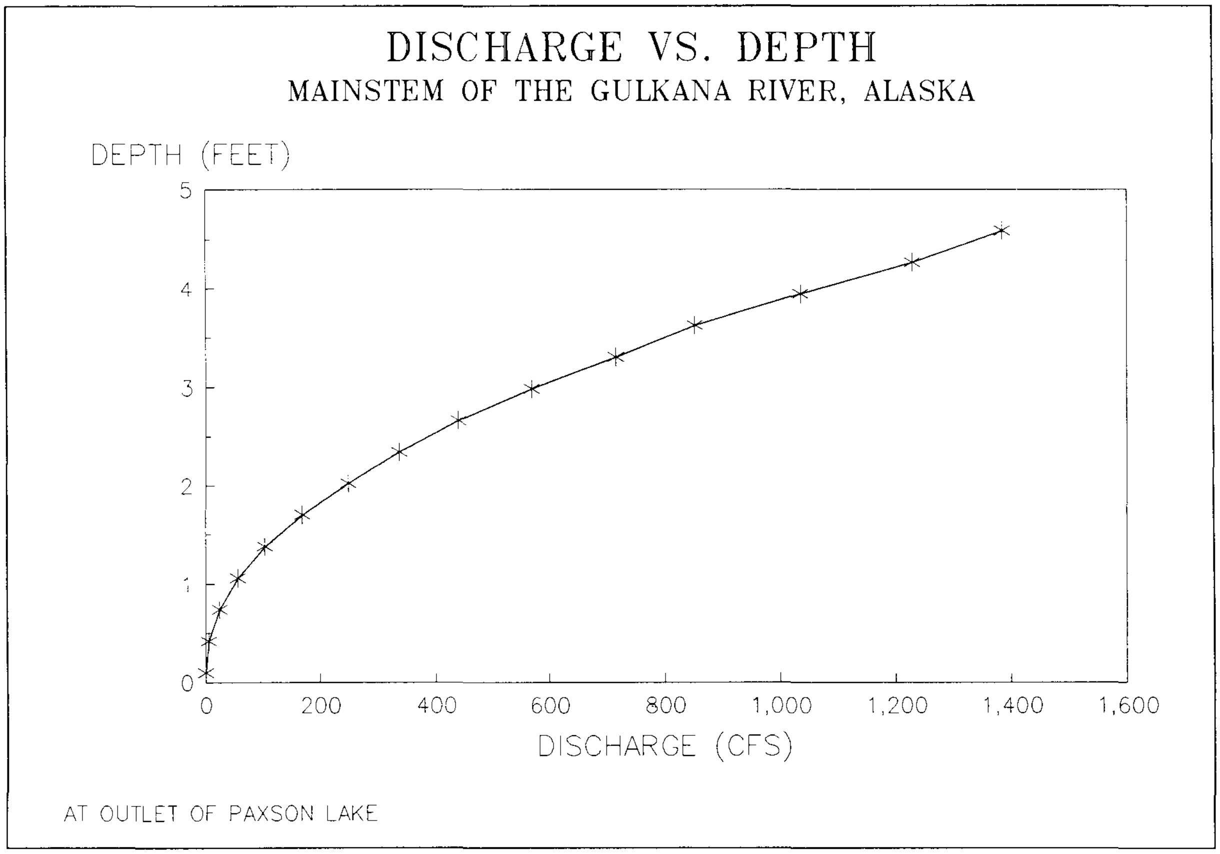


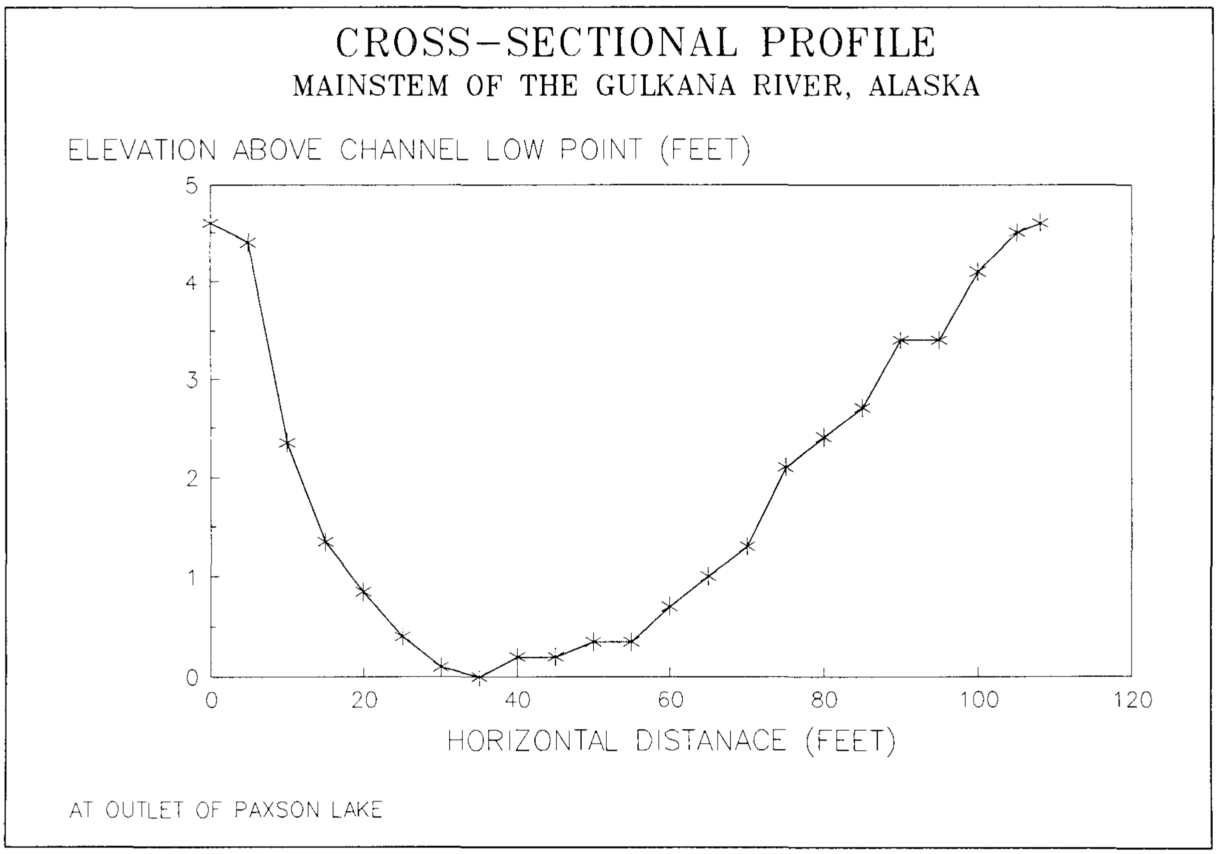

CROSS-SECTIONAL PROFILE
MAINSTEM OF THE GULKANA RIVER
ELEVATION ABOVE CHANNEL LOW POINT (FEET)
3.5
3
2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
120
HORIZONTAL DISTANCE (FEET)
RIVER MILE 2.5

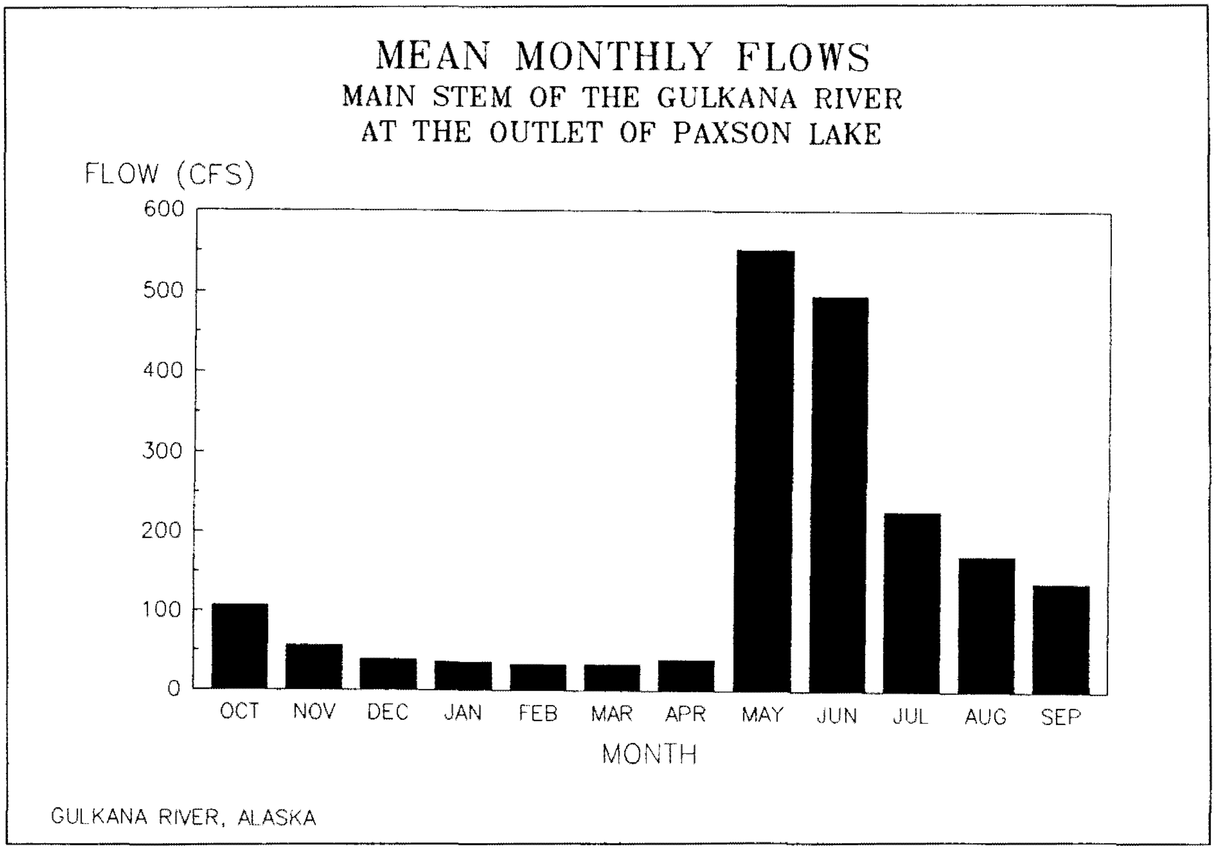

DISCHARGE VS. WETTED PERIMETER
MAINSTEM OF THE GULKANA RIVER, ALASKA
WETTED PERIMETER (FEET)
120
100
80
60
40
20
0
0
200
400
600
800
1,000
1,200
1,400
1,600
DISCHARGE (CFS)
AT OUTLET OF PAXSON LAKE

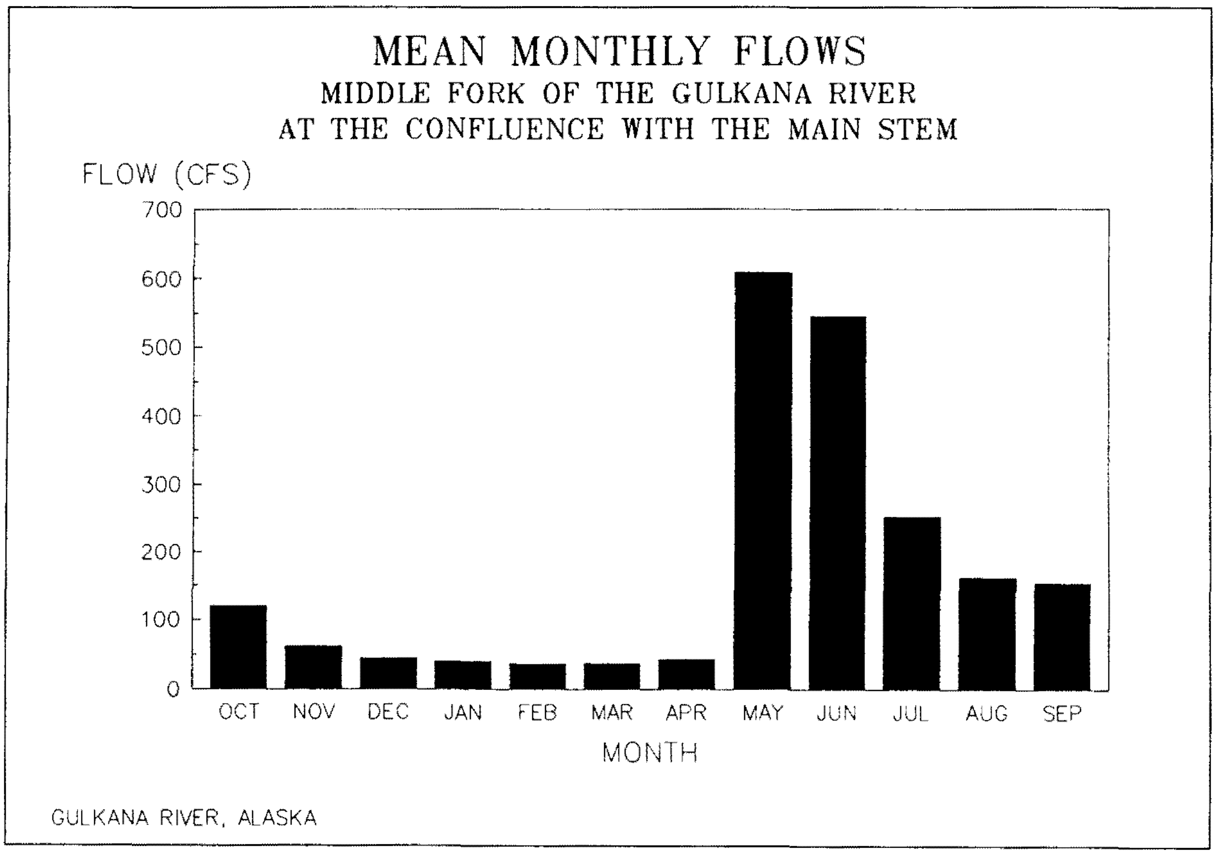

DISCHARGE VS. CROSS-SECTIONAL AREA
MAINSTEM OF THE GULKANA RIVER, ALASKA
CROSS-SECTIONAL AREA (SQUARE FEET)
350
300
250
200
150
100
50
0
0
200
400
600
800
1,000
1,200
1,400
1,600
DISCHARGE (CFS)
AT OUTLET OF PAXSON LAKE

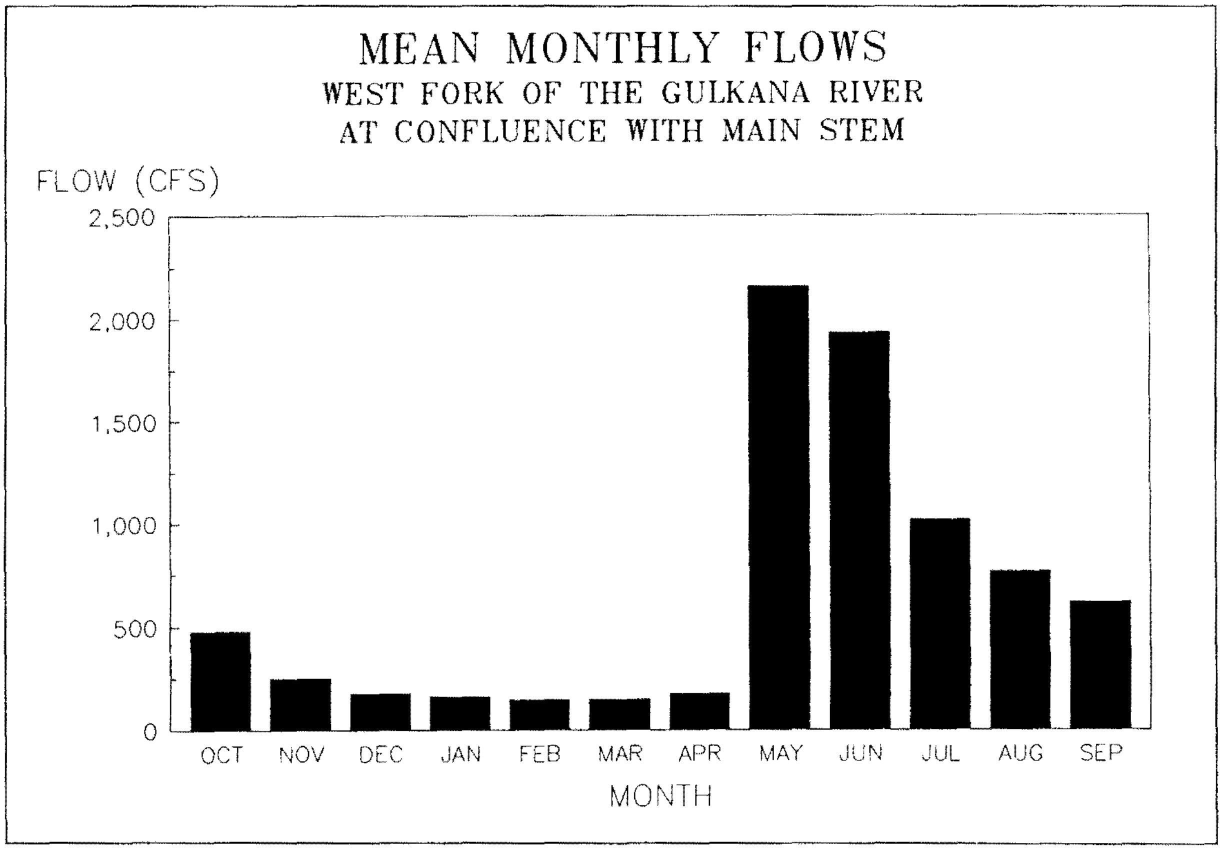

DISCHARGE VS. VELOCITY
MAINSTEM OF THE GULKANA RIVER, ALASKA
VELOCITY (FT/S)
5
4
3
2
1
0
0
200
400
600
800
1,000
1,200
1,400
1,600
DISCHARGE (CFS)
AT OUTLET OF PAXSON LAKE

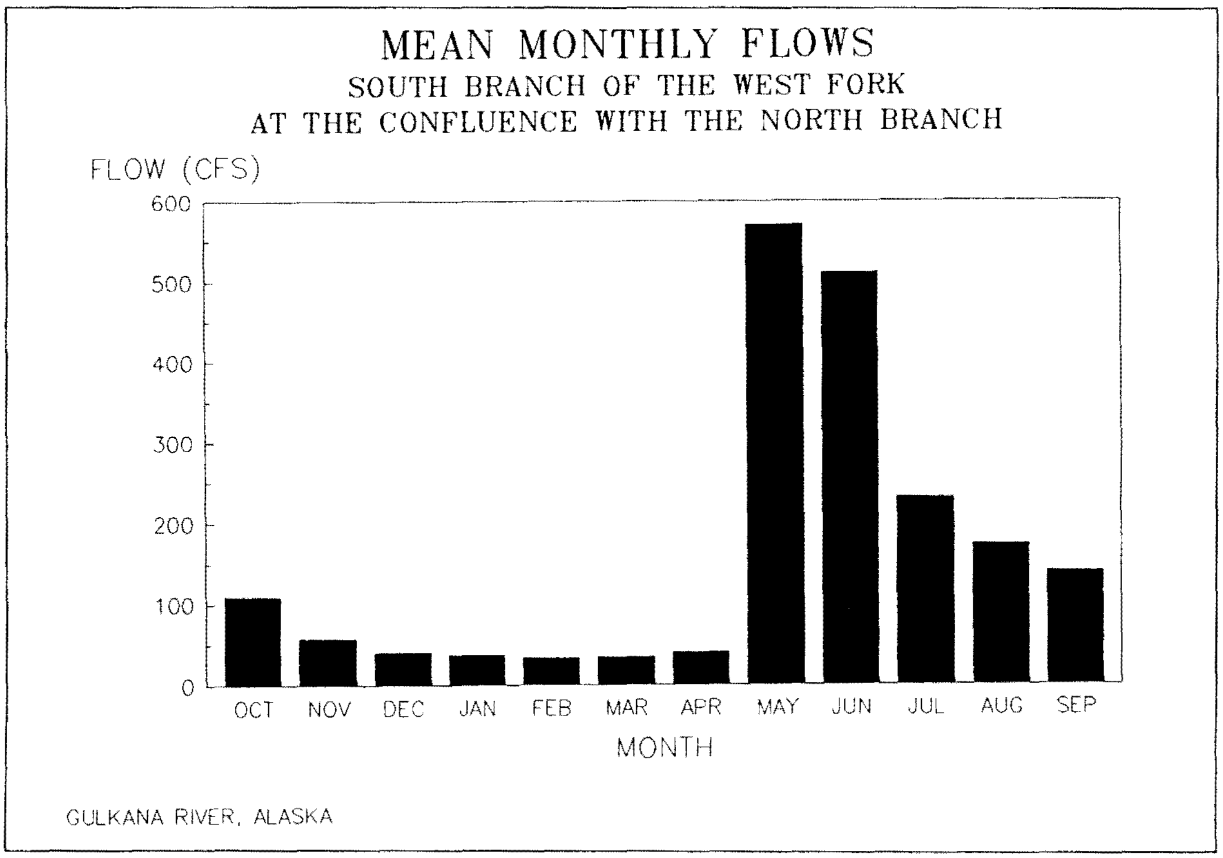

DISCHARGE VS. DEPTH
MAINSTEM OF THE GULKANA RIVER, ALASKA
DEPTH (FEET)
5
4
3
2
1
0
0
200
400
600
800
1,000
1,200
1,400
1,600
DISCHARGE (CFS)
AT OUTLET OF PAXSON LAKE

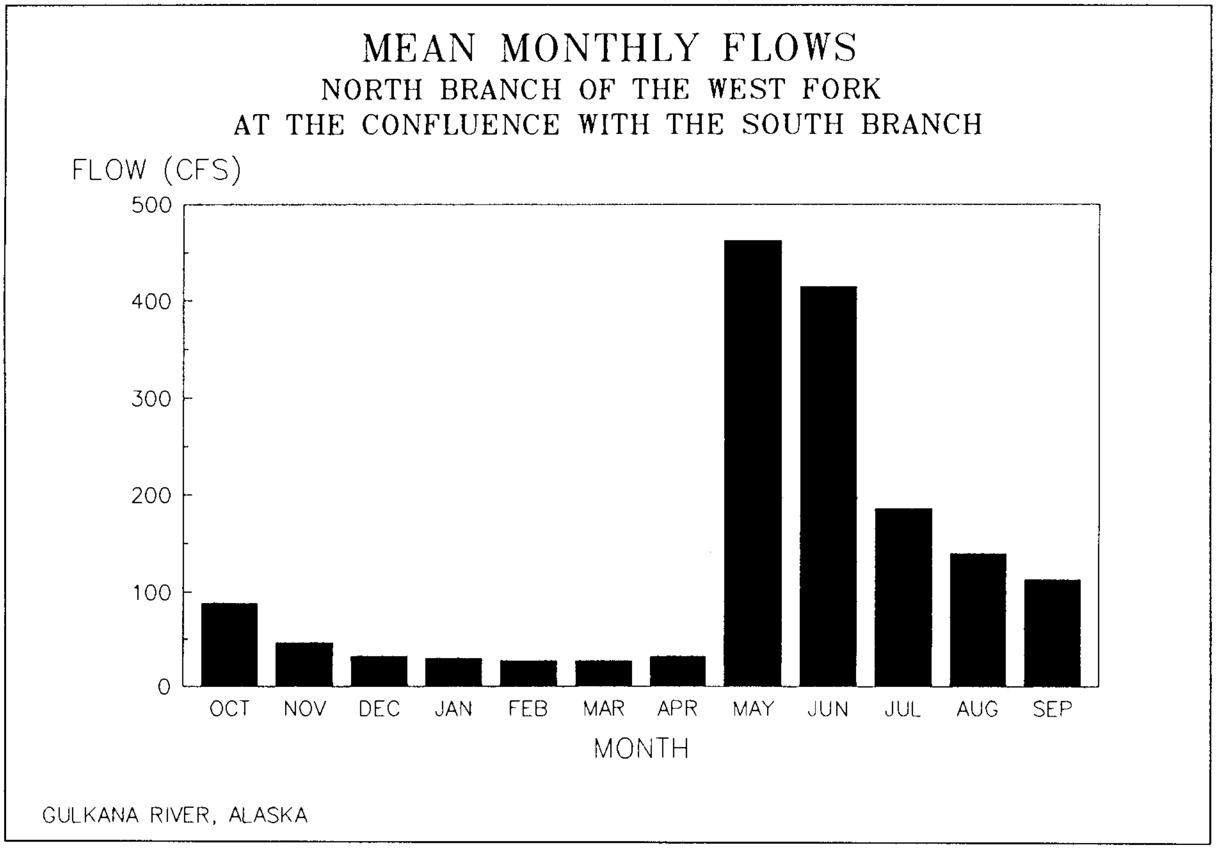

CROSS-SECTIONAL PROFILE
MAINSTEM OF THE GULKANA RIVER, ALASKA
ELEVATION ABOVE CHANNEL LOW POINT (FEET)
5
4
3
2
1
0
0
20
40
60
80
100
120
HORIZONTAL DISTANACE (FEET)
AT OUTLET OF PAXSON LAKE

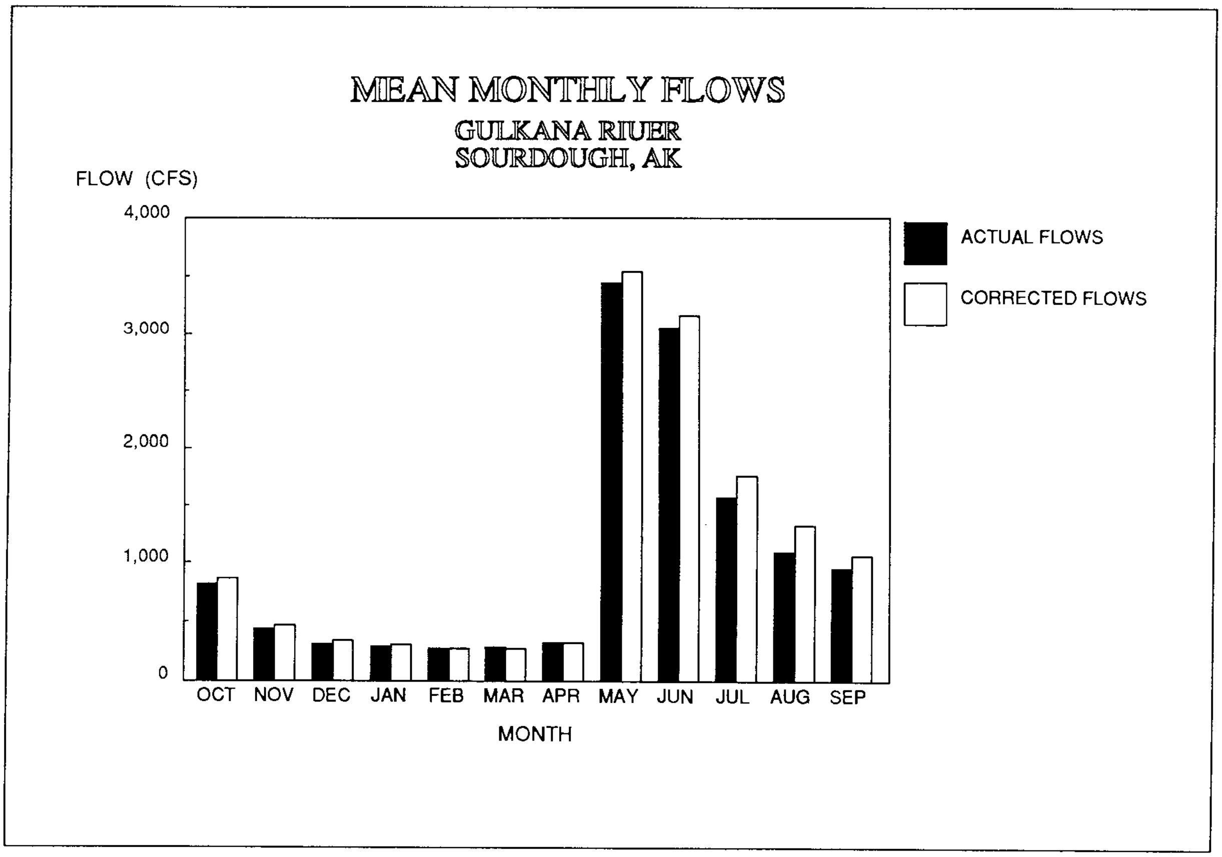

MEAN MONTHLY FLOWS
MAIN STEM OF THE GULKANA RIVER
AT THE OUTLET OF PAXSON LAKE
FLOW (CFS)
600
500
400
300
200
100
0
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
MONTH
GULKANA RIVER, ALASKA

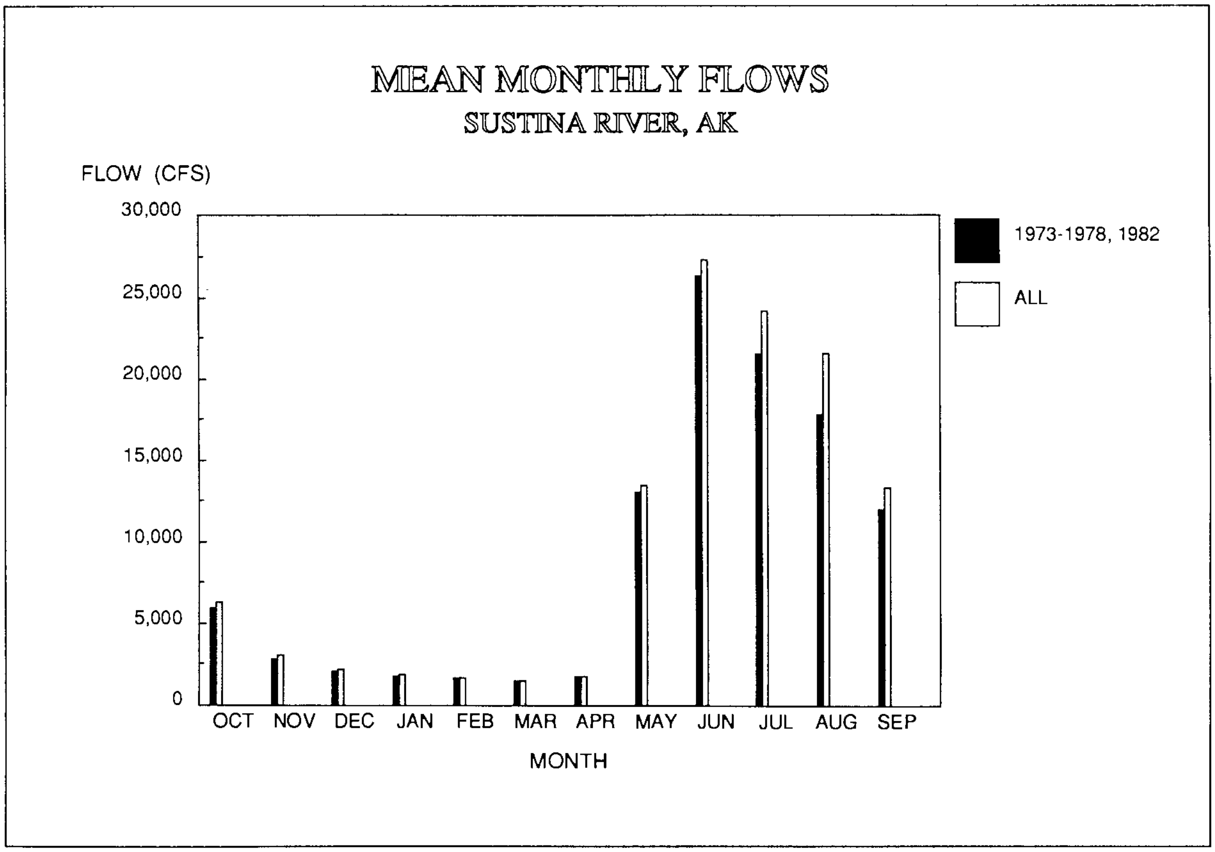

MEAN MONTHLY FLOWS
MIDDLE FORK OF THE GULKANA RIVER
AT THE CONFLUENCE WITH THE MAIN STEM
FLOW (CFS)
700
600
500
400
300
200
100
0
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
MONTH
GULKANA RIVER, ALASKA

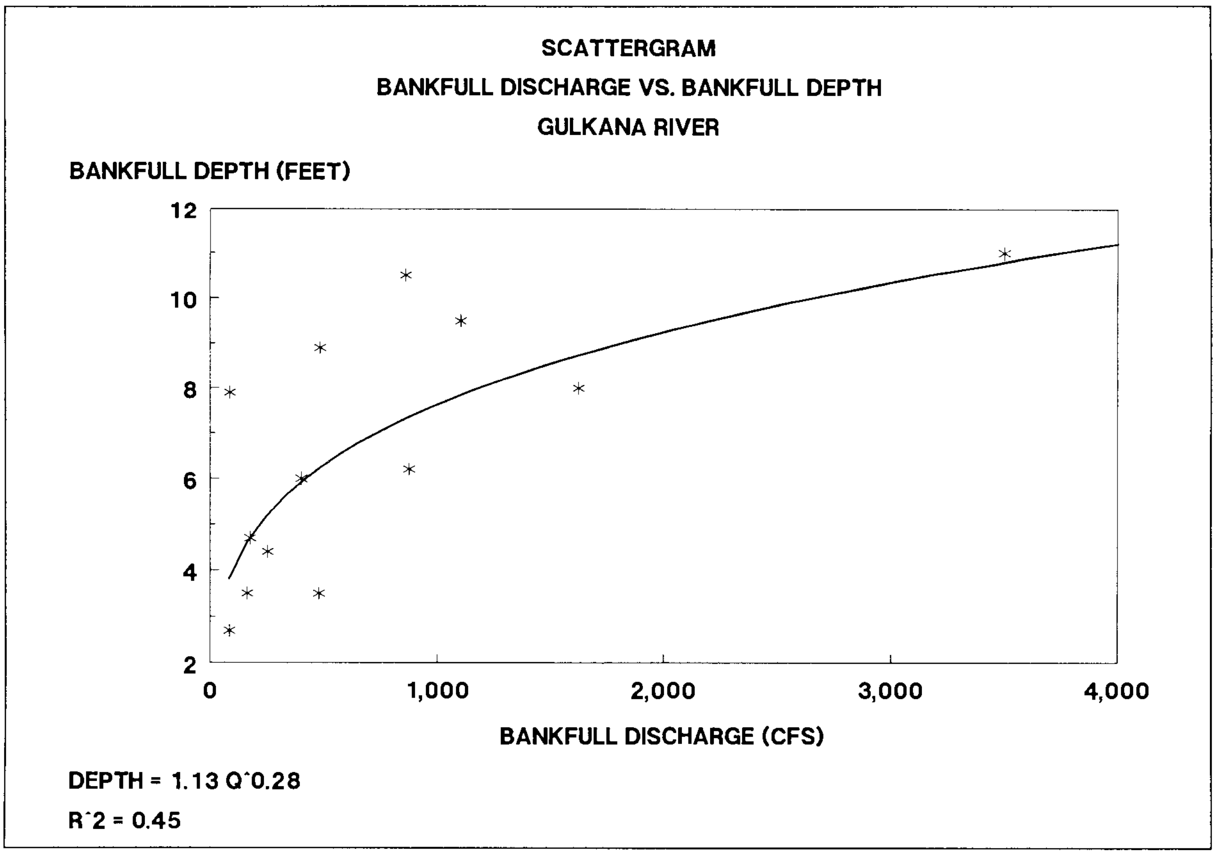

MEAN MONTHLY FLOWS
WEST FORK OF THE GULKANA RIVER
AT CONFLUENCE WITH MAIN STEM
FLOW (CFS)
2,500
2,000
1,500
1,000
500
0
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
MONTH

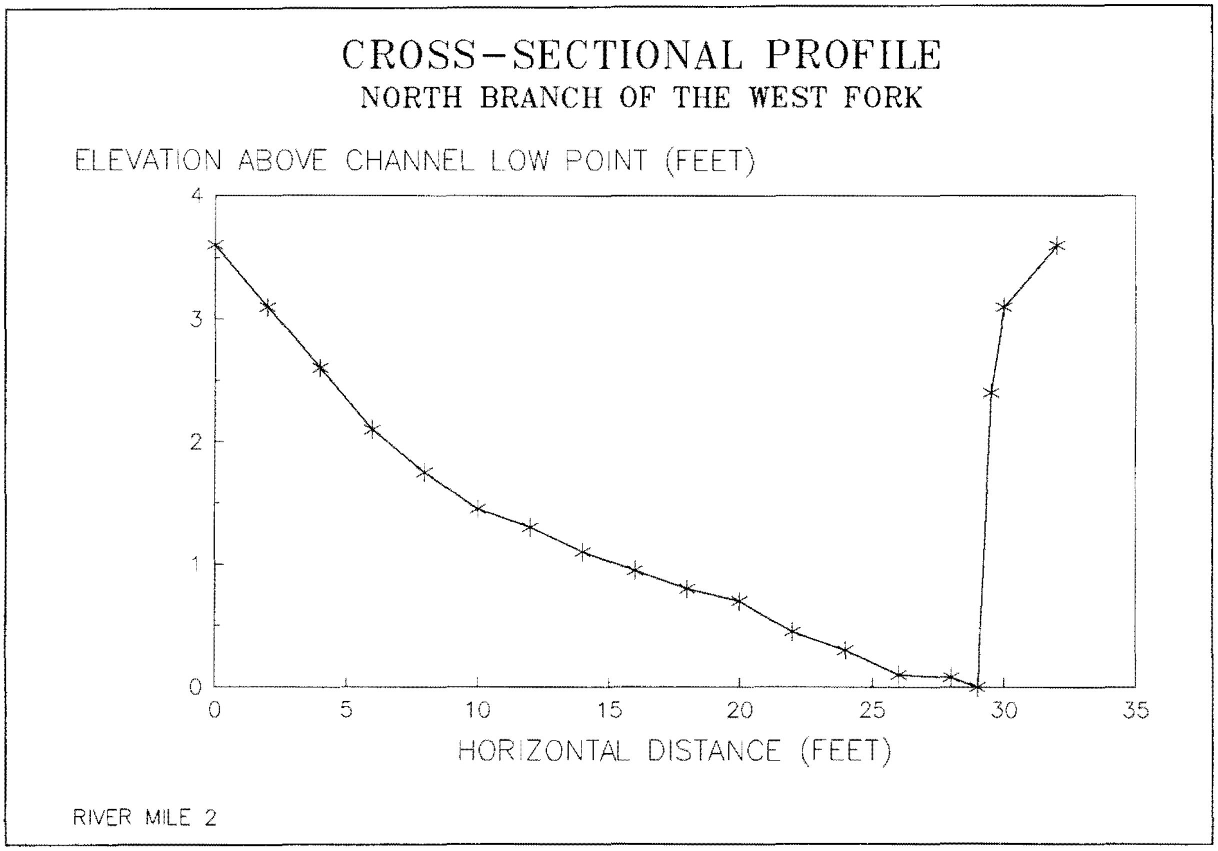

MEAN MONTHLY FLOWS
SOUTH BRANCH OF THE WEST FORK
AT THE CONFLUENCE WITH THE NORTH BRANCH
FLOW (CFS)
600
500
400
300
200
100
0
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
MONTH
GULKANA RIVER, ALASKA

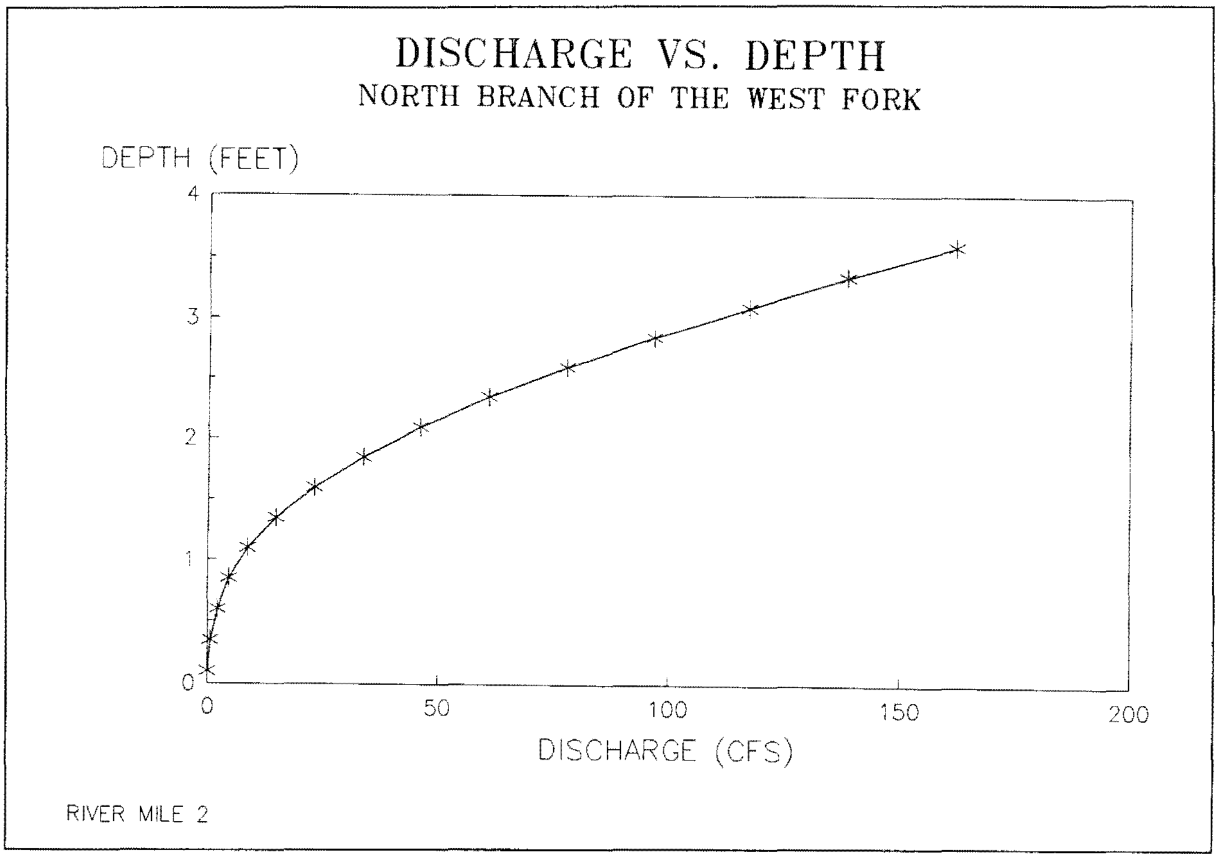

MEAN MONTHLY FLOWS
NORTH BRANCH OF THE WEST FORK
AT THE CONFLUENCE WITH THE SOUTH BRANCH
FLOW (CFS)
500
400
300
200
100
0
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
MONTH
GULKANA RIVER, ALASKA

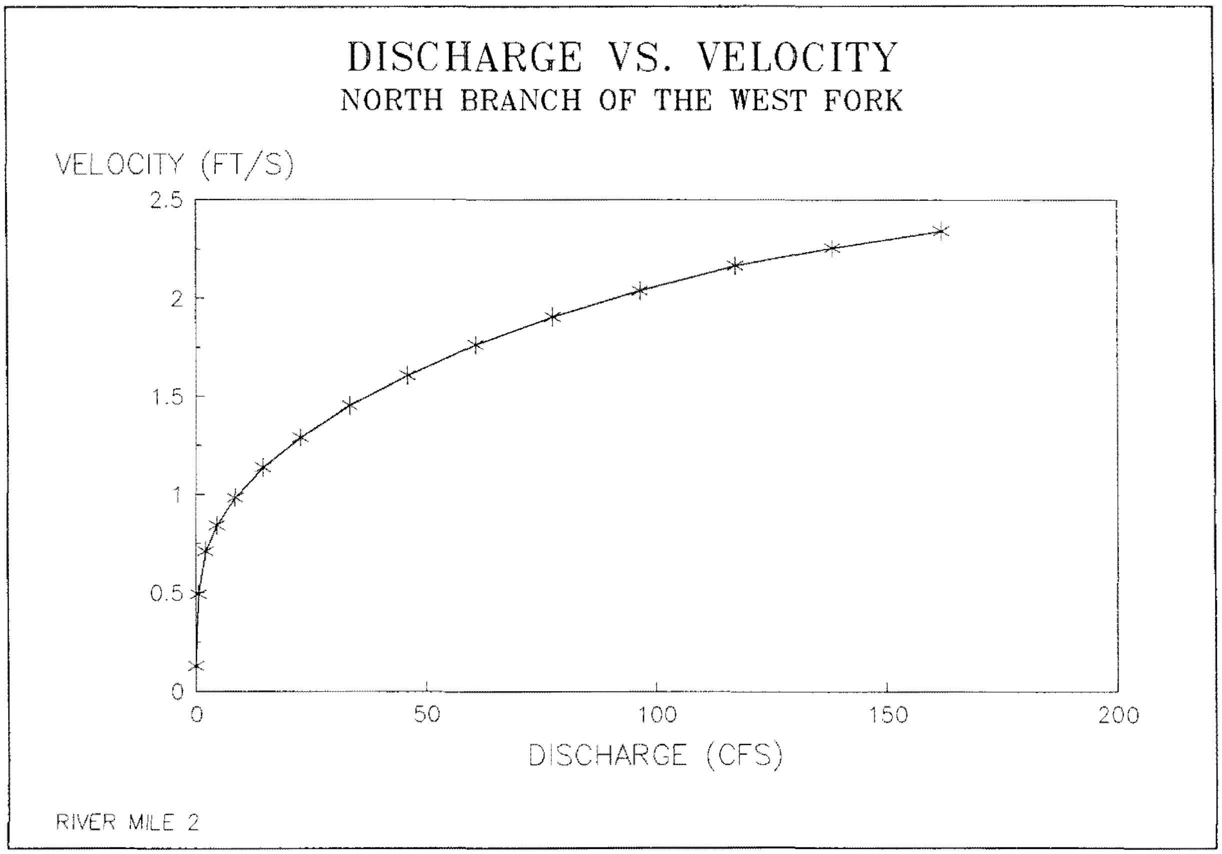

MEAN MONTHLY FLOWS
GULKANA RIUER
SOURDOUGH, AK
FLOW (CFS)
4,000
3,000
2,000
1,000
0
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
MONTH
ACTUAL FLOWS
CORRECTED FLOWS

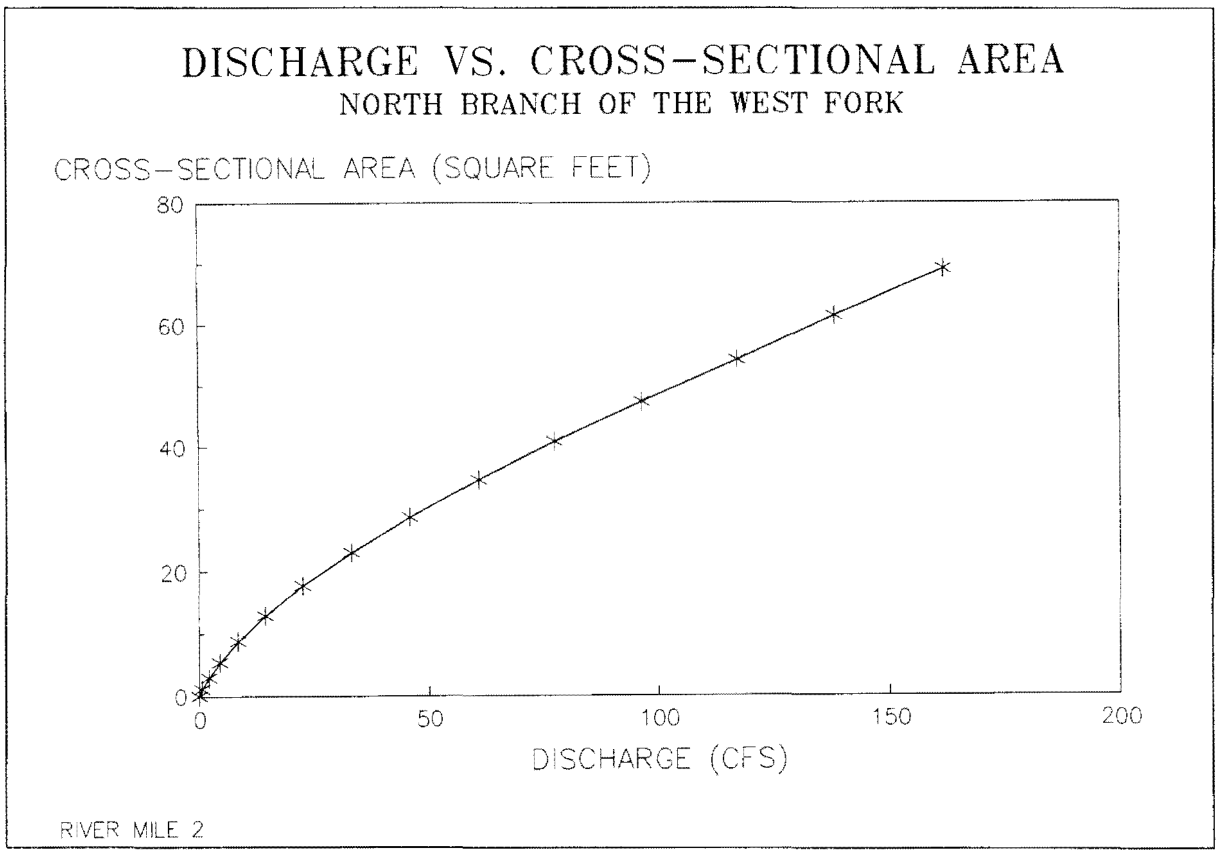

MEAN MONTHLY FLOWS
SUSTINA RIVER, AK
FLOW (CFS)
30,000
25,000
20,000
15,000
10,000
5,000
0
1973-1978, 1982
ALL
OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP
MONTH

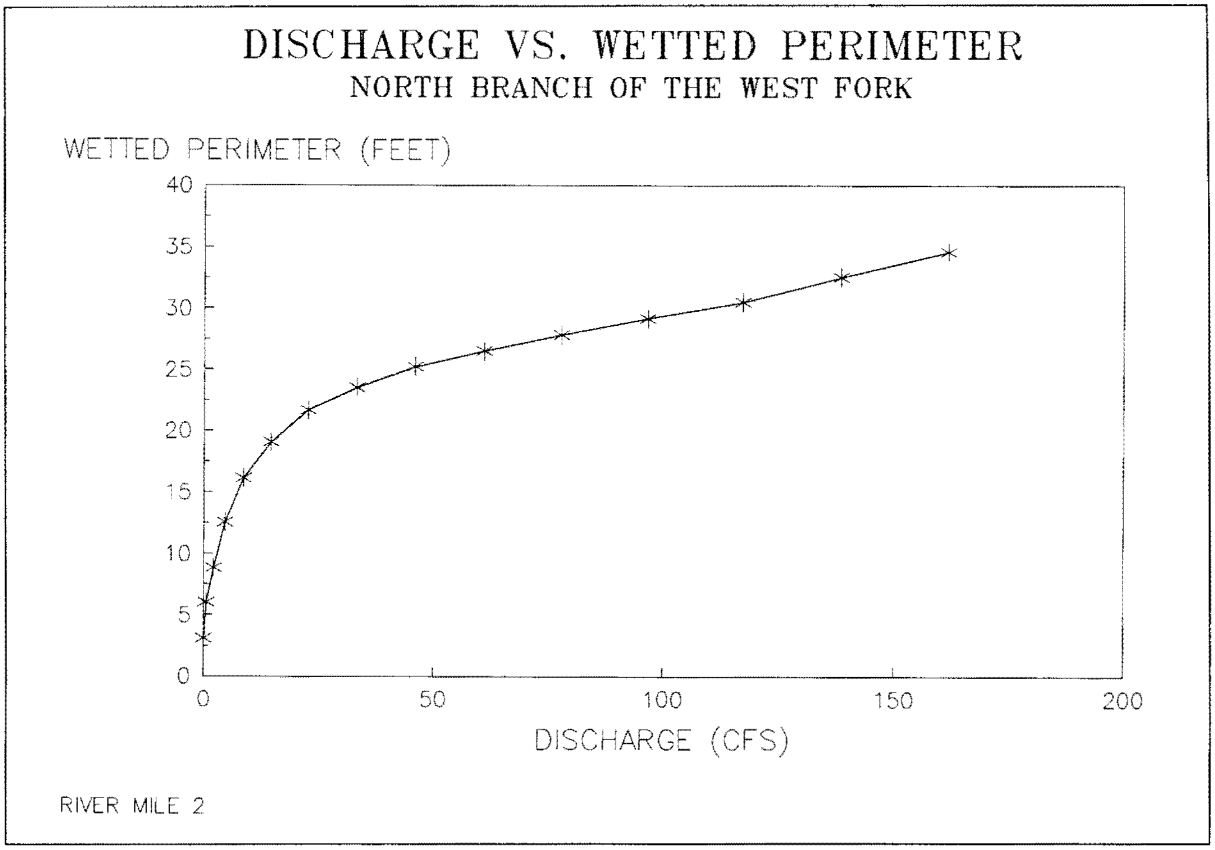

SCATTERGRAM
BANKFULL DISCHARGE VS. BANKFULL DEPTH
GULKANA RIVER
BANKFULL DEPTH (FEET)
12
10
8
6
4
2
0
1,000
2,000
3,000
4,000
BANKFULL DISCHARGE (CFS)
DEPTH = 1.13 Q^0.28
R^2 = 0.45

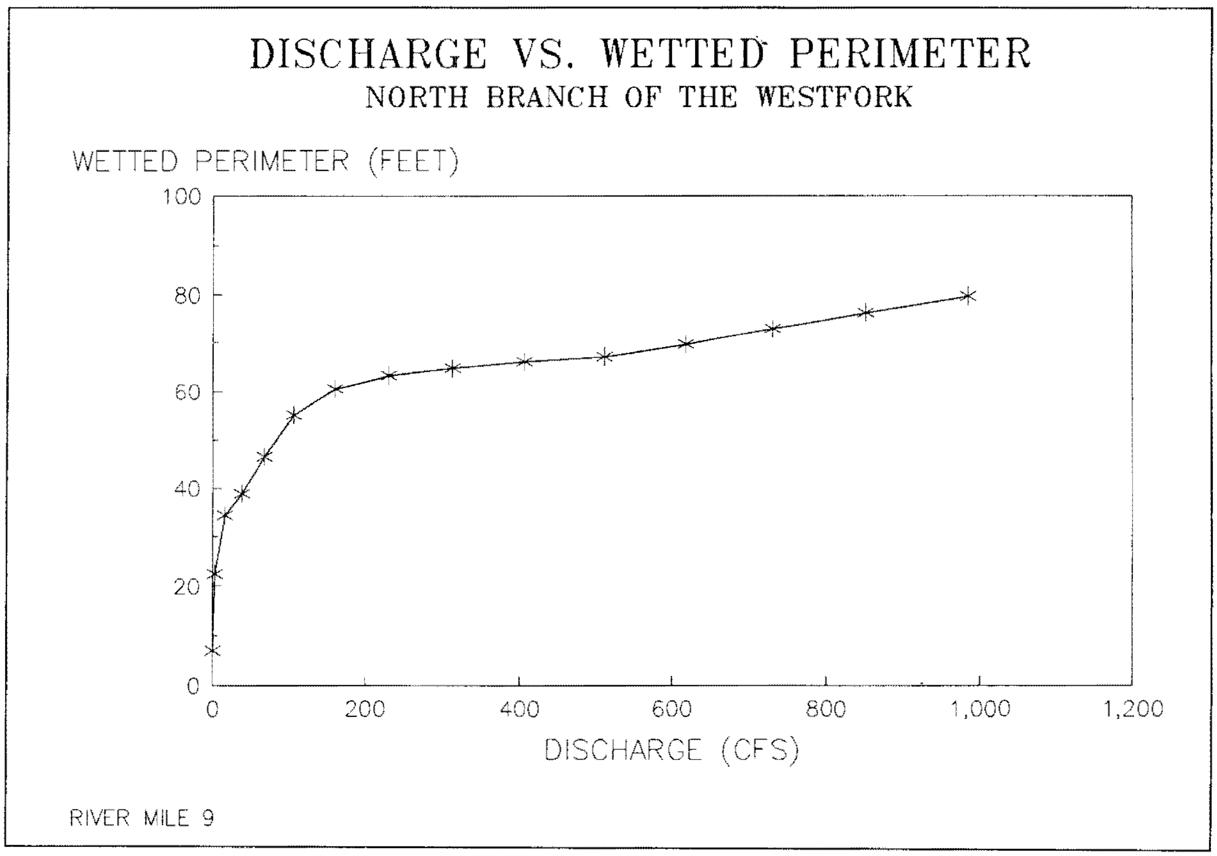

CROSS-SECTIONAL PROFILE
NORTH BRANCH OF THE WEST FORK
ELEVATION ABOVE CHANNEL LOW POINT (FEET)
HORIZONTAL DISTANCE (FEET)
RIVER MILE 2

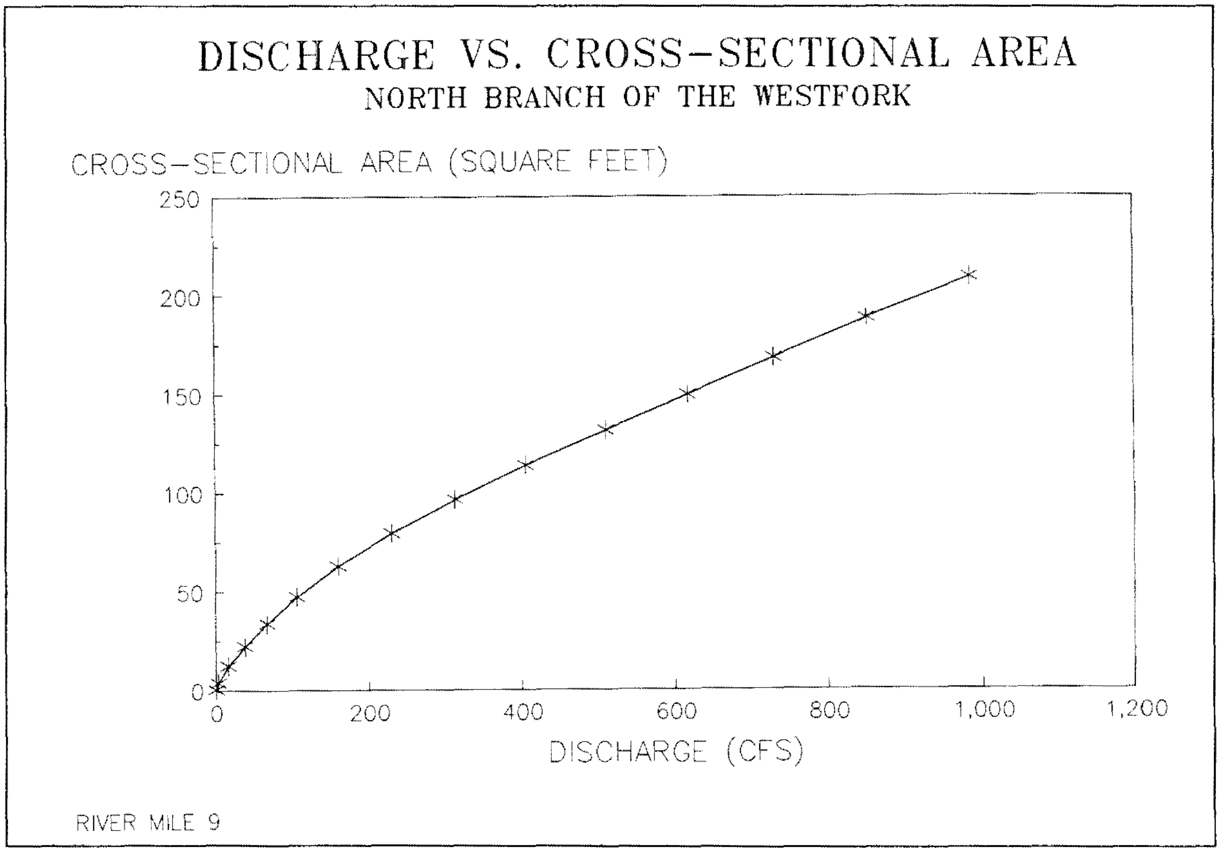

DISCHARGE VS. DEPTH
NORTH BRANCH OF THE WEST FORK
DEPTH (FEET)
DISCHARGE (CFS)
RIVER MILE 2

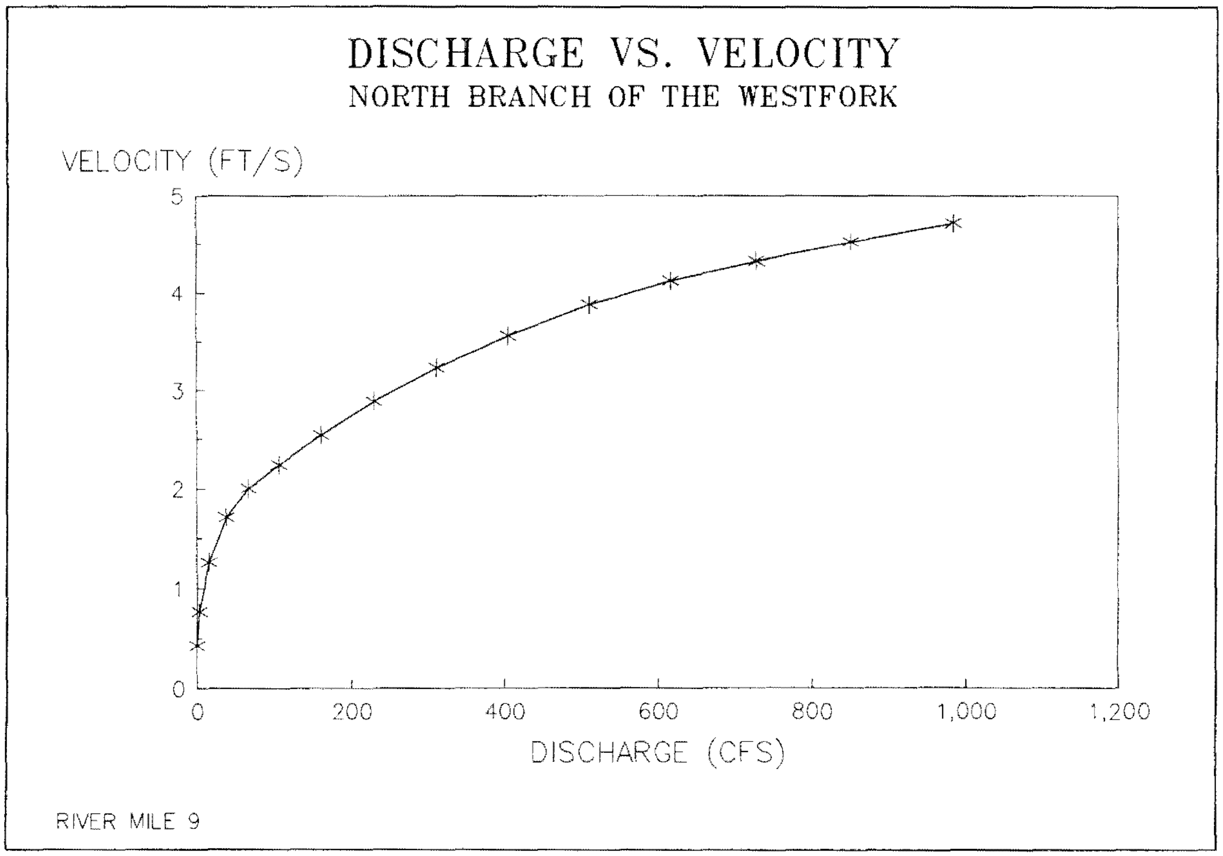

DISCHARGE VS. VELOCITY
NORTH BRANCH OF THE WEST FORK
VELOCITY (FT/S)
2.5
2
1.5
1
0.5
0
0
50
100
150
200
DISCHARGE (CFS)
RIVER MILE 2

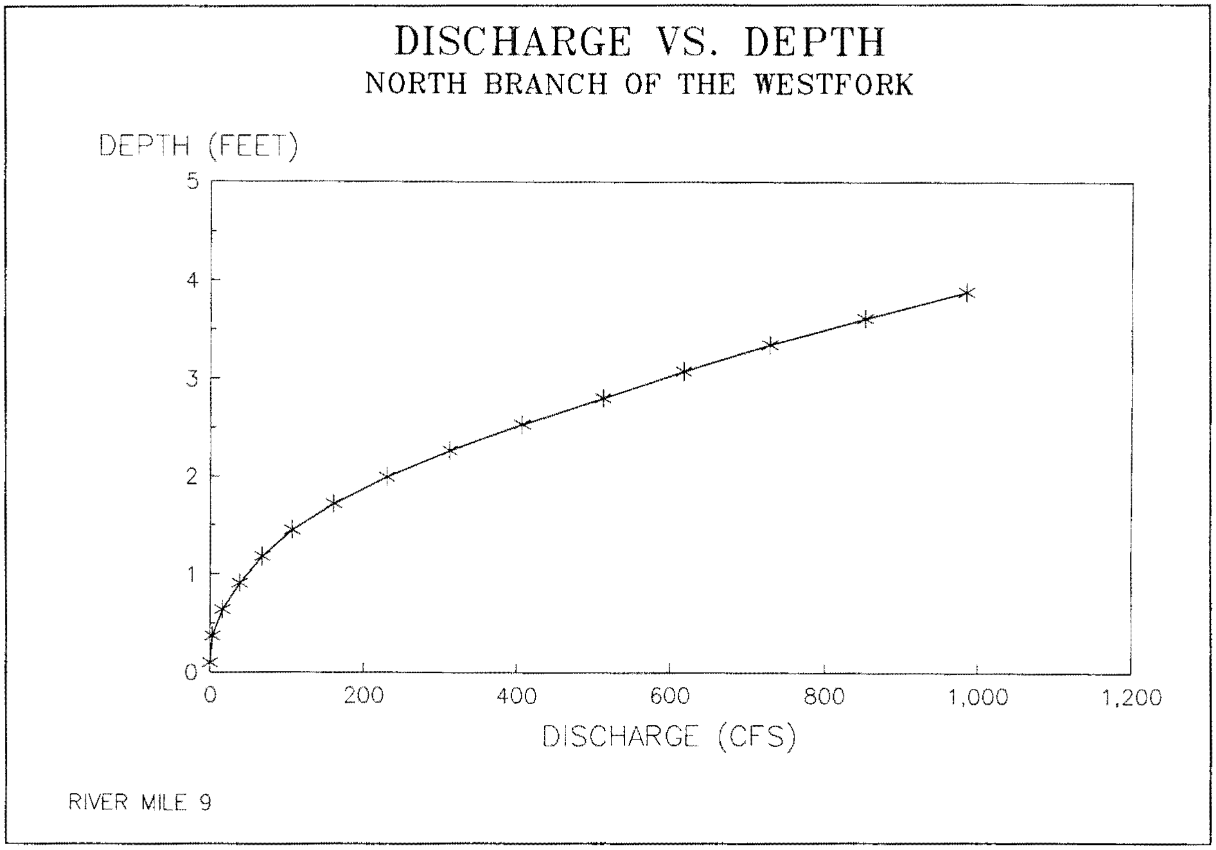

DISCHARGE VS. CROSS-SECTIONAL AREA
NORTH BRANCH OF THE WEST FORK
CROSS-SECTIONAL AREA (SQUARE FEET)
80
60
40
20
0
0
50
100
150
200
DISCHARGE (CFS)
RIVER MILE 2

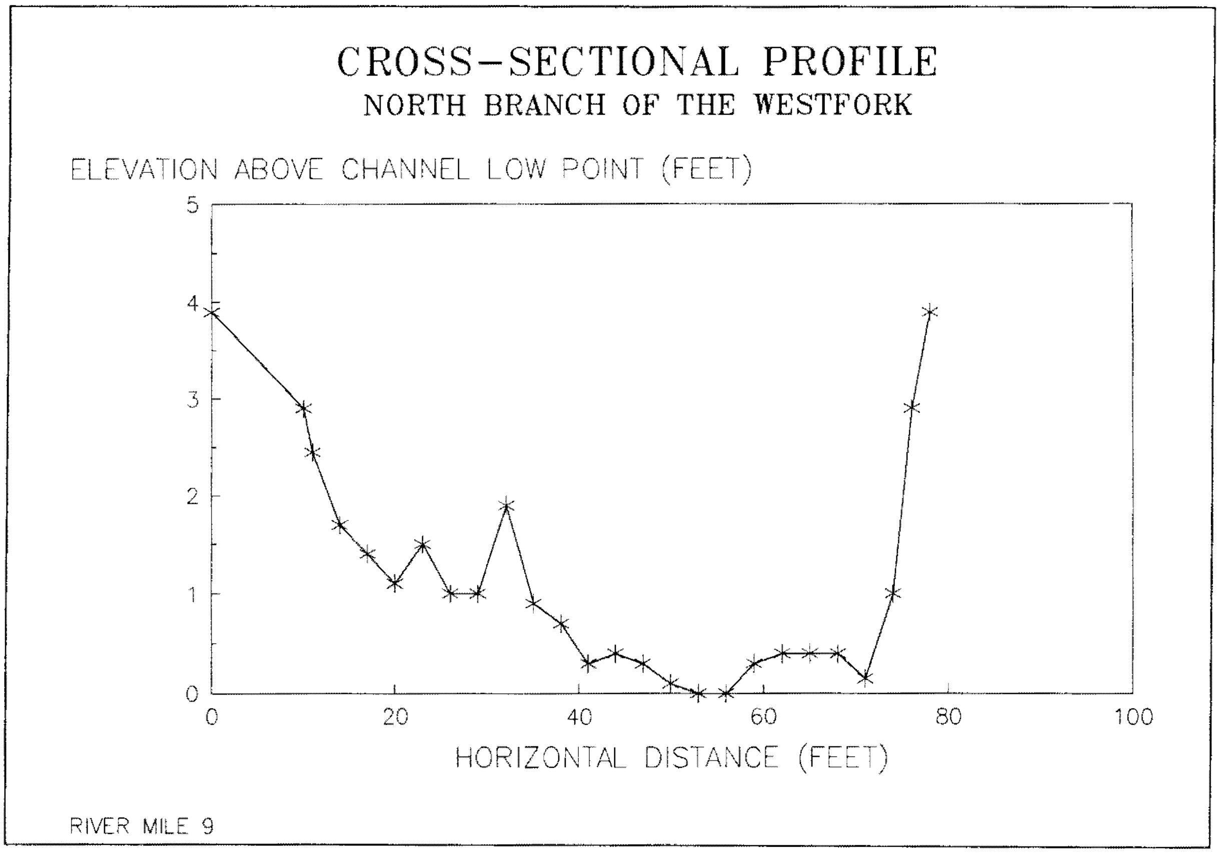

DISCHARGE VS. WETTED PERIMETER
NORTH BRANCH OF THE WEST FORK
WETTED PERIMETER (FEET)
40
35
30
25
20
15
10
5
0
0
50
100
150
200
DISCHARGE (CFS)
RIVER MILE 2

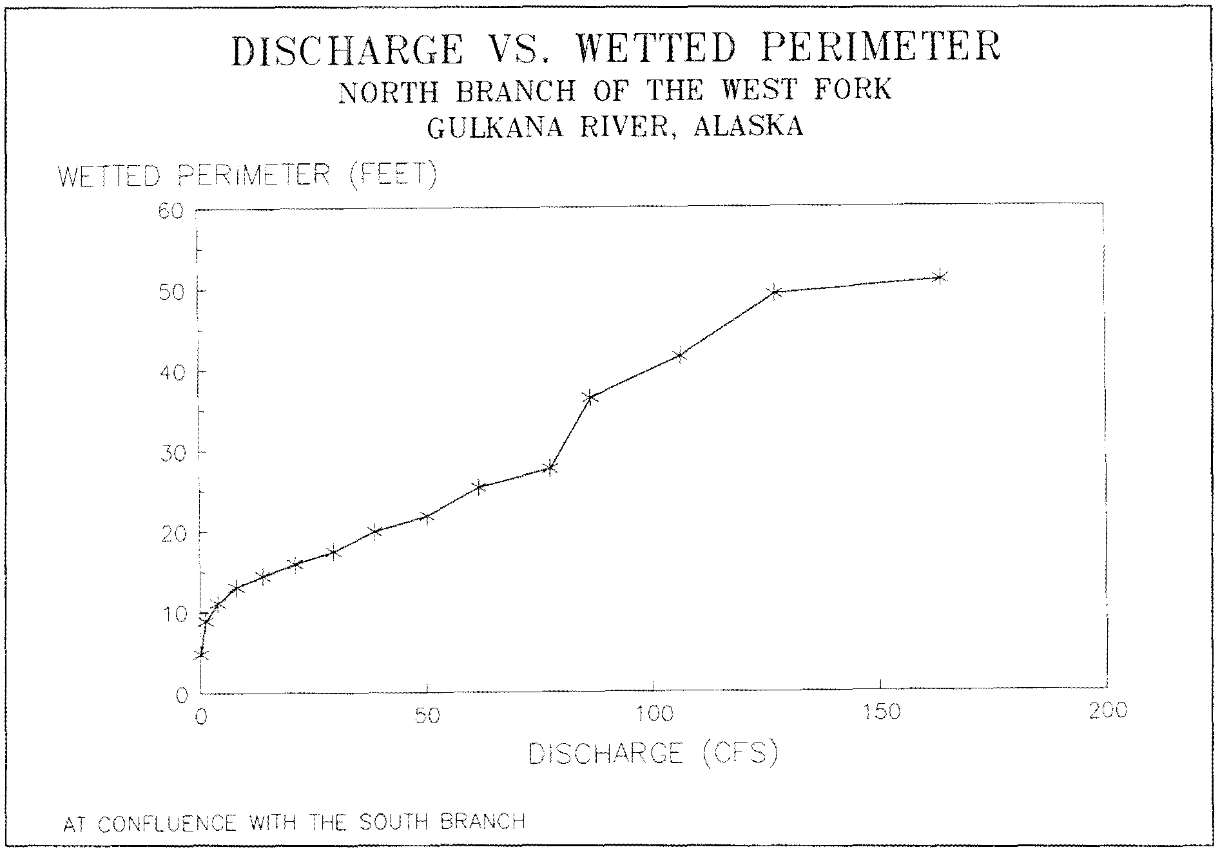

DISCHARGE VS. WETTED PERIMETER
NORTH BRANCH OF THE WESTFORK
WETTED PERIMETER (FEET)
100
80
60
40
20
0
0
200
400
600
800
1,000
1,200
DISCHARGE (CFS)
RIVER MILE 9

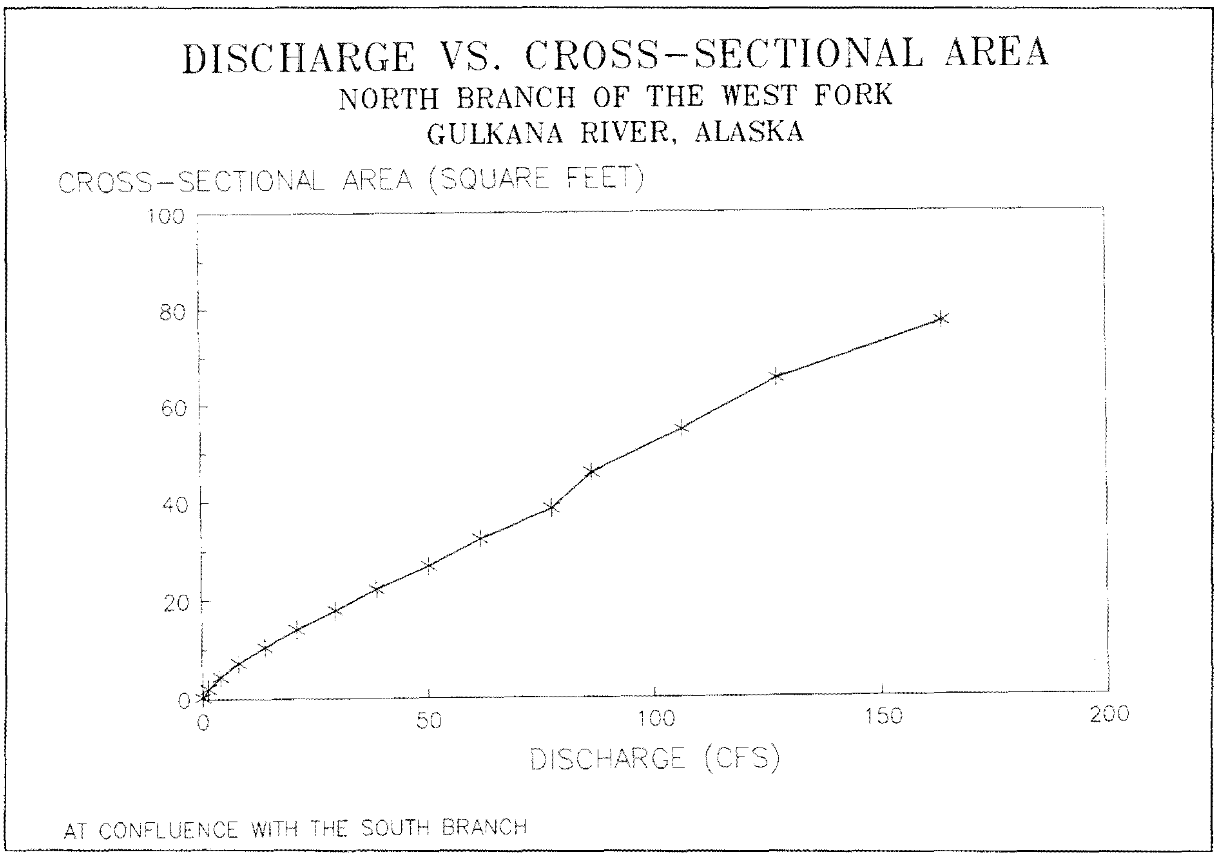

DISCHARGE VS. CROSS-SECTIONAL AREA
NORTH BRANCH OF THE WESTFORK
CROSS-SECTIONAL AREA (SQUARE FEET)
250
200
150
100
50
0
0
200
400
600
800
1,000
1,200
DISCHARGE (CFS)
RIVER MILE 9

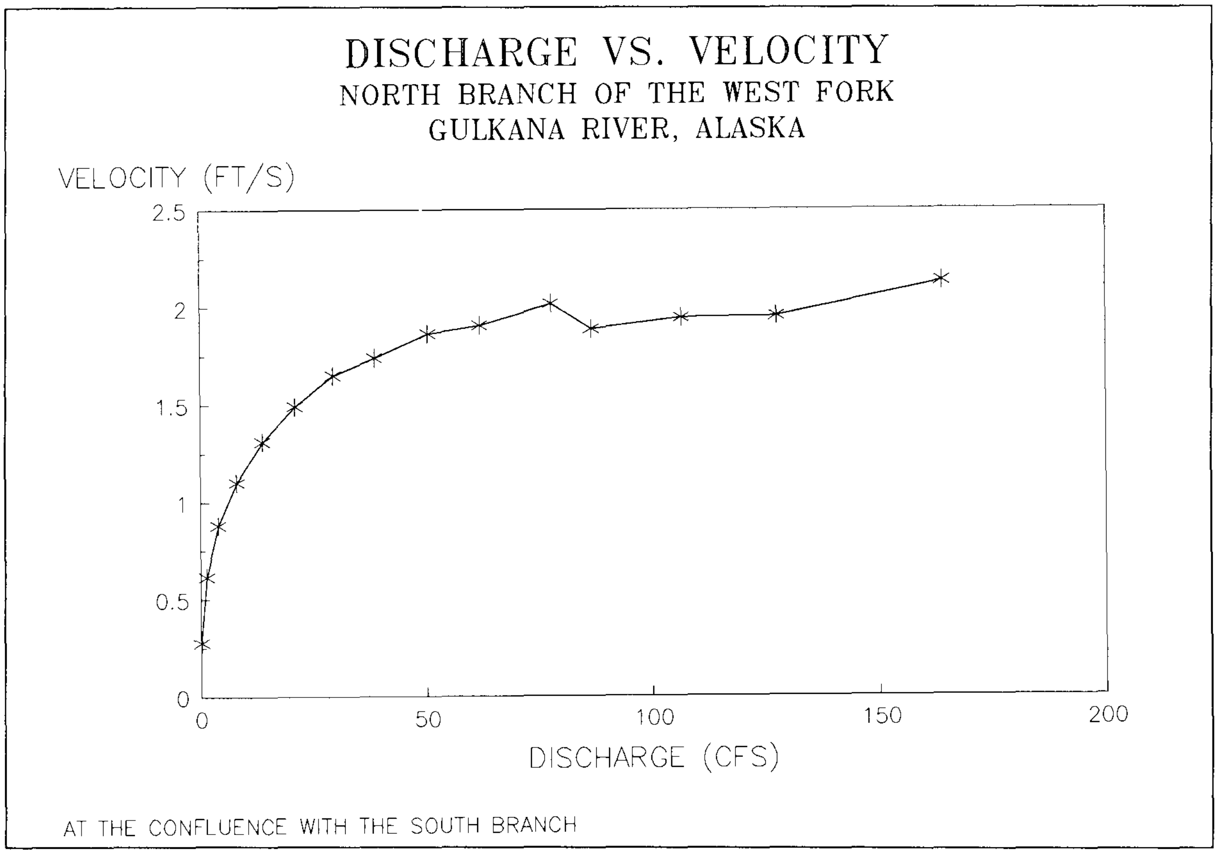

DISCHARGE VS. VELOCITY
NORTH BRANCH OF THE WESTFORK
VELOCITY (FT/S)
5
4
3
2
1
0
0
200
400
600
800
1,000
1,200
DISCHARGE (CFS)
RIVER MILE 9

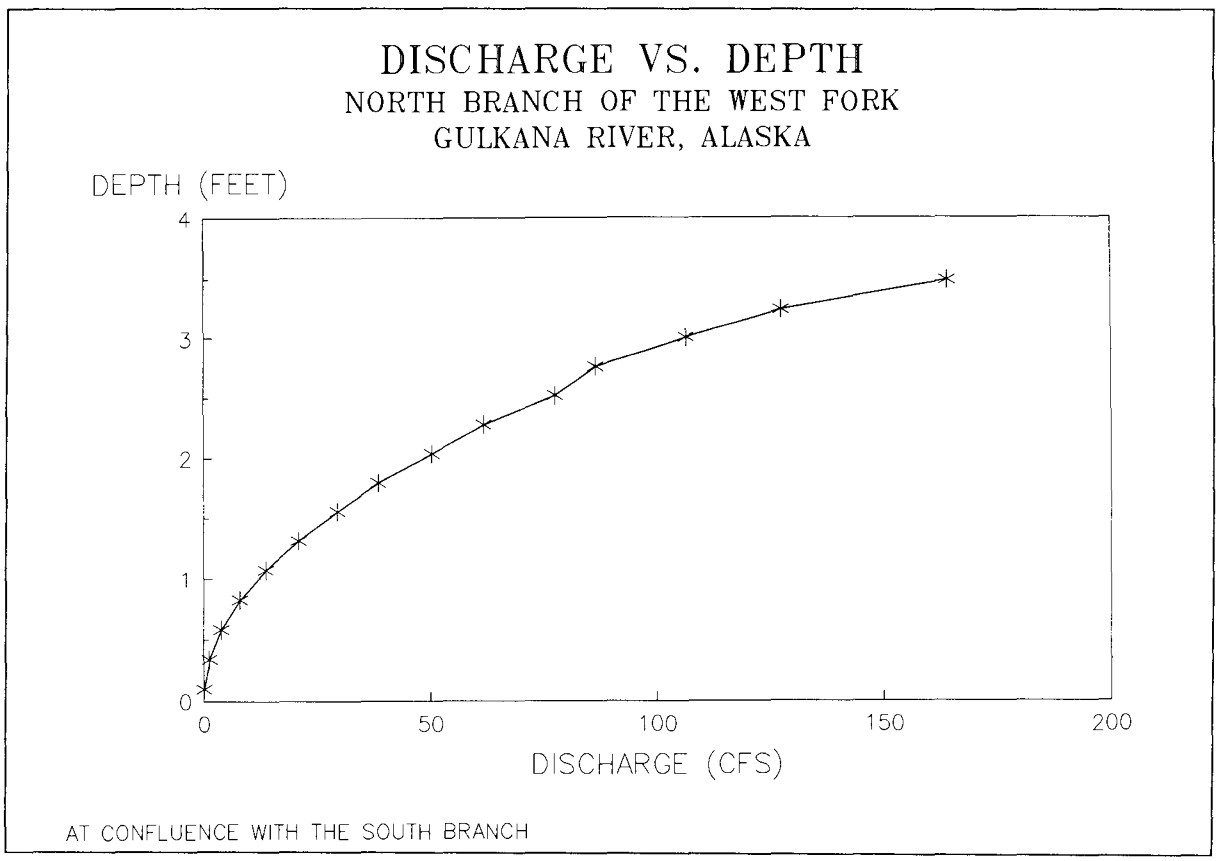

DISCHARGE VS. DEPTH
NORTH BRANCH OF THE WESTFORK
DEPTH (FEET)
5
4
3
2
1
0
0
200
400
600
800
1,000
1,200
DISCHARGE (CFS)
RIVER MILE 9

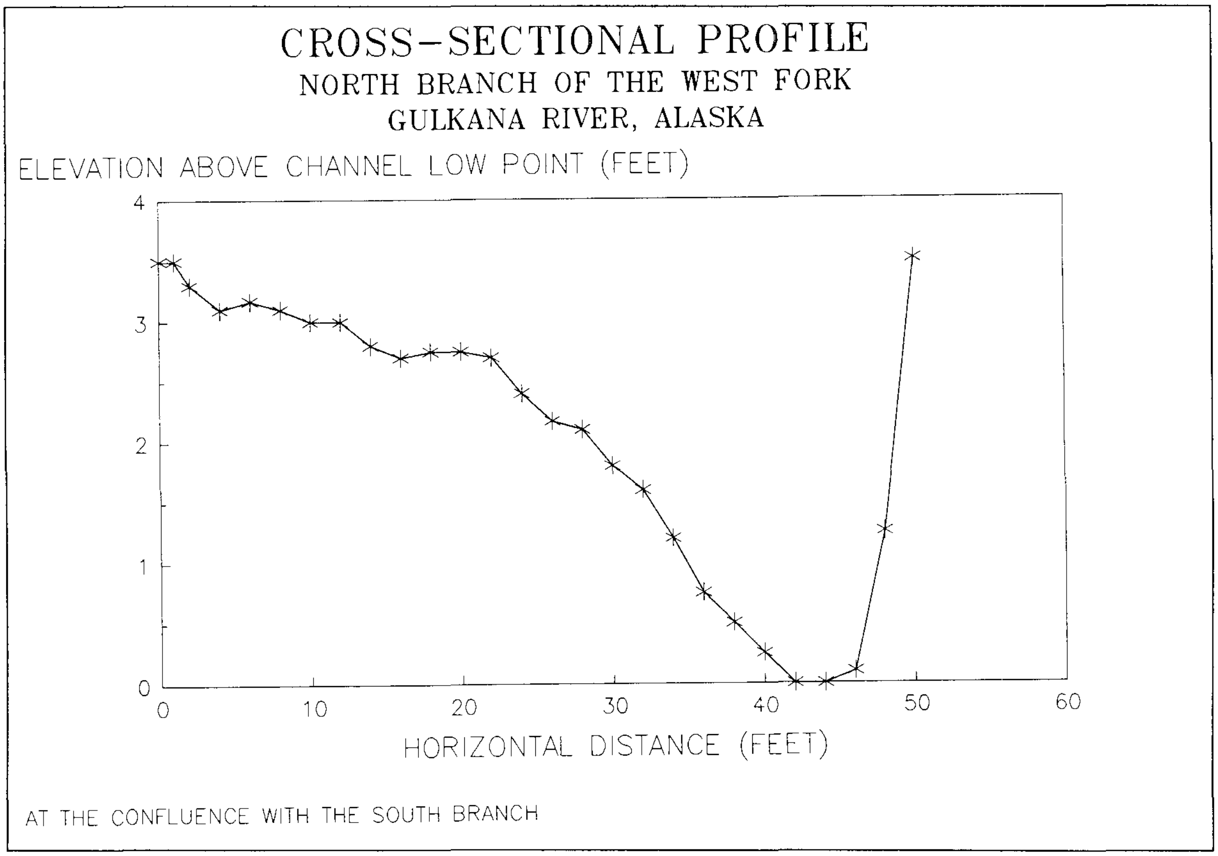

CROSS-SECTIONAL PROFILE
NORTH BRANCH OF THE WESTFORK
ELEVATION ABOVE CHANNEL LOW POINT (FEET)
5
4
3
2
1
0
0
20
40
60
80
100
HORIZONTAL DISTANCE (FEET)
RIVER MILE 9

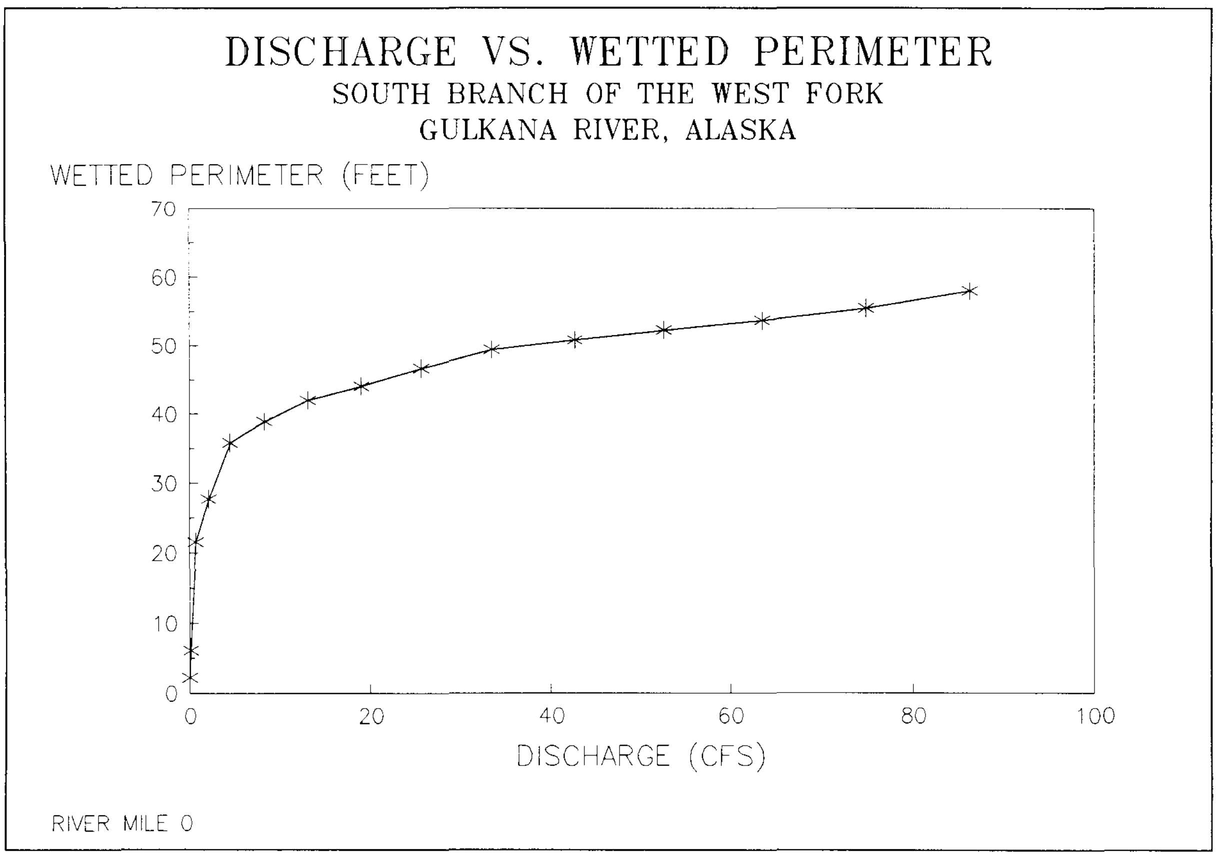

DISCHARGE VS. WETTED PERIMETER
NORTH BRANCH OF THE WEST FORK
GULKANA RIVER, ALASKA
WETTED PERIMETER (FEET)
60
50
40
30
20
10
0
0
50
100
150
200
DISCHARGE (CFS)
AT CONFLUENCE WITH THE SOUTH BRANCH

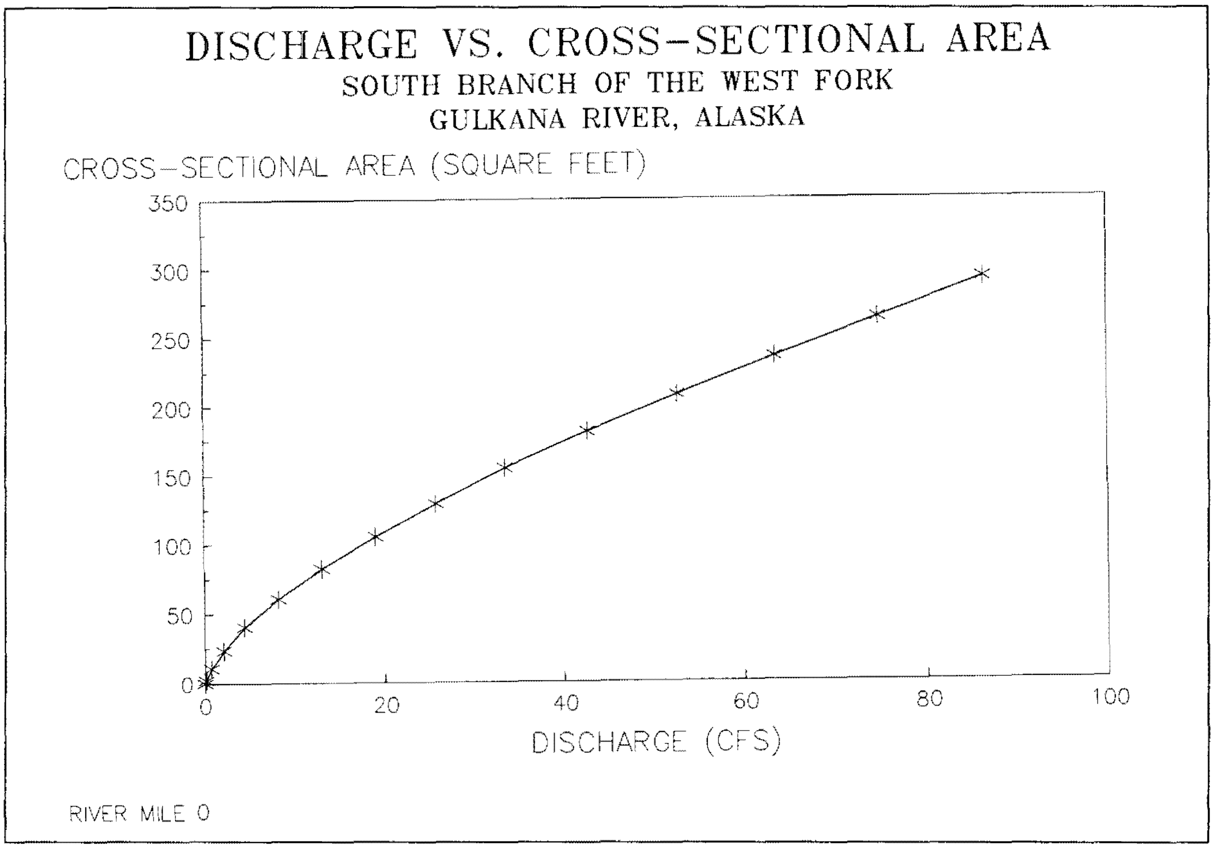

DISCHARGE VS. CROSS-SECTIONAL AREA
NORTH BRANCH OF THE WEST FORK
GULKANA RIVER, ALASKA
CROSS-SECTIONAL AREA (SQUARE FEET)
100
80
60
40
20
0
0
50
100
150
200
DISCHARGE (CFS)
AT CONFLUENCE WITH THE SOUTH BRANCH

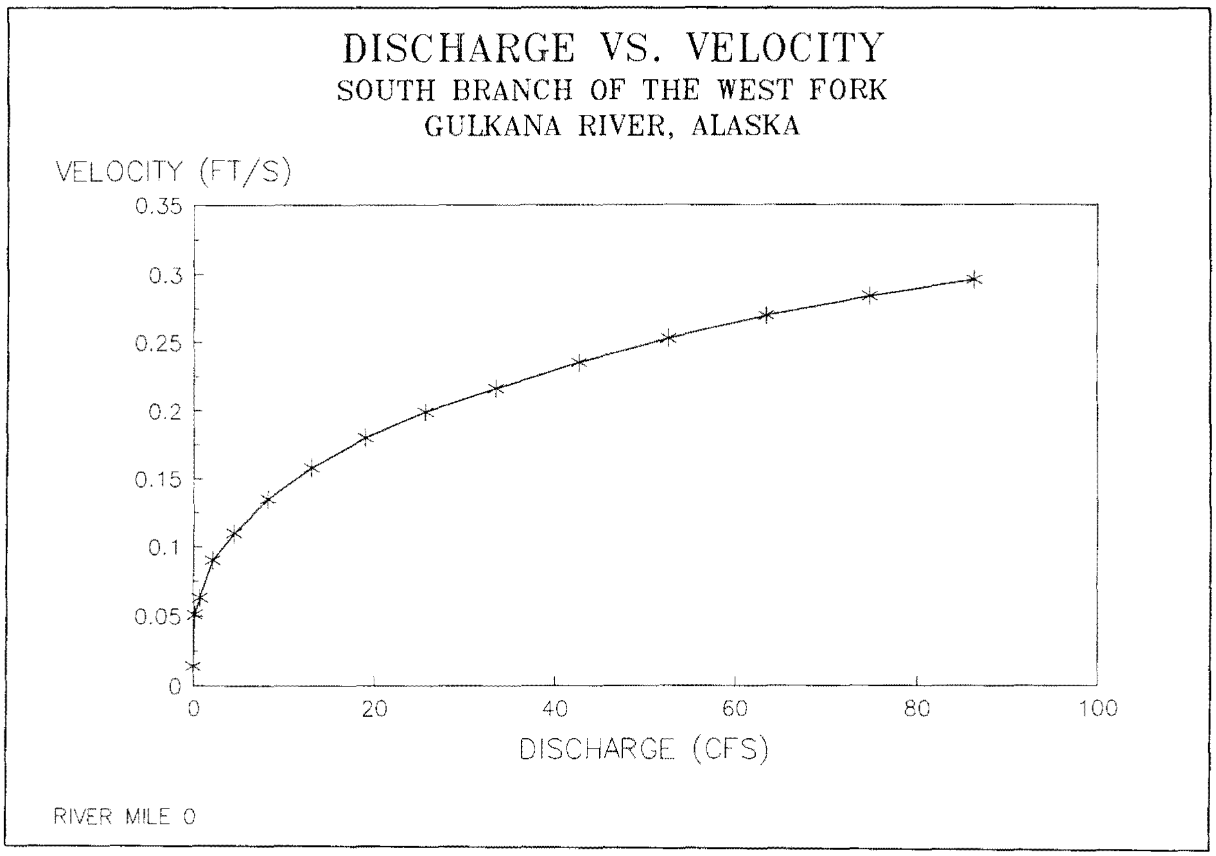

DISCHARGE VS. VELOCITY
NORTH BRANCH OF THE WEST FORK
GULKANA RIVER, ALASKA
VELOCITY (FT/S)
2.5
2
1.5
1
0.5
0
0
50
100
150
200
DISCHARGE (CFS)
AT THE CONFLUENCE WITH THE SOUTH BRANCH

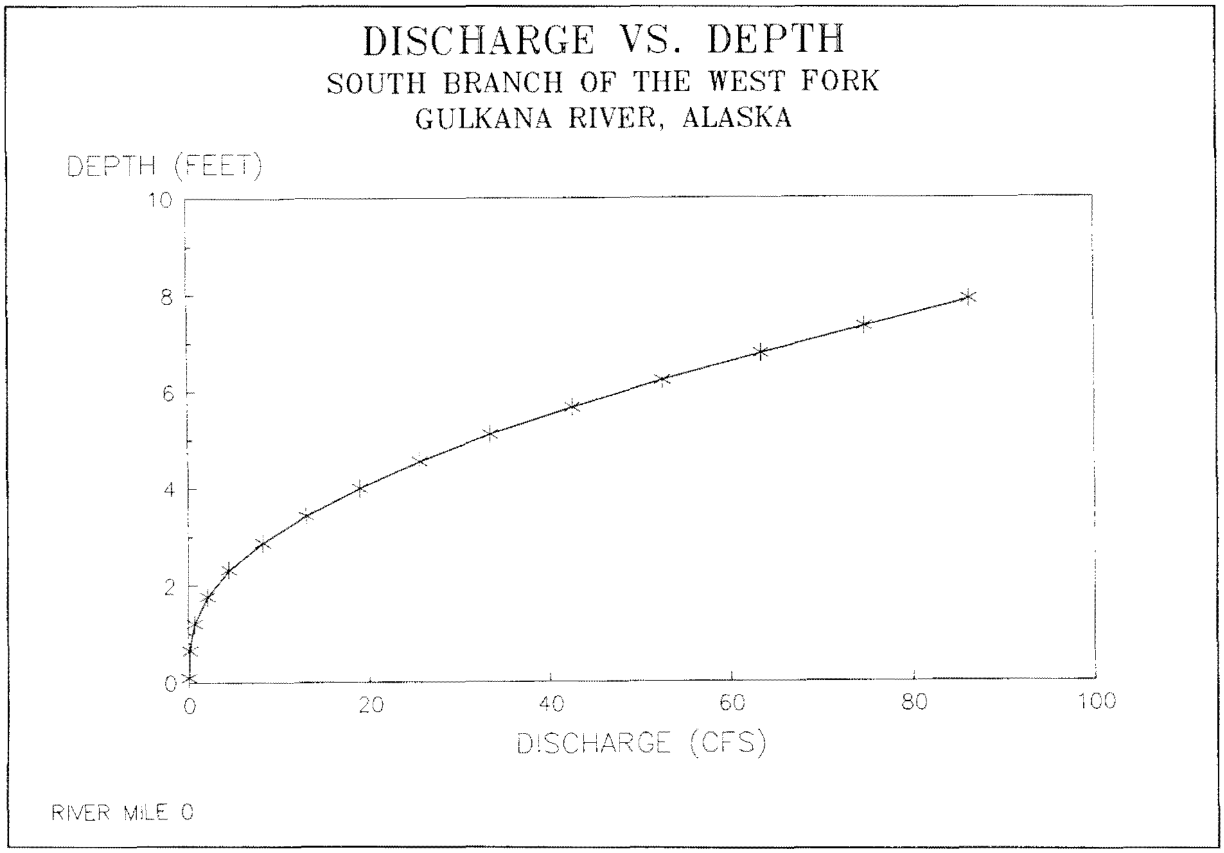

DISCHARGE VS. DEPTH
NORTH BRANCH OF THE WEST FORK
GULKANA RIVER, ALASKA
DEPTH (FEET)
4
3
2
1
0
0
50
100
150
200
DISCHARGE (CFS)
AT CONFLUENCE WITH THE SOUTH BRANCH

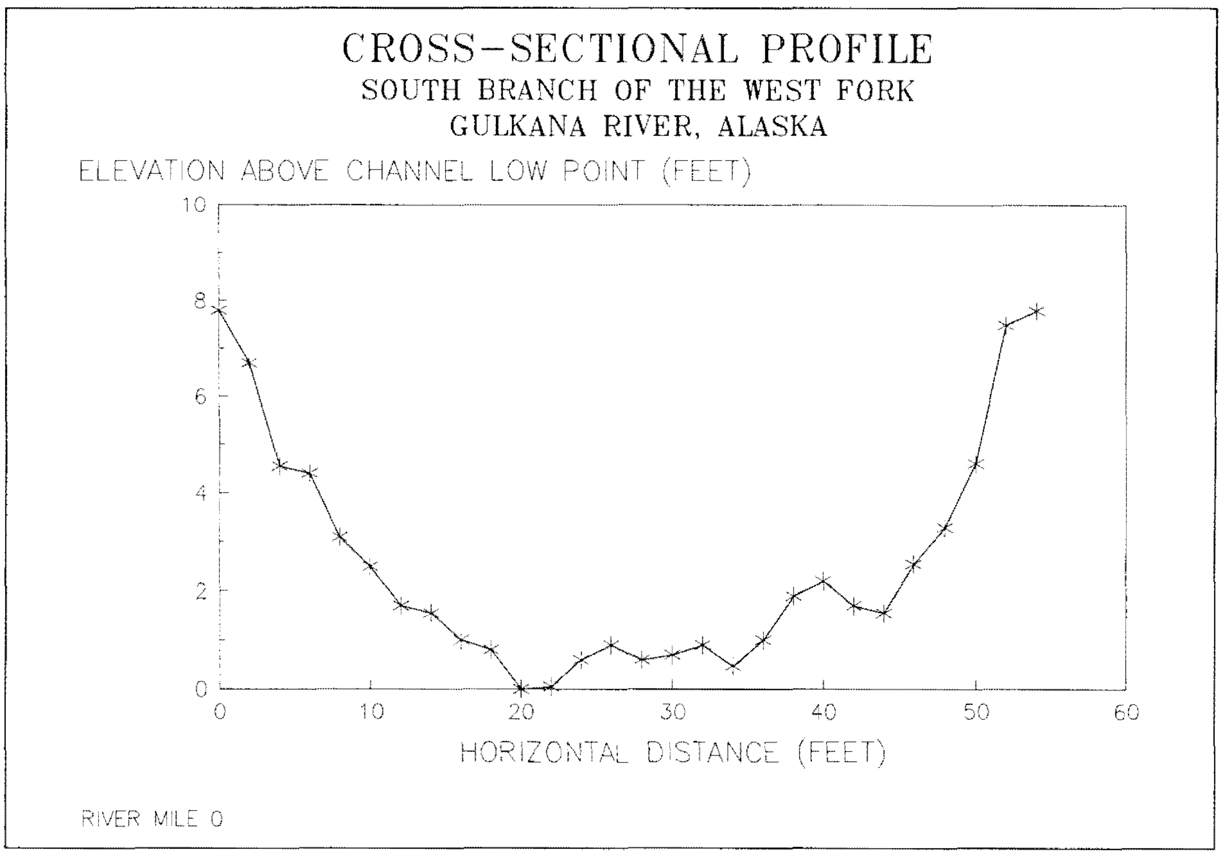

CROSS-SECTIONAL PROFILE
NORTH BRANCH OF THE WEST FORK
GULKANA RIVER, ALASKA
ELEVATION ABOVE CHANNEL LOW POINT (FEET)
4
3
2
1
0
0
10
20
30
40
50
60
HORIZONTAL DISTANCE (FEET)
AT THE CONFLUENCE WITH THE SOUTH BRANCH

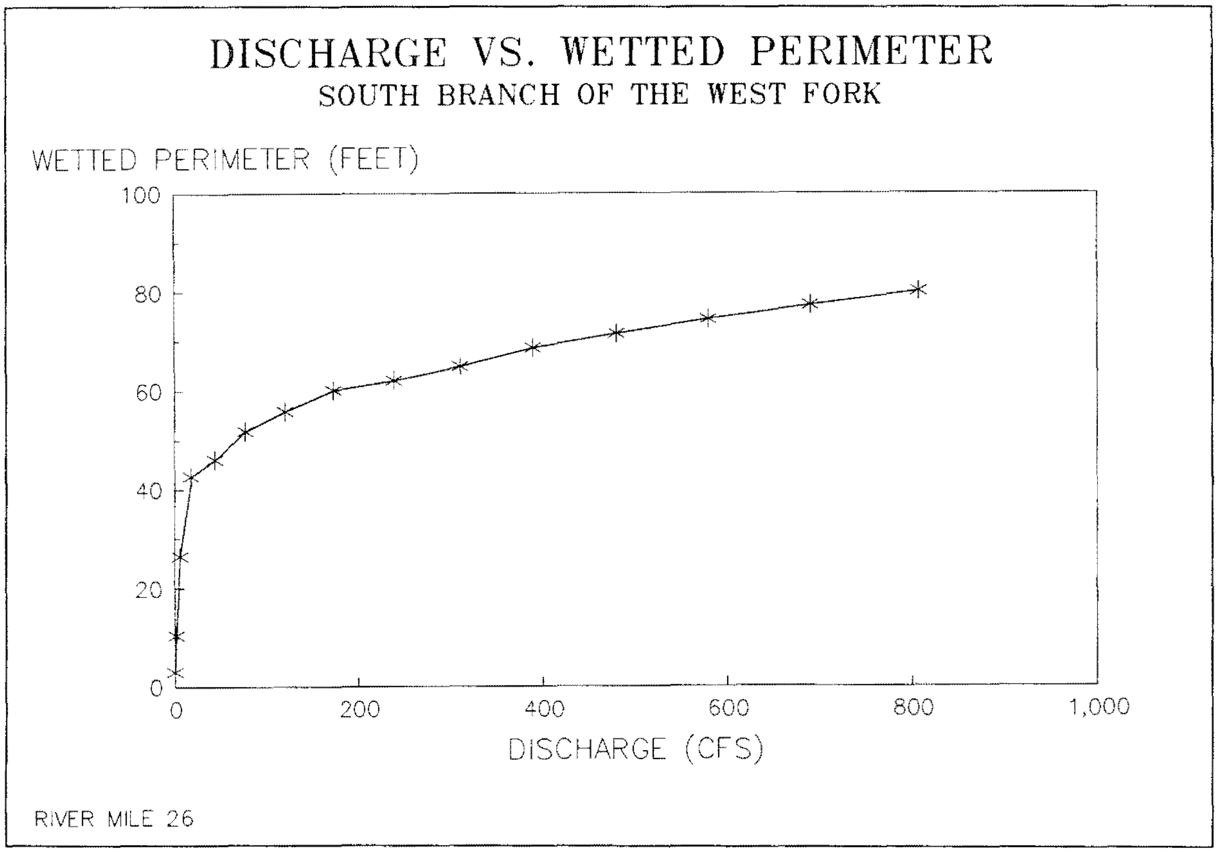

DISCHARGE VS. WETTED PERIMETER
SOUTH BRANCH OF THE WEST FORK
GULKANA RIVER, ALASKA
WETTED PERIMETER (FEET)
70
60
50
40
30
20
10
0
0
20
40
60
80
100
DISCHARGE (CFS)
RIVER MILE 0

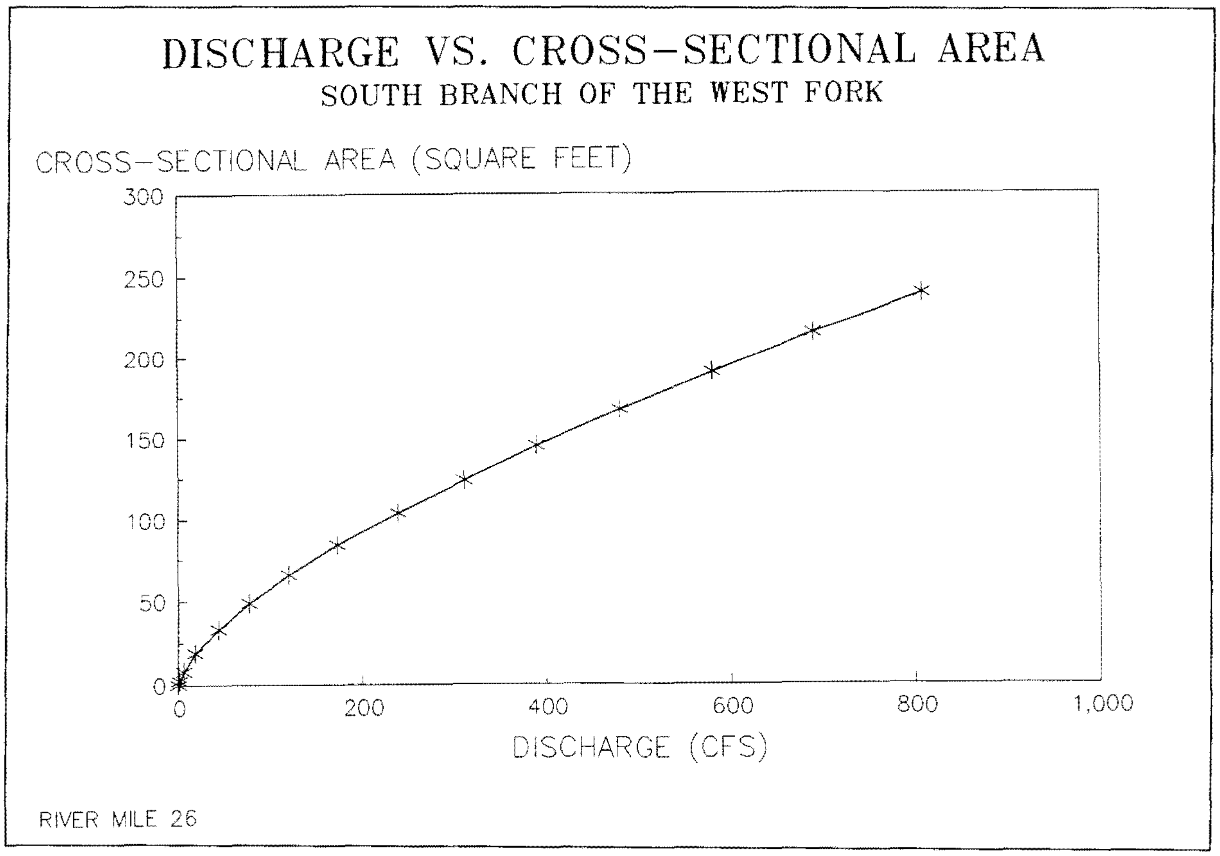

DISCHARGE VS. CROSS-SECTIONAL AREA
SOUTH BRANCH OF THE WEST FORK
GULKANA RIVER, ALASKA
CROSS-SECTIONAL AREA (SQUARE FEET)
350
300
250
200
150
100
50
0
0
20
40
60
80
100
DISCHARGE (CFS)
RIVER MILE 0

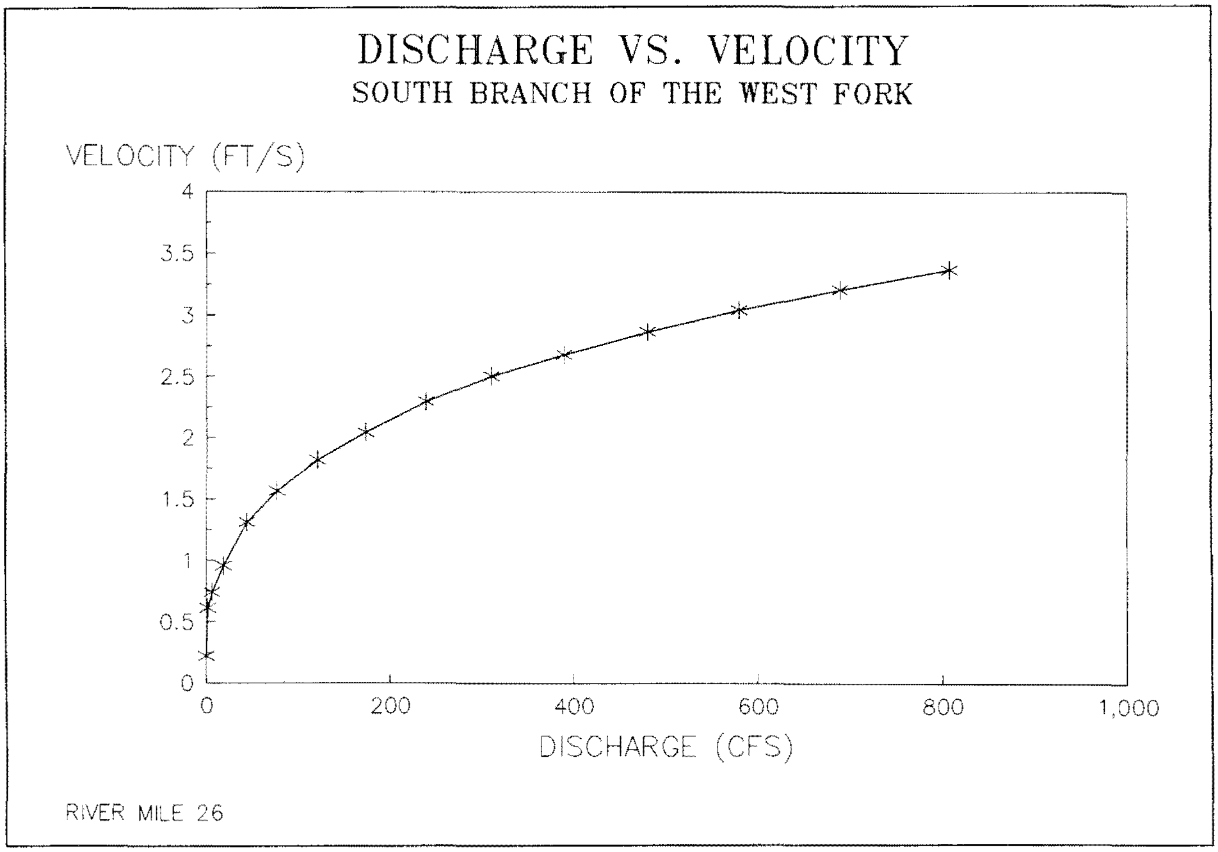

DISCHARGE VS. VELOCITY
SOUTH BRANCH OF THE WEST FORK
GULKANA RIVER, ALASKA
VELOCITY (FT/S)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
20
40
60
80
100
DISCHARGE (CFS)
RIVER MILE 0

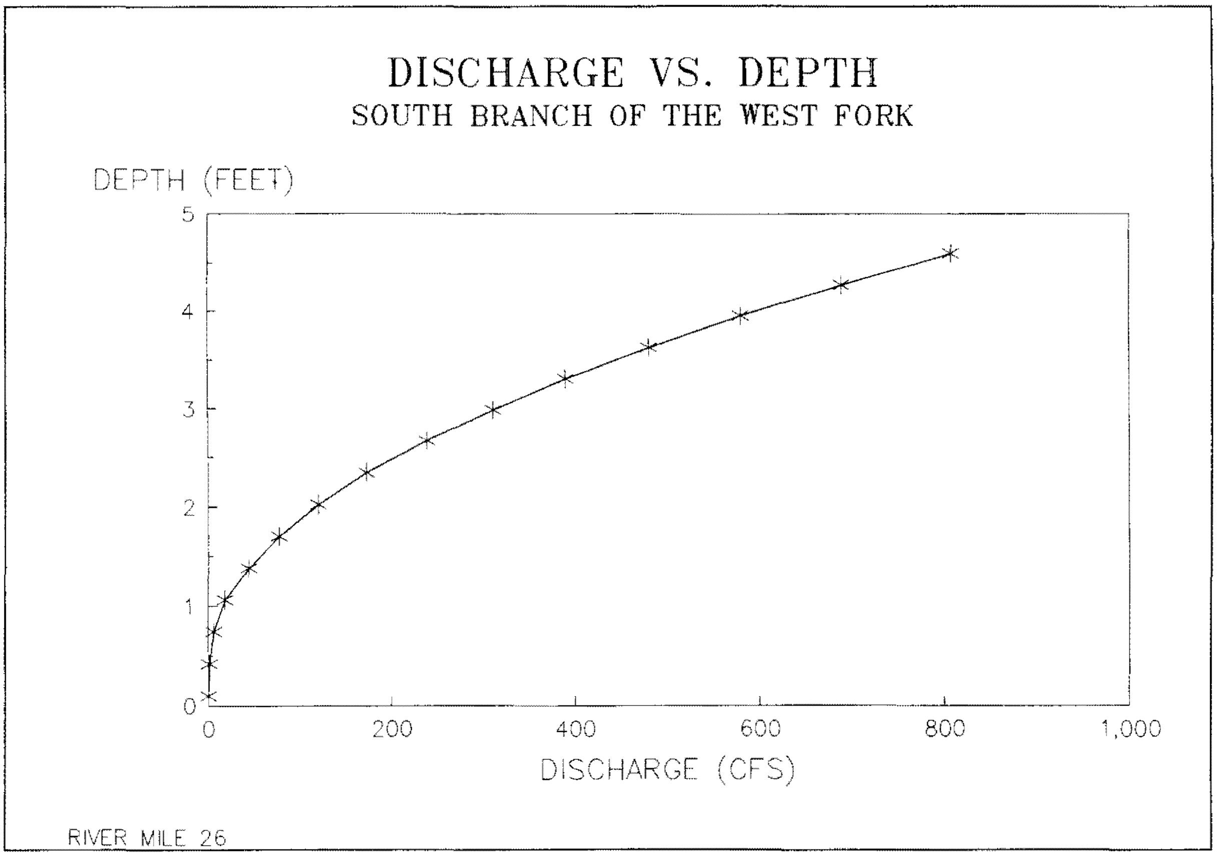

DISCHARGE VS. DEPTH
SOUTH BRANCH OF THE WEST FORK
GULKANA RIVER, ALASKA
DEPTH (FEET)
10
8
6
4
2
0
0
20
40
60
80
100
DISCHARGE (CFS)
RIVER MILE 0

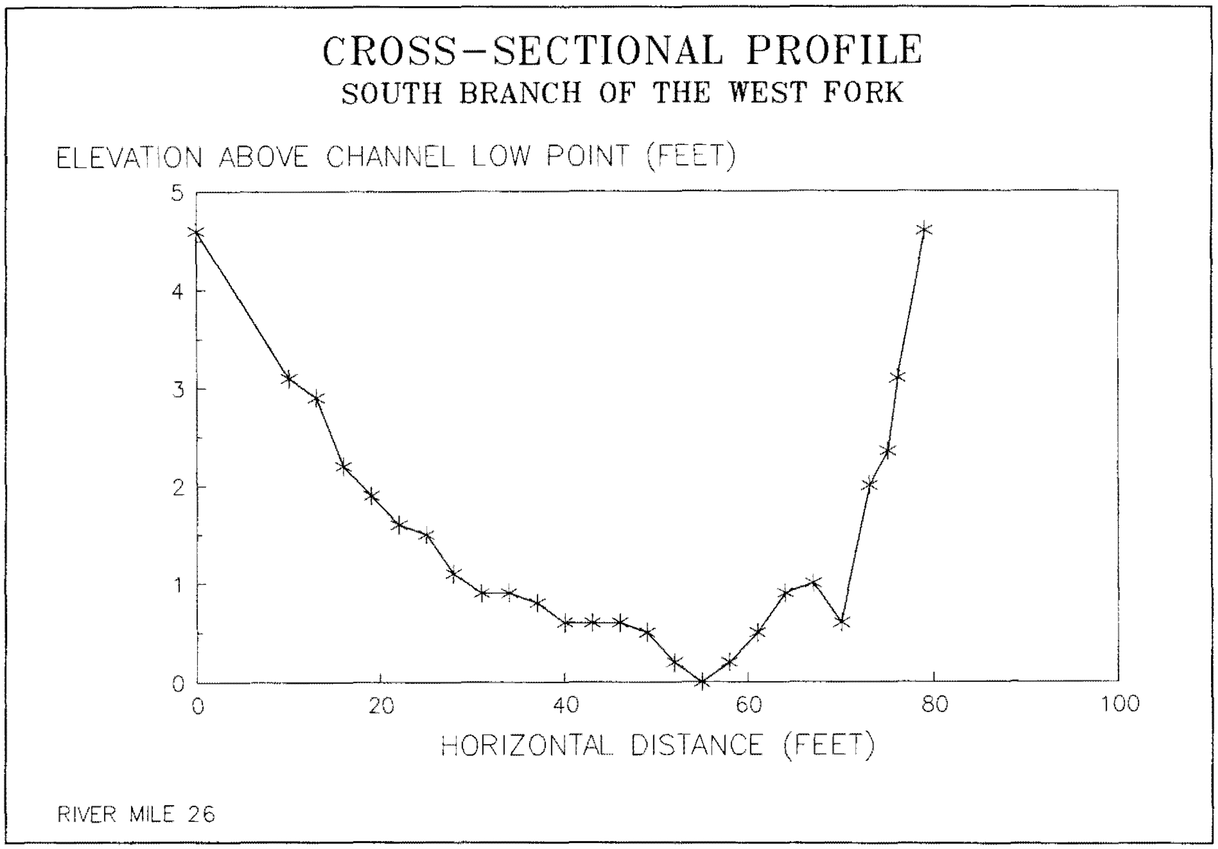

CROSS-SECTIONAL PROFILE
SOUTH BRANCH OF THE WEST FORK
GULKANA RIVER, ALASKA
ELEVATION ABOVE CHANNEL LOW POINT (FEET)
10
8
6
4
2
0
0
10
20
30
40
50
60
HORIZONTAL DISTANCE (FEET)
RIVER MILE 0


DISCHARGE VS. WETTED PERIMETER
SOUTH BRANCH OF THE WEST FORK
WETTED PERIMETER (FEET)
100
80
60
40
20
0
0
200
400
600
800
1,000
DISCHARGE (CFS)
RIVER MILE 26

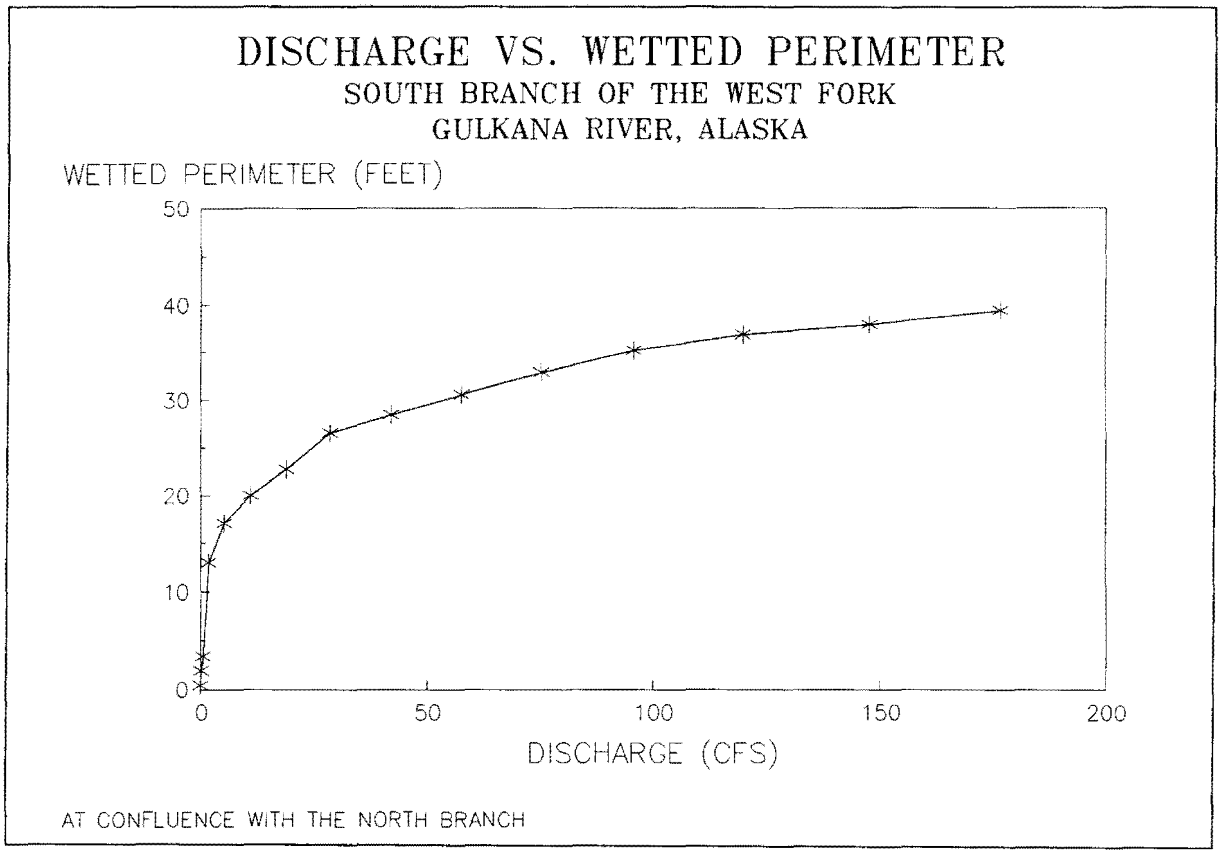

DISCHARGE VS. CROSS-SECTIONAL AREA
SOUTH BRANCH OF THE WEST FORK
CROSS-SECTIONAL AREA (SQUARE FEET)
300
250
200
150
100
50
0
0
200
400
600
800
1,000
DISCHARGE (CFS)
RIVER MILE 26


DISCHARGE VS. VELOCITY
SOUTH BRANCH OF THE WEST FORK
VELOCITY (FT/S)
4
3.5
3
2.5
2
1.5
1
0.5
0
0
200
400
600
800
1,000
DISCHARGE (CFS)
RIVER MILE 26

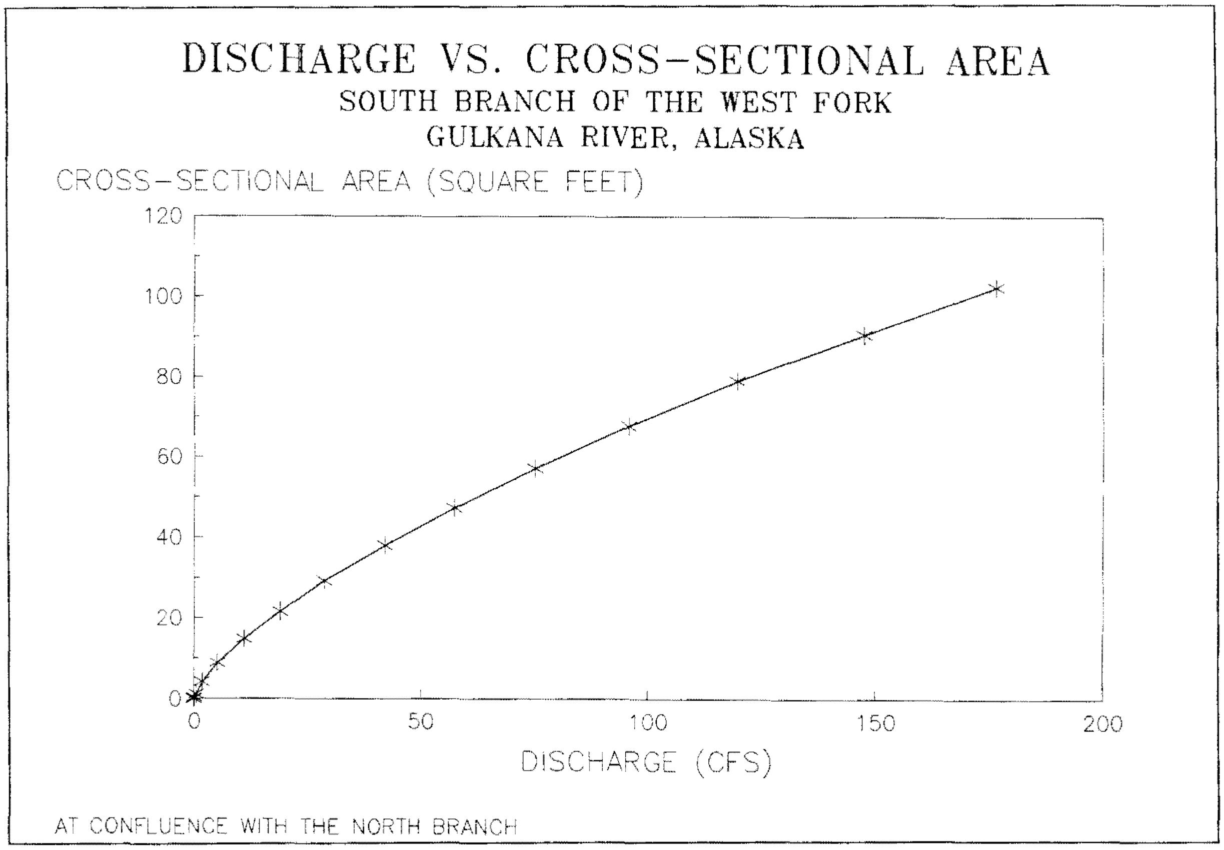

DISCHARGE VS. DEPTH
SOUTH BRANCH OF THE WEST FORK
DEPTH (FEET)
5
4
3
2
1
0
0
200
400
600
800
1,000
DISCHARGE (CFS)
RIVER MILE 26

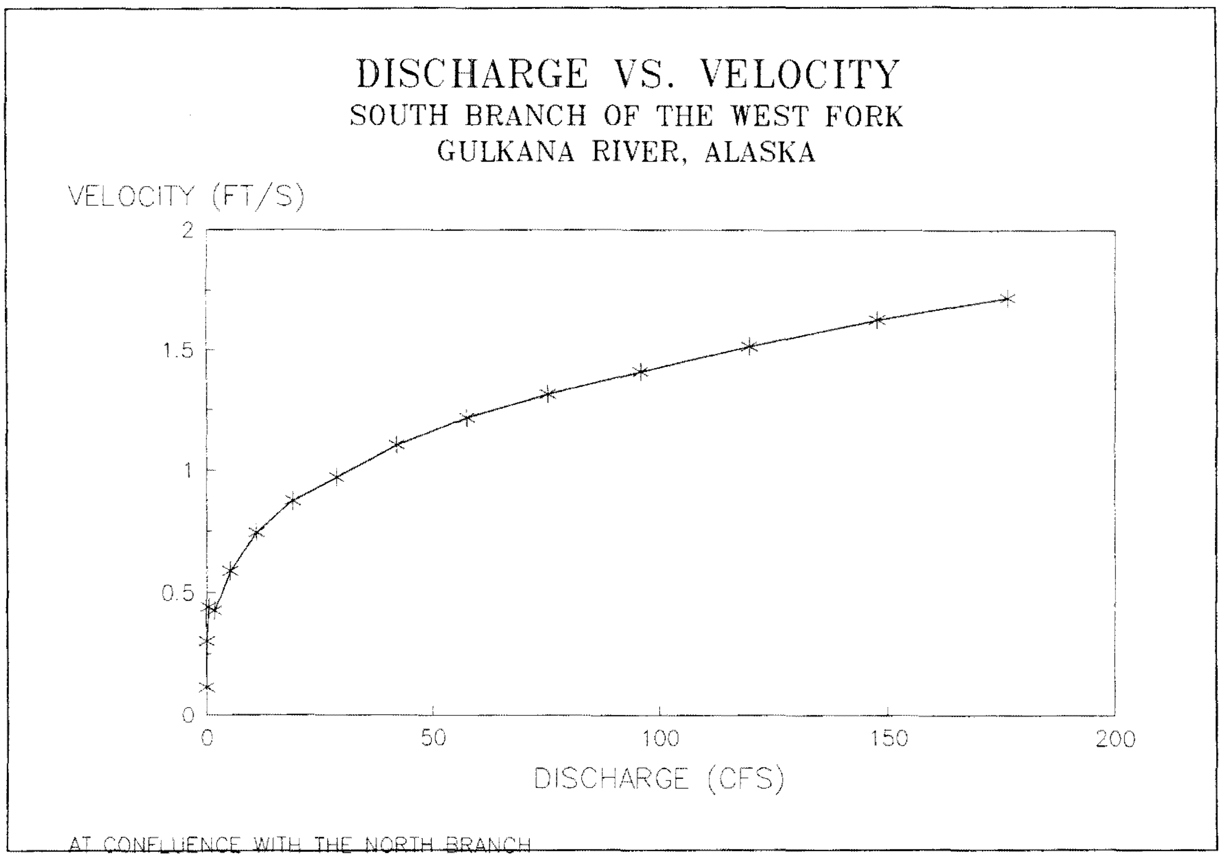


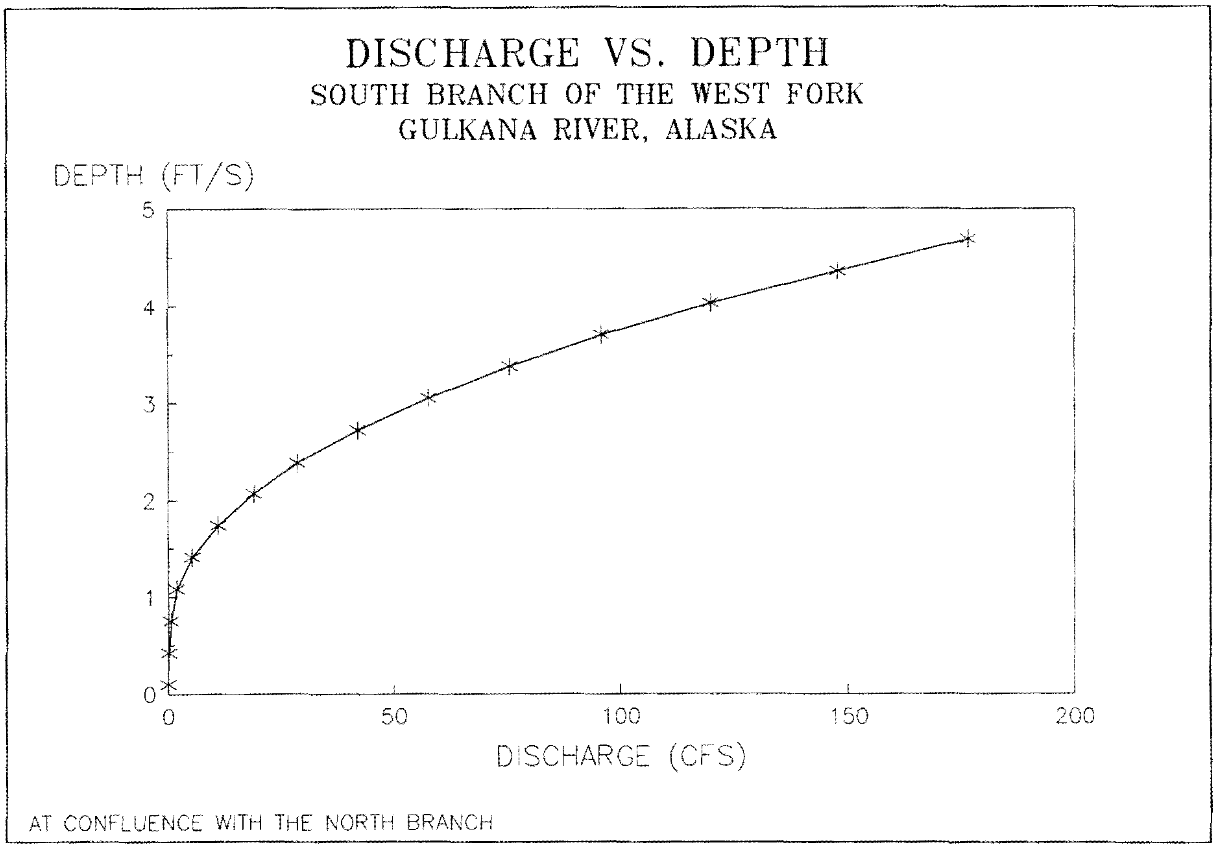
CROSS-SECTIONAL PROFILE
SOUTH BRANCH OF THE WEST FORK
ELEVATION ABOVE CHANNEL LOW POINT (FEET)
5
4
3
2
1
0
0
20
40
60
80
100
HORIZONTAL DISTANCE (FEET)
RIVER MILE 26

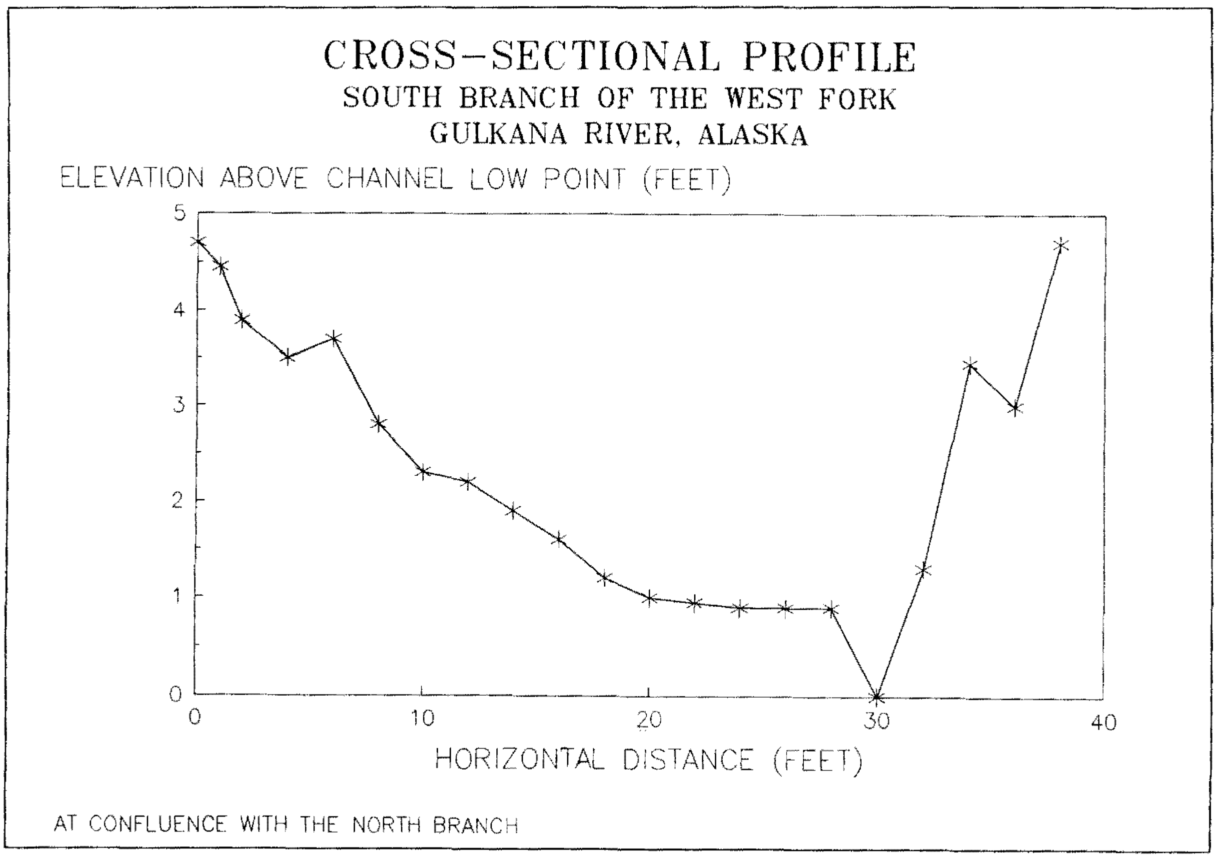


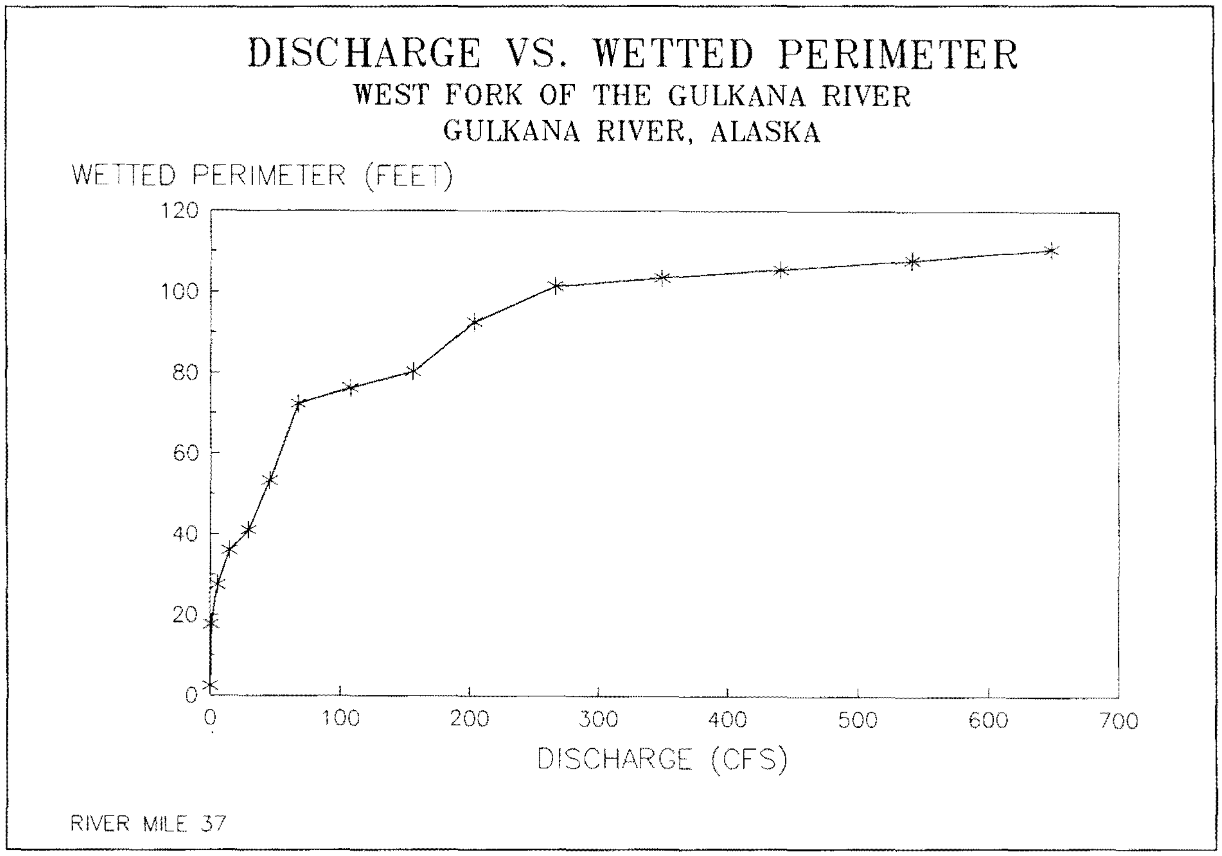
DISCHARGE VS. WETTED PERIMETER
SOUTH BRANCH OF THE WEST FORK
GULKANA RIVER, ALASKA
WETTED PERIMETER (FEET)
50
40
30
20
10
0
0
50
100
150
200
DISCHARGE (CFS)
AT CONFLUENCE WITH THE NORTH BRANCH


DISCHARGE VS. CROSS-SECTIONAL AREA
SOUTH BRANCH OF THE WEST FORK
GULKANA RIVER, ALASKA
CROSS-SECTIONAL AREA (SQUARE FEET)
120
100
80
60
40
20
0
0
50
100
150
200
DISCHARGE (CFS)
AT CONFLUENCE WITH THE NORTH BRANCH

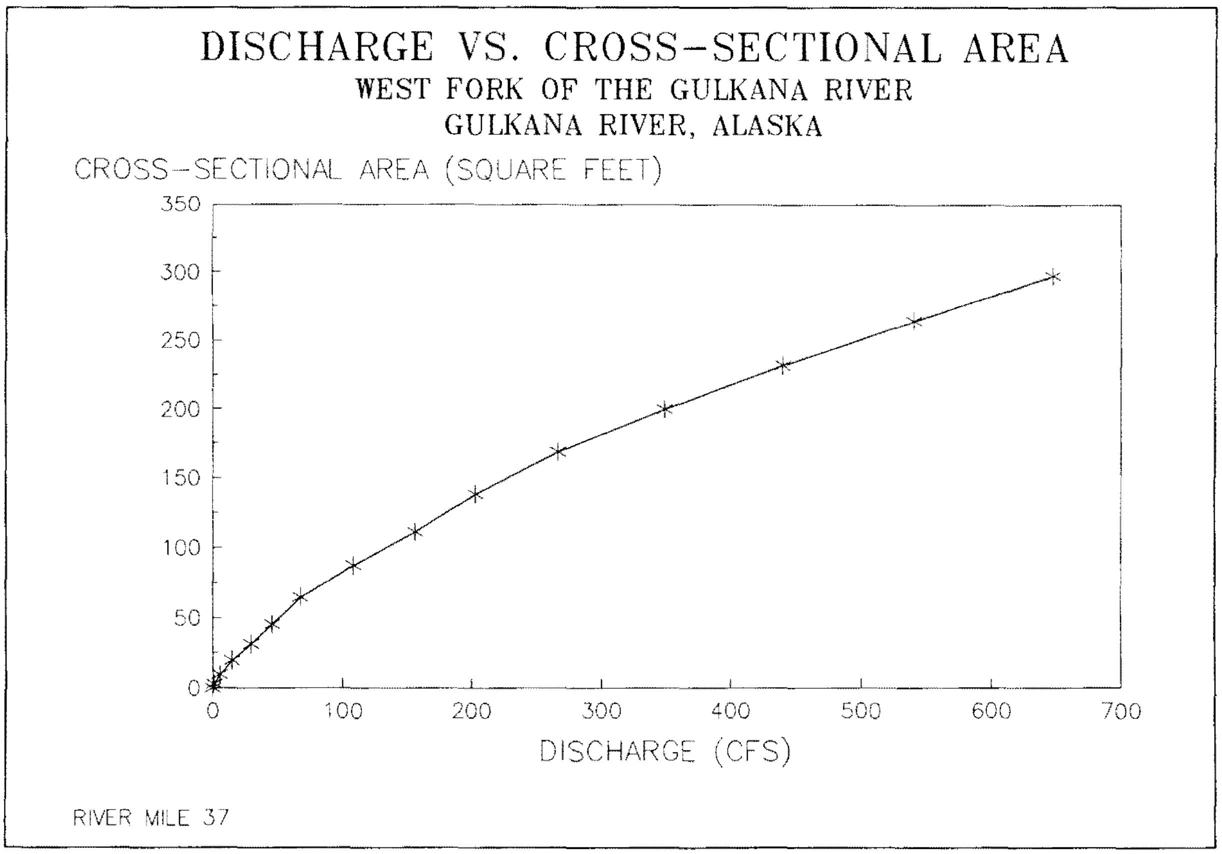

DISCHARGE VS. VELOCITY
SOUTH BRANCH OF THE WEST FORK
GULKANA RIVER, ALASKA
VELOCITY (FT/S)
2
1.5
1
0.5
0
0
50
100
150
200
DISCHARGE (CFS)
AT CONFLUENCE WITH THE NORTH BRANCH


DISCHARGE VS. DEPTH
SOUTH BRANCH OF THE WEST FORK
GULKANA RIVER, ALASKA
DEPTH (FT/S)
0
1
2
3
4
5
0
50
100
150
200
DISCHARGE (CFS)
AT CONFLUENCE WITH THE NORTH BRANCH

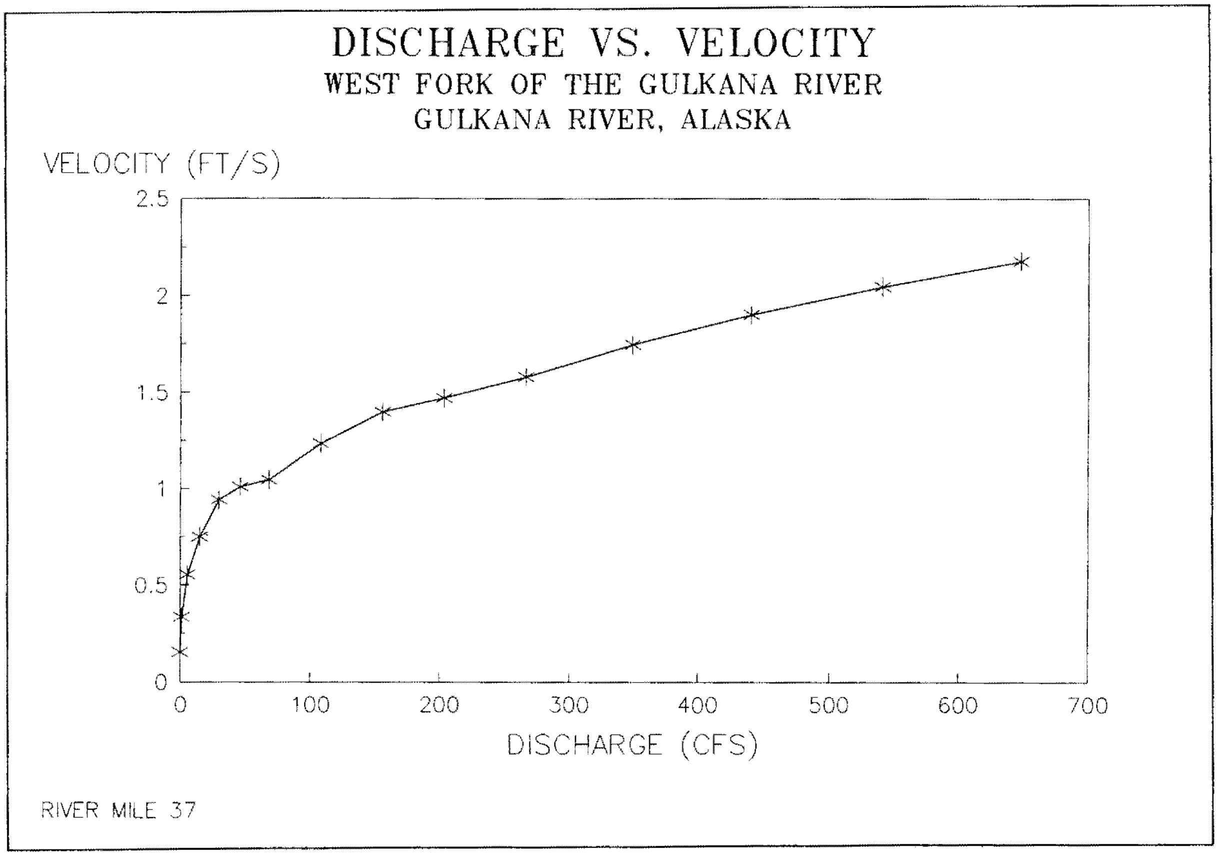

CROSS-SECTIONAL PROFILE
SOUTH BRANCH OF THE WEST FORK
GULKANA RIVER, ALASKA
ELEVATION ABOVE CHANNEL LOW POINT (FEET)
0
1
2
3
4
5
0
10
20
30
40
HORIZONTAL DISTANCE (FEET)
AT CONFLUENCE WITH THE NORTH BRANCH

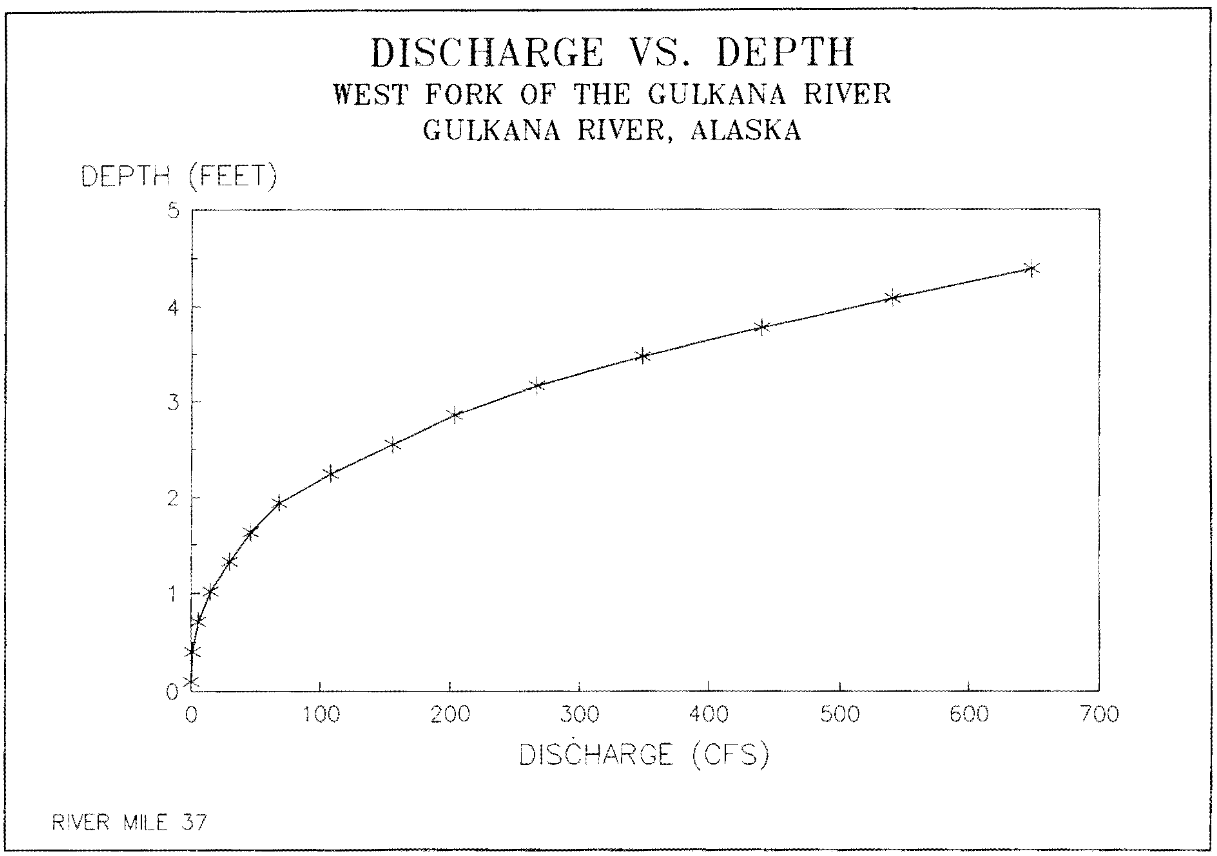


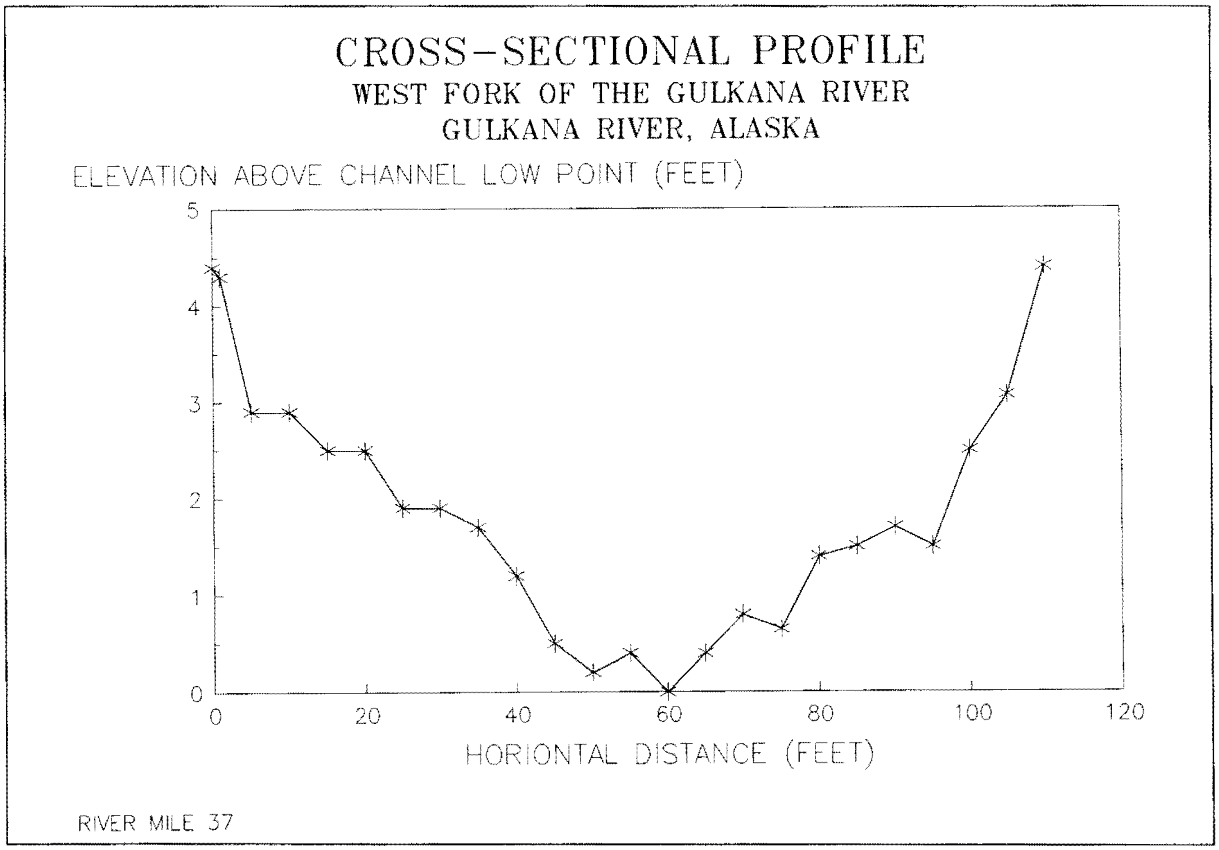
DISCHARGE VS. WETTED PERIMETER
WEST FORK OF THE GULKANA RIVER
GULKANA RIVER, ALASKA
WETTED PERIMETER (FEET)
120
100
80
60
40
20
0
0
100
200
300
400
500
600
700
DISCHARGE (CFS)
RIVER MILE 37

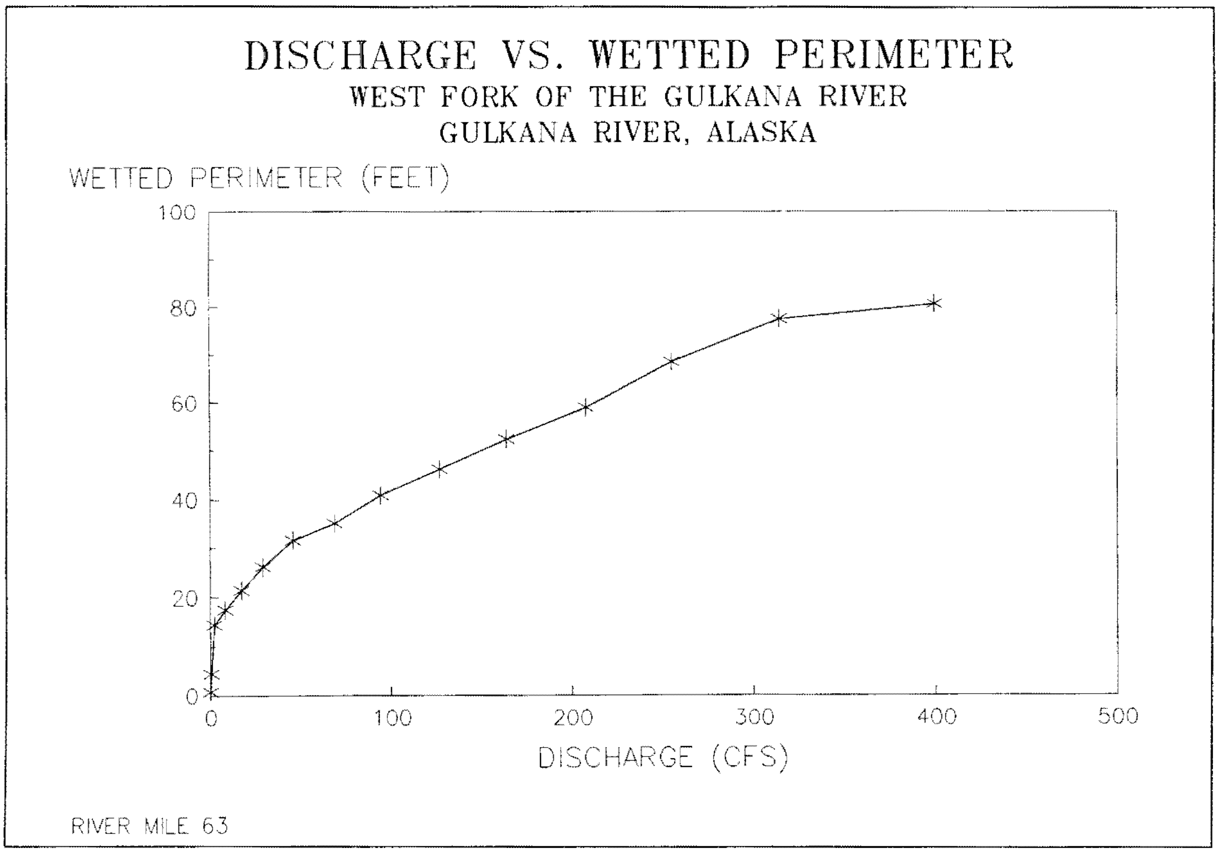


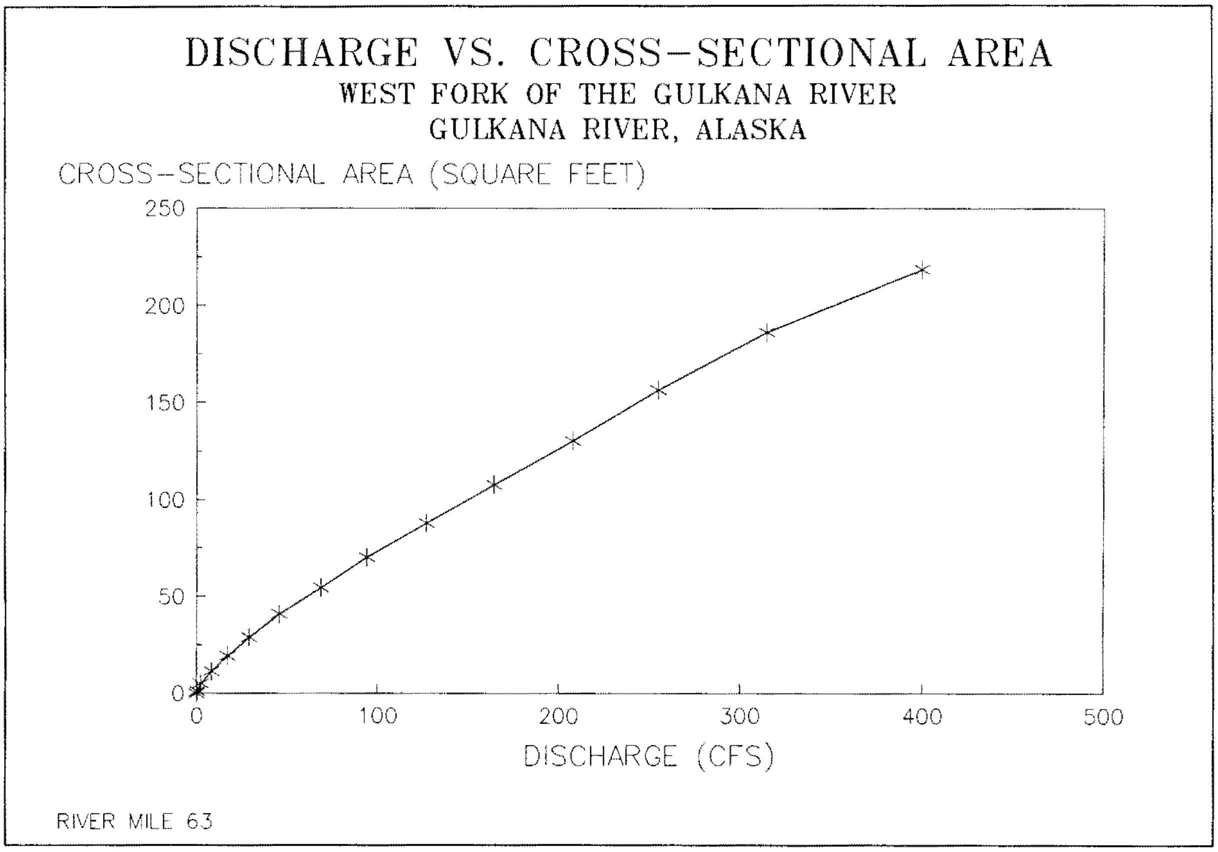
DISCHARGE VS. CROSS-SECTIONAL AREA
WEST FORK OF THE GULKANA RIVER
GULKANA RIVER, ALASKA
CROSS-SECTIONAL AREA (SQUARE FEET)
350
300
250
200
150
100
50
0
0
100
200
300
400
500
600
700
DISCHARGE (CFS)
RIVER MILE 37

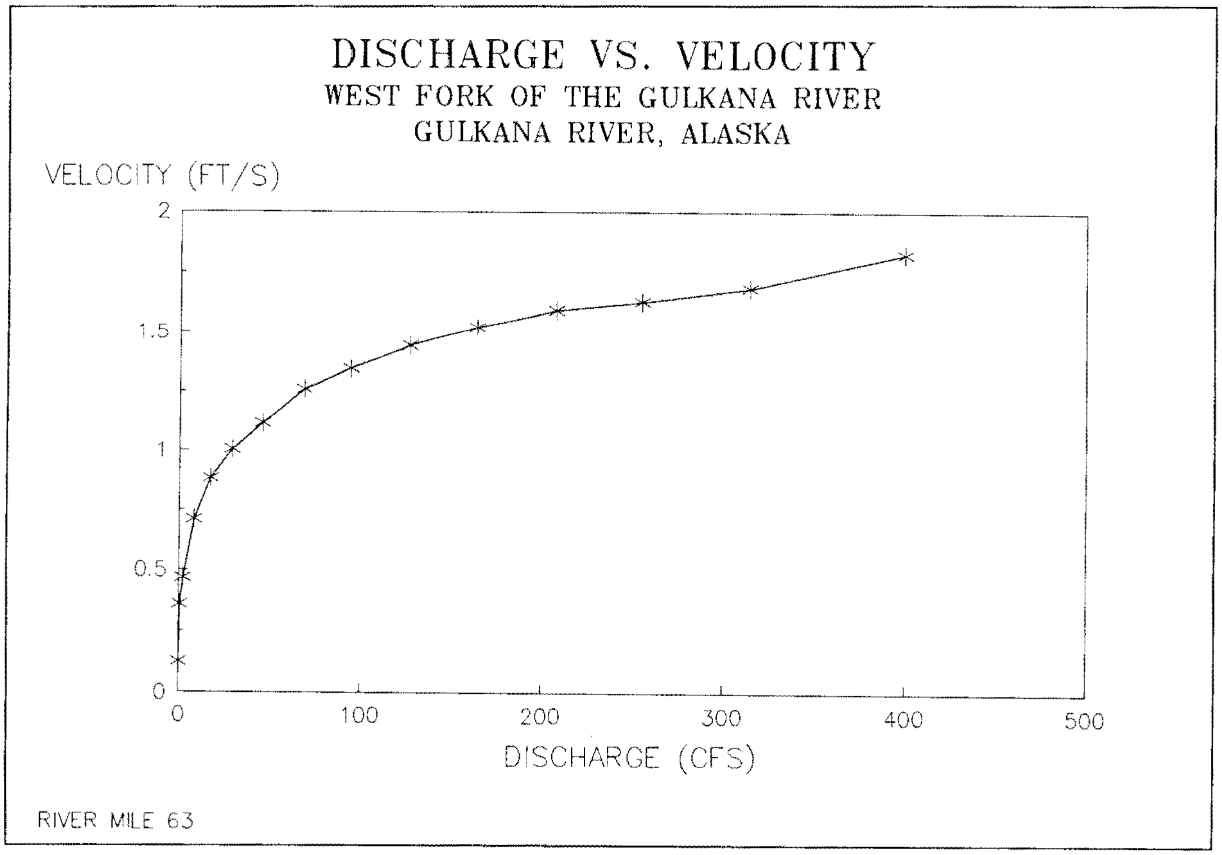

DISCHARGE VS. VELOCITY
WEST FORK OF THE GULKANA RIVER
GULKANA RIVER, ALASKA
VELOCITY (FT/S)
2.5
2
1.5
1
0.5
0
0
100
200
300
400
500
600
700
DISCHARGE (CFS)
RIVER MILE 37

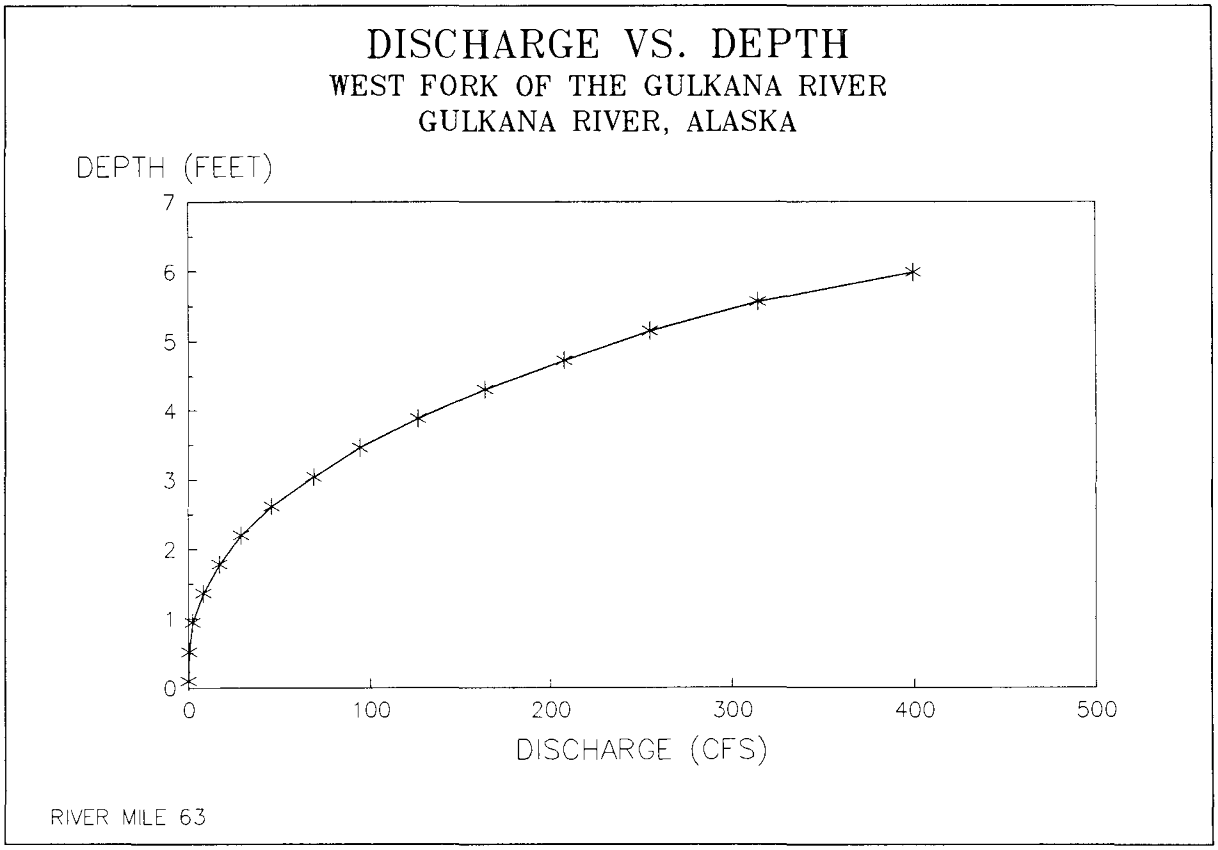

DISCHARGE VS. DEPTH
WEST FORK OF THE GULKANA RIVER
GULKANA RIVER, ALASKA
DEPTH (FEET)
5
4
3
2
1
0
0
100
200
300
400
500
600
700
DISCHARGE (CFS)
RIVER MILE 37

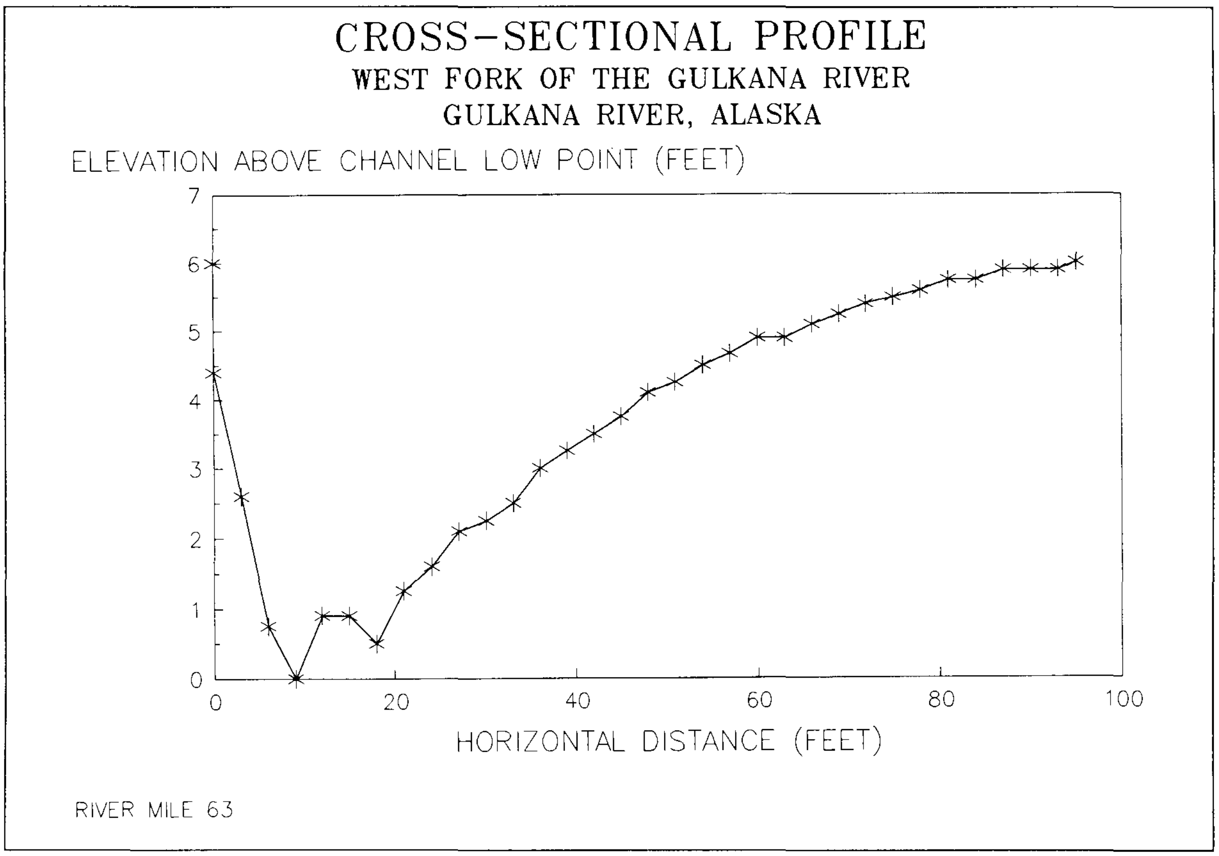

CROSS-SECTIONAL PROFILE
WEST FORK OF THE GULKANA RIVER
GULKANA RIVER, ALASKA
ELEVATION ABOVE CHANNEL LOW POINT (FEET)
5
4
3
2
1
0
0
20
40
60
80
100
120
HORIONTAL DISTANCE (FEET)
RIVER MILE 37

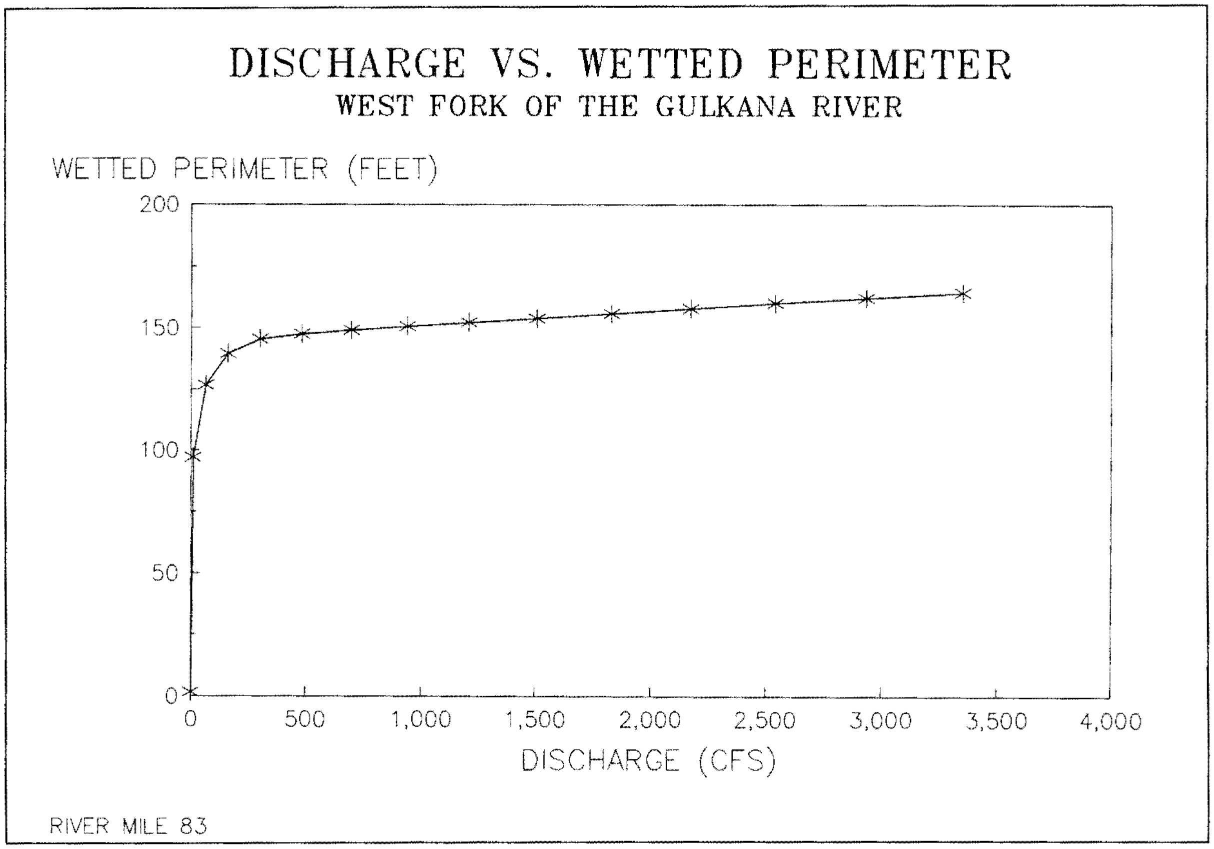

DISCHARGE VS. WETTED PERIMETER
WEST FORK OF THE GULKANA RIVER
GULKANA RIVER, ALASKA
WETTED PERIMETER (FEET)
100
80
60
40
20
0
0
100
200
300
400
500
DISCHARGE (CFS)
RIVER MILE 63

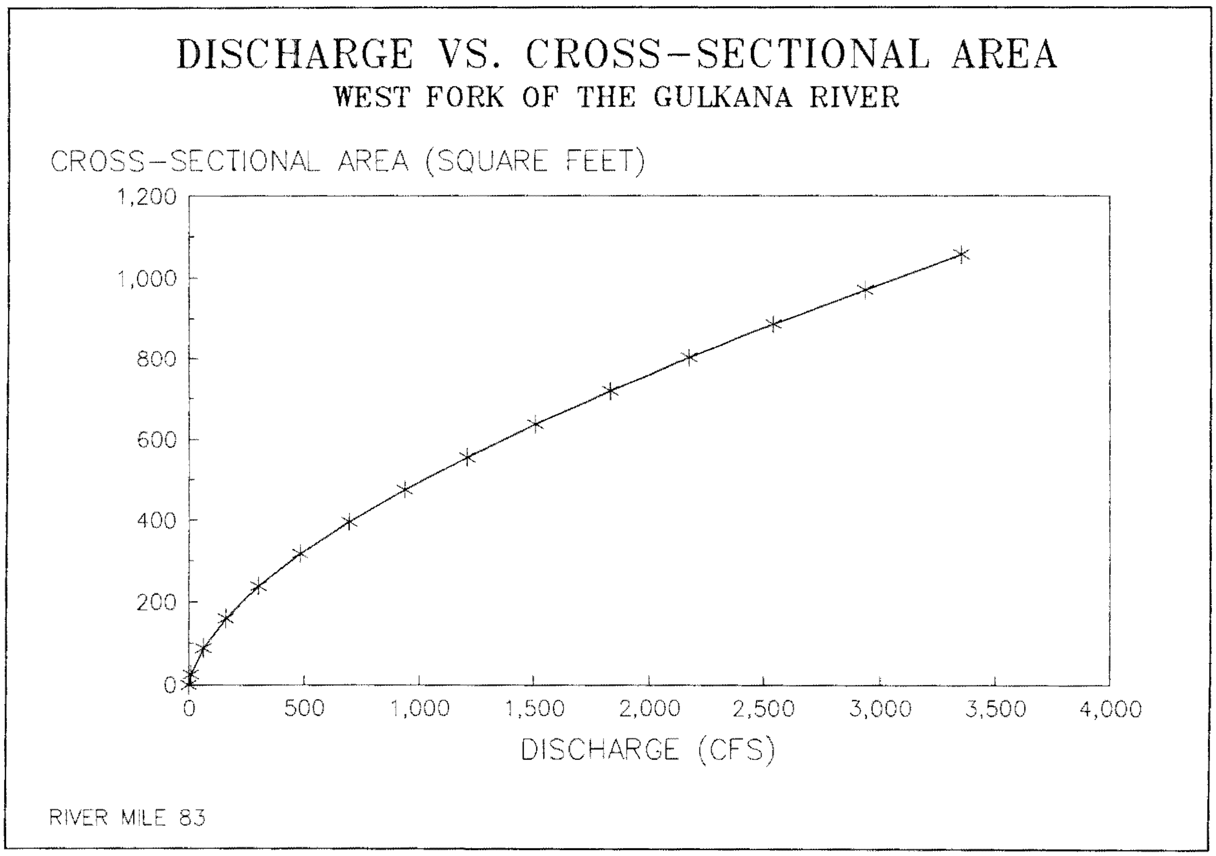

DISCHARGE VS. CROSS-SECTIONAL AREA
WEST FORK OF THE GULKANA RIVER
GULKANA RIVER, ALASKA
CROSS-SECTIONAL AREA (SQUARE FEET)
250
200
150
100
50
0
0
100
200
300
400
500
DISCHARGE (CFS)
RIVER MILE 63

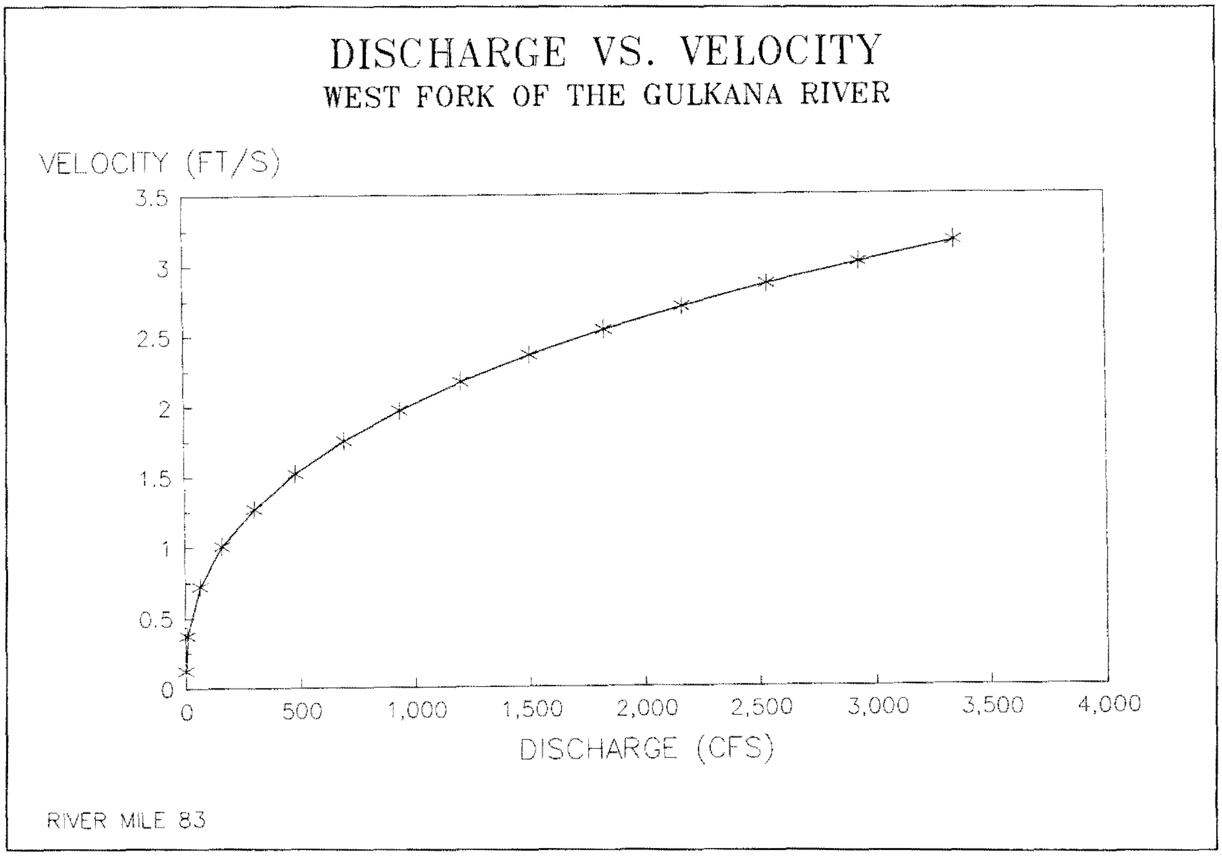

DISCHARGE VS. VELOCITY
WEST FORK OF THE GULKANA RIVER
GULKANA RIVER, ALASKA
VELOCITY (FT/S)
2
1.5
1
0.5
0
0
100
200
300
400
500
DISCHARGE (CFS)
RIVER MILE 63

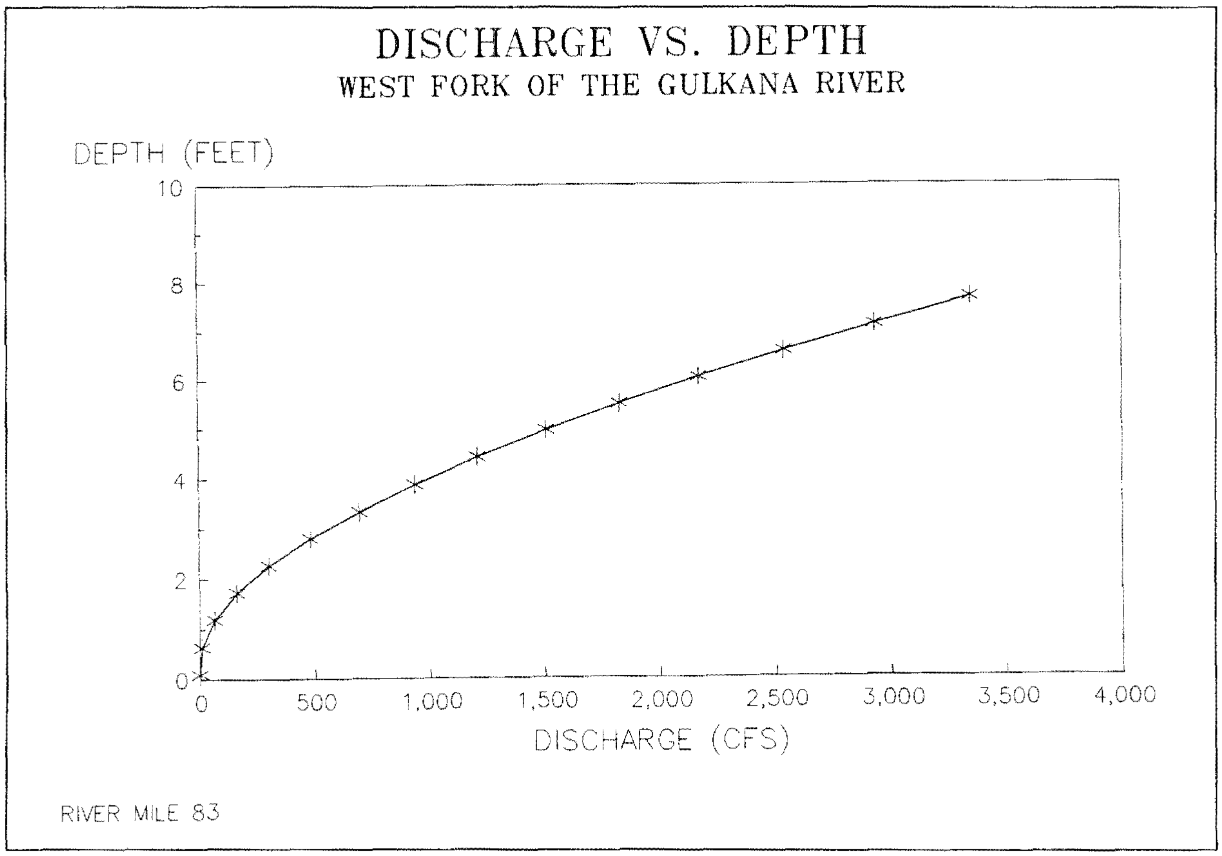

DISCHARGE VS. DEPTH
WEST FORK OF THE GULKANA RIVER
GULKANA RIVER, ALASKA
DEPTH (FEET)
7
6
5
4
3
2
1
0
0
100
200
300
400
500
DISCHARGE (CFS)
RIVER MILE 63

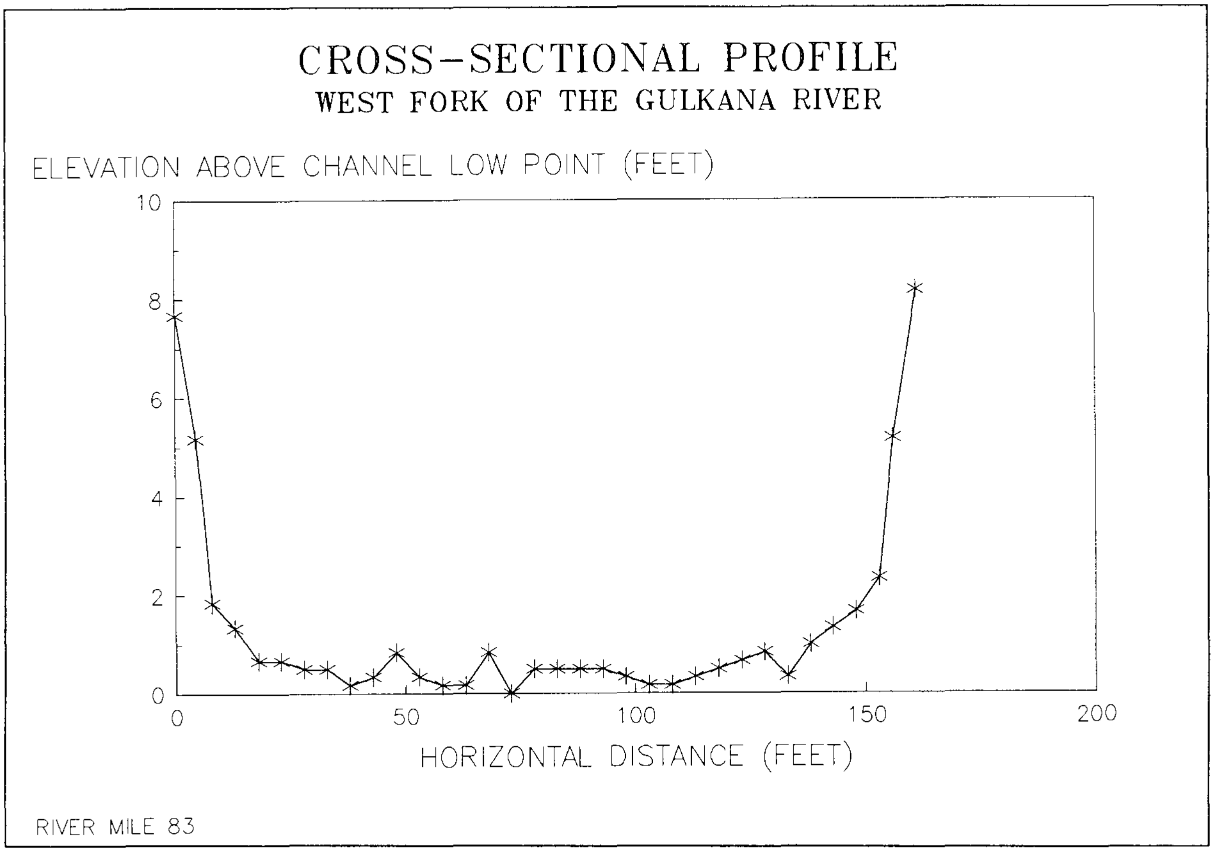

CROSS-SECTIONAL PROFILE
WEST FORK OF THE GULKANA RIVER
GULKANA RIVER, ALASKA
ELEVATION ABOVE CHANNEL LOW POINT (FEET)
7
6
5
4
3
2
1
0
0
20
40
60
80
100
HORIZONTAL DISTANCE (FEET)
RIVER MILE 63

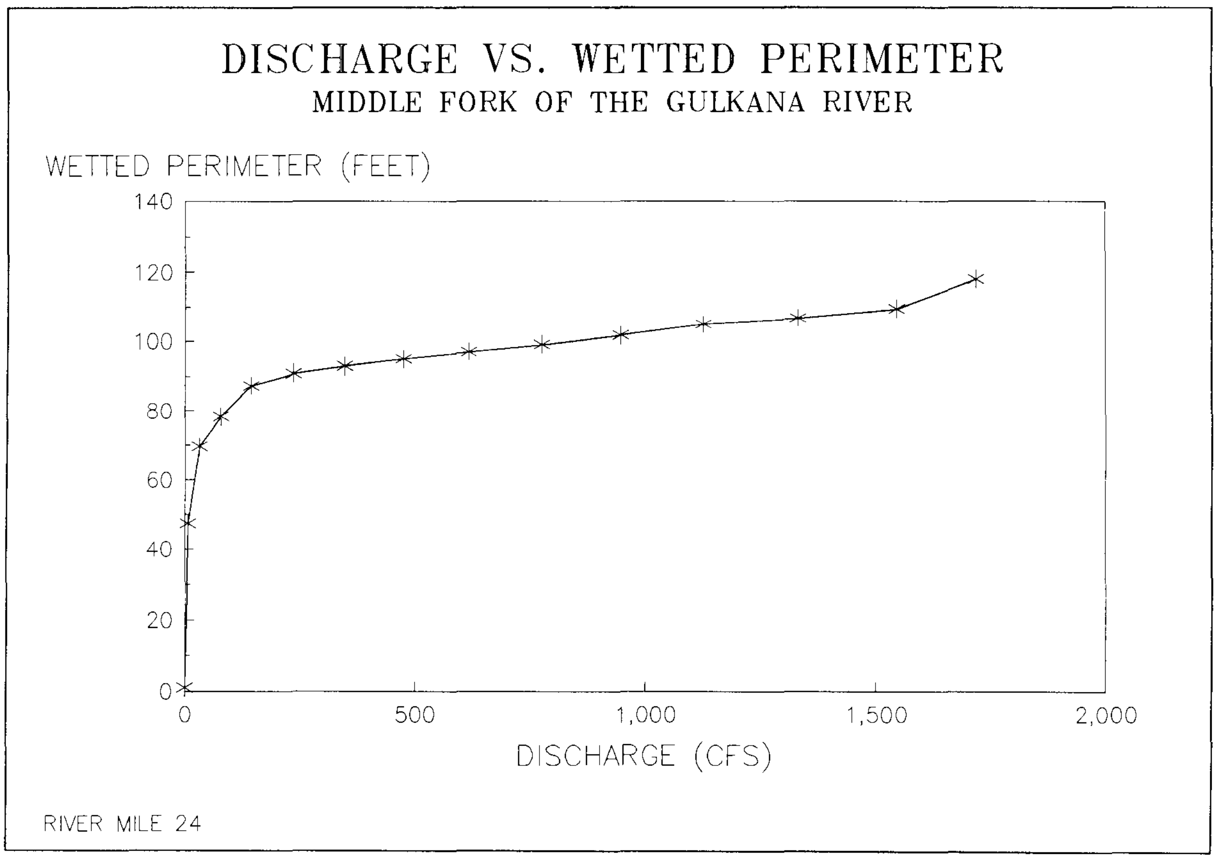

DISCHARGE VS. WETTED PERIMETER
WEST FORK OF THE GULKANA RIVER
WETTED PERIMETER (FEET)
200
150
100
50
0
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
DISCHARGE (CFS)
RIVER MILE 83

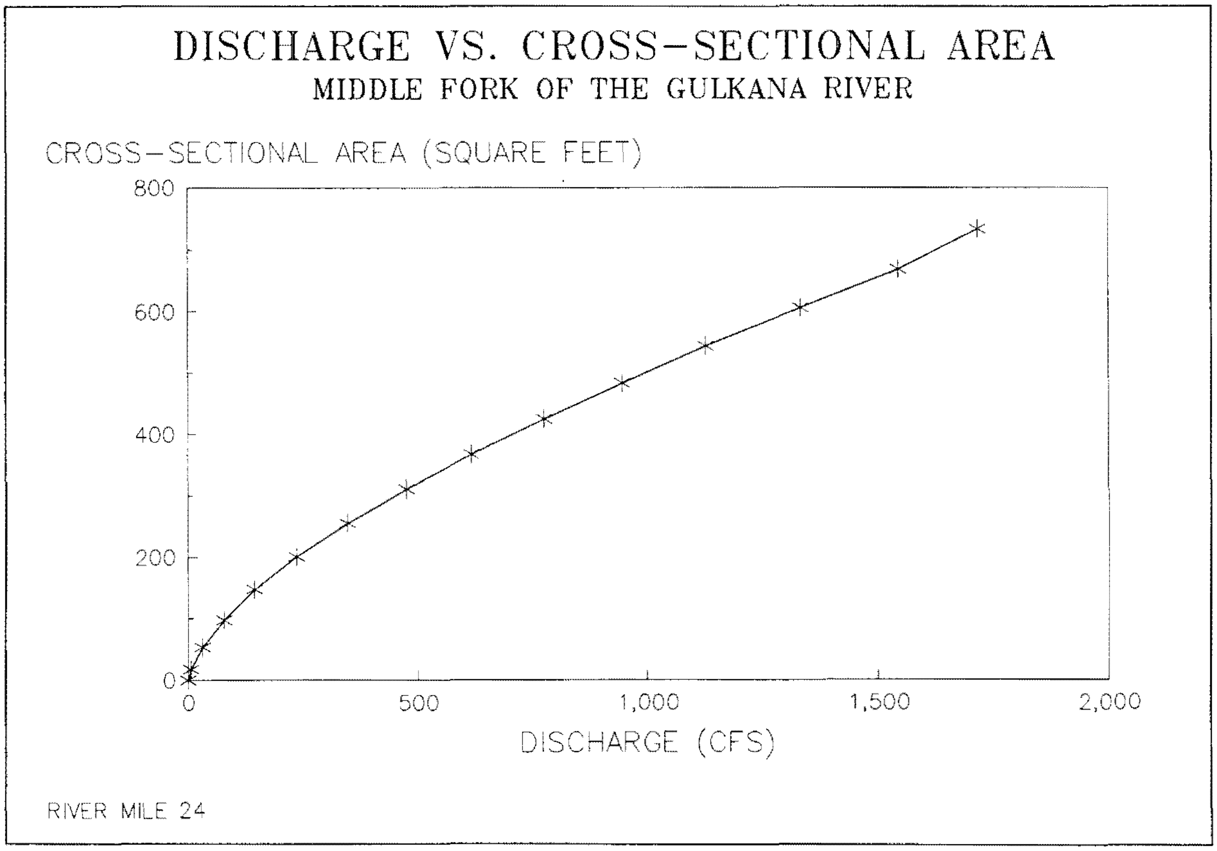

DISCHARGE VS. CROSS-SECTIONAL AREA
WEST FORK OF THE GULKANA RIVER
CROSS-SECTIONAL AREA (SQUARE FEET)
1,200
1,000
800
600
400
200
0
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
DISCHARGE (CFS)
RIVER MILE 83


DISCHARGE VS. VELOCITY
WEST FORK OF THE GULKANA RIVER
VELOCITY (FT/S)
3.5
3
2.5
2
1.5
1
0.5
0
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
DISCHARGE (CFS)
RIVER MILE 83

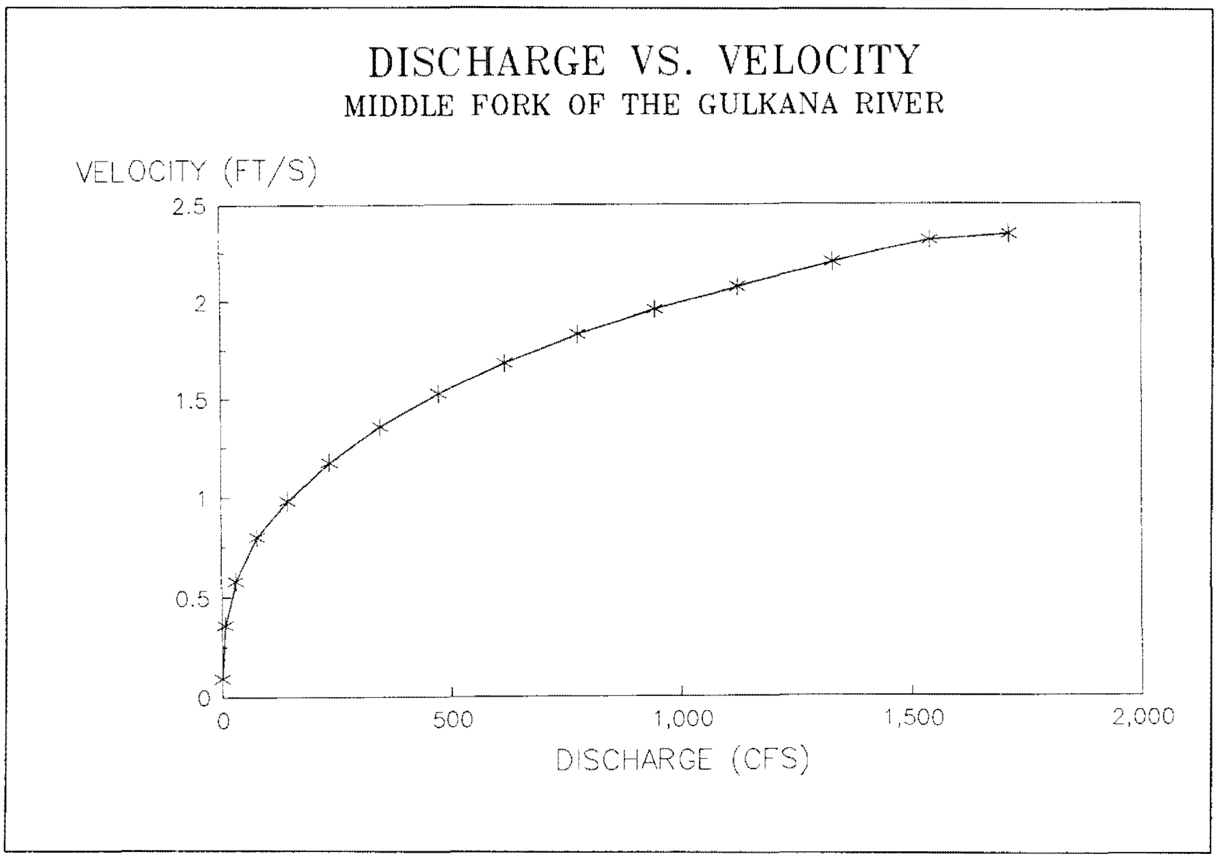

DISCHARGE VS. DEPTH
WEST FORK OF THE GULKANA RIVER
DEPTH (FEET)
10
8
6
4
2
0
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
DISCHARGE (CFS)
RIVER MILE 83


CROSS-SECTIONAL PROFILE
WEST FORK OF THE GULKANA RIVER
ELEVATION ABOVE CHANNEL LOW POINT (FEET)
10
8
6
4
2
0
0
50
100
150
200
HORIZONTAL DISTANCE (FEET)
RIVER MILE 83

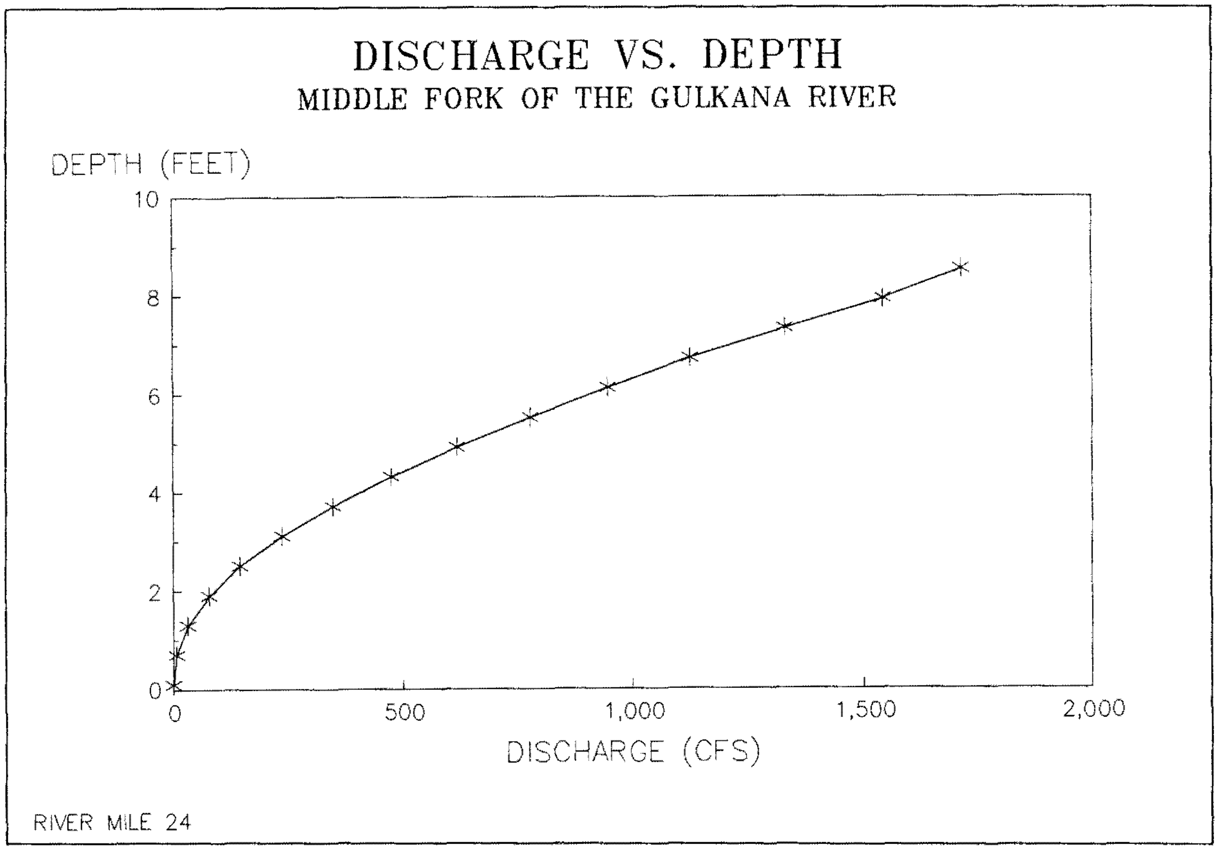

DISCHARGE VS. WETTED PERIMETER
MIDDLE FORK OF THE GULKANA RIVER
WETTED PERIMETER (FEET)
140
120
100
80
60
40
20
0
0
500
1,000
1,500
2,000
DISCHARGE (CFS)
RIVER MILE 24



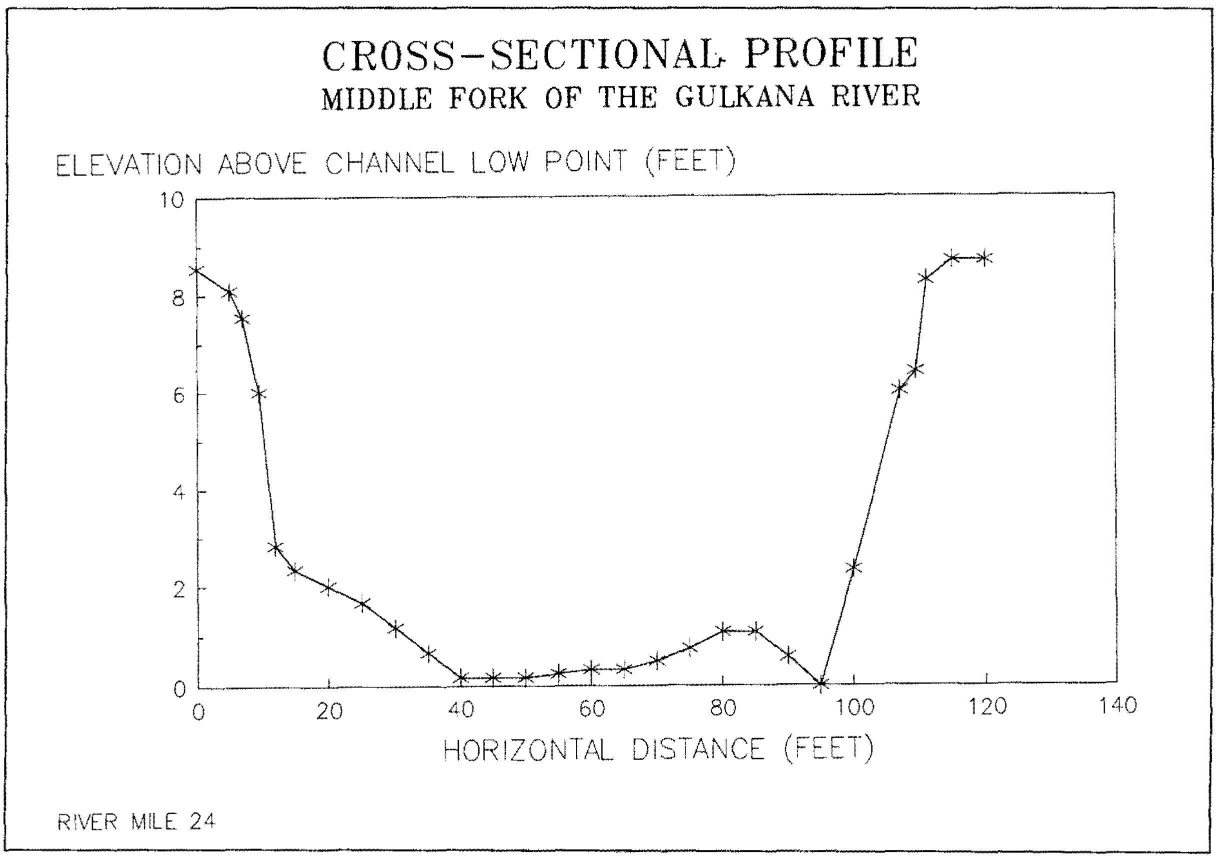
DISCHARGE VS. CROSS-SECTIONAL AREA
MIDDLE FORK OF THE GULKANA RIVER
CROSS-SECTIONAL AREA (SQUARE FEET)
800
600
400
200
0
0
500
1,000
1,500
2,000
DISCHARGE (CFS)
RIVER MILE 24



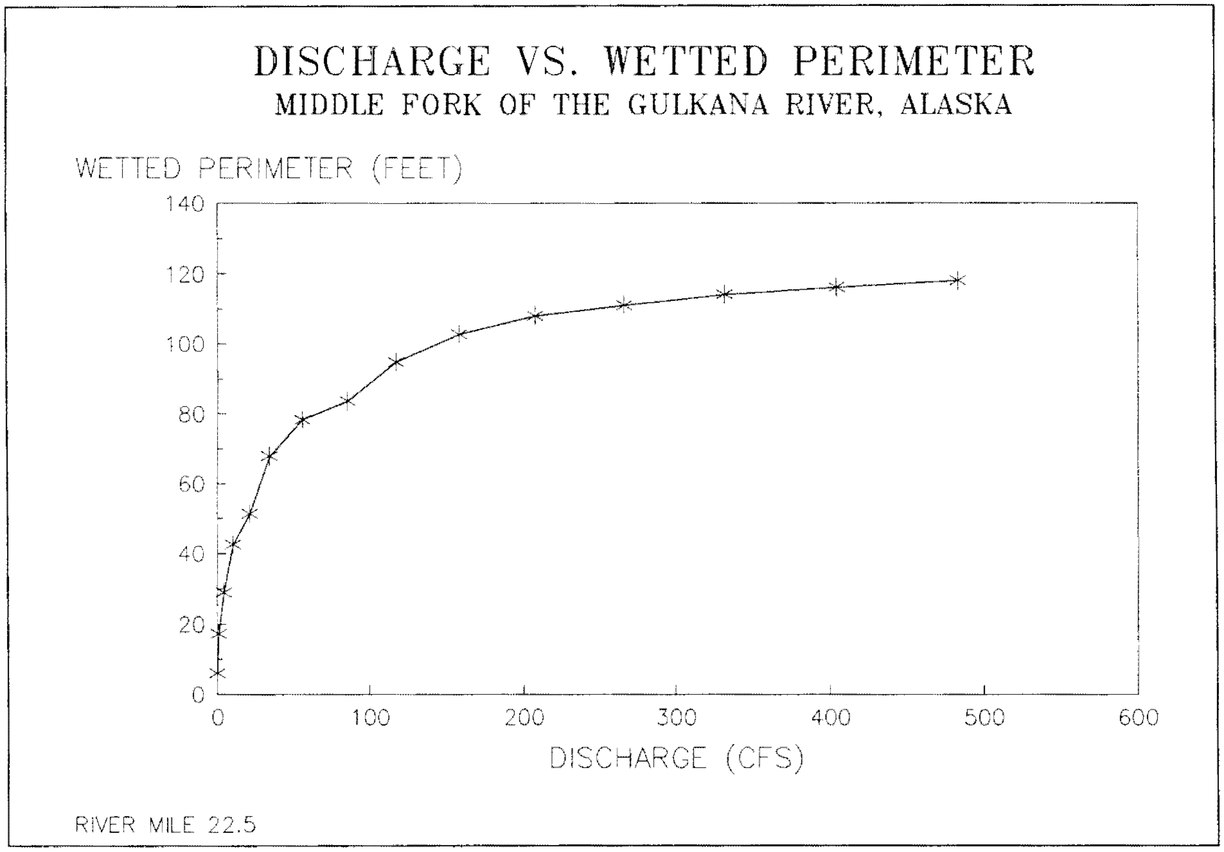
DISCHARGE VS. VELOCITY
MIDDLE FORK OF THE GULKANA RIVER
VELOCITY (FT/S)
2.5
2
1.5
1
0.5
0
0
500
1,000
1,500
2,000
DISCHARGE (CFS)

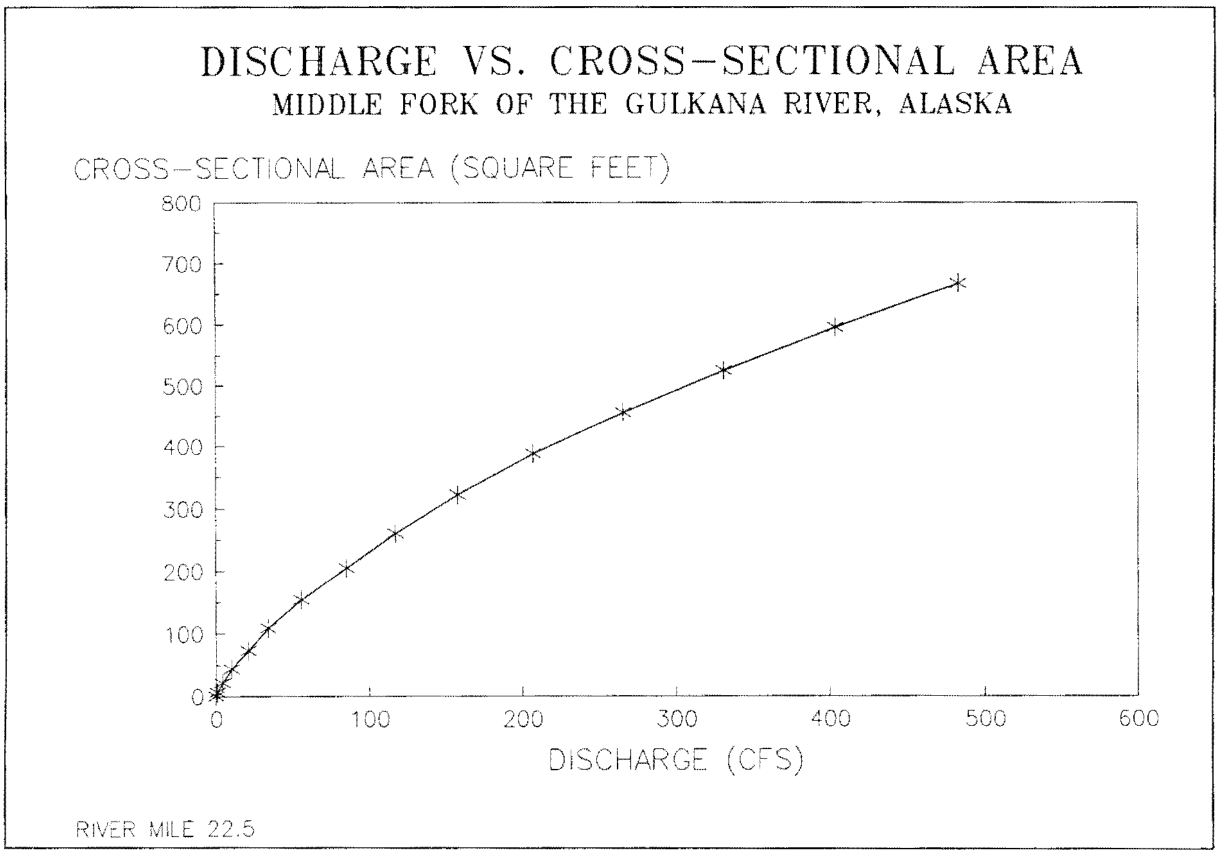


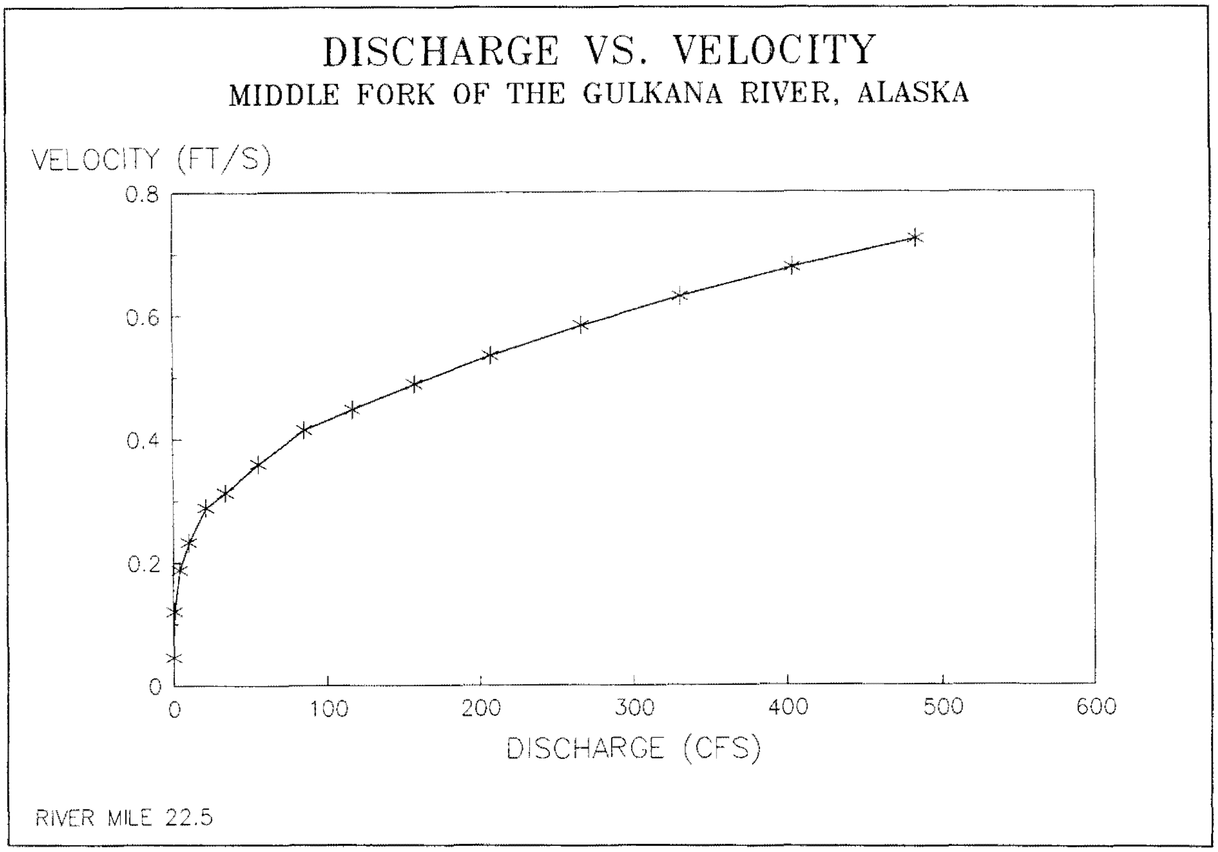
DISCHARGE VS. DEPTH
MIDDLE FORK OF THE GULKANA RIVER
DEPTH (FEET)
10
8
6
4
2
0
0
500
1,000
1,500
2,000
DISCHARGE (CFS)
RIVER MILE 24



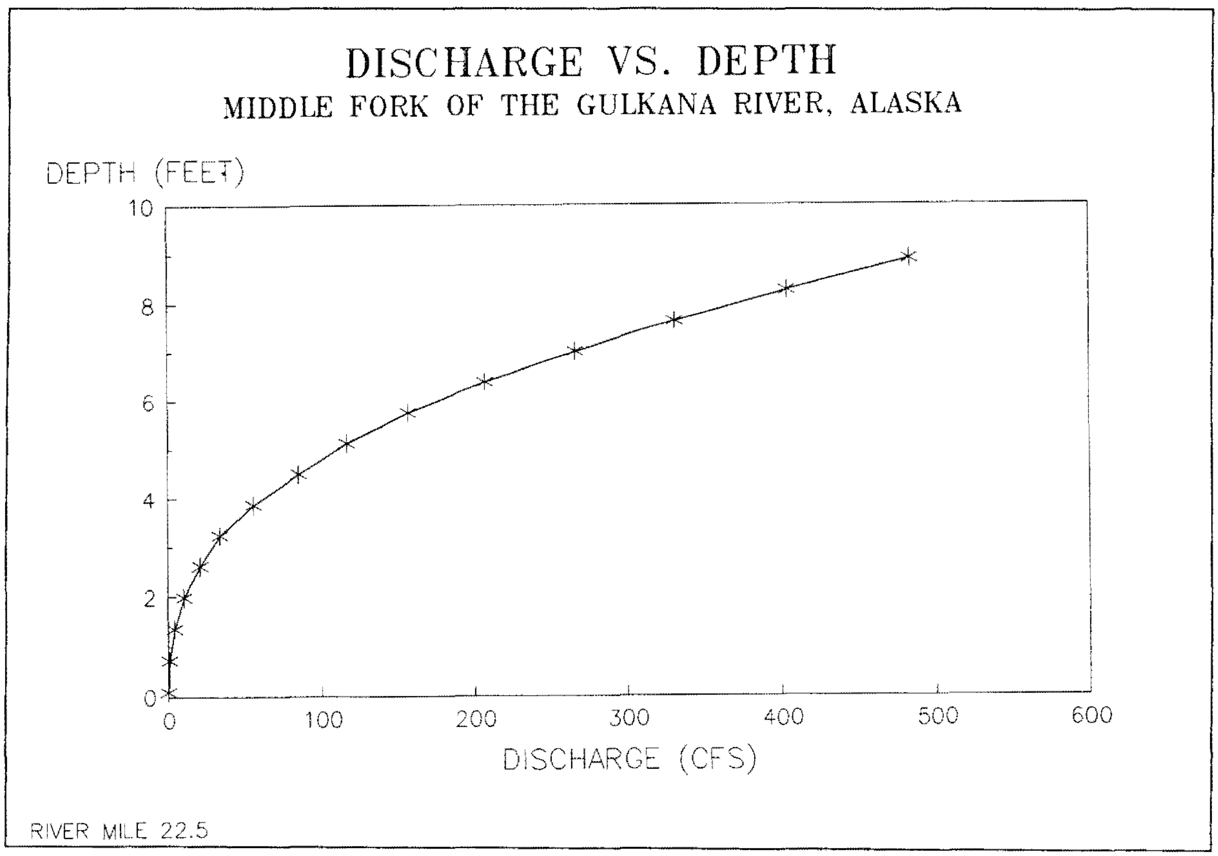
CROSS-SECTIONAL PROFILE
MIDDLE FORK OF THE GULKANA RIVER
ELEVATION ABOVE CHANNEL LOW POINT (FEET)
10
8
6
4
2
0
0
20
40
60
80
100
120
140
HORIZONTAL DISTANCE (FEET)
RIVER MILE 24


DISCHARGE VS. WETTED PERIMETER
MIDDLE FORK OF THE GULKANA RIVER, ALASKA
WETTED PERIMETER (FEET)
140
120
100
80
60
40
20
0
0
100
200
300
400
500
600
DISCHARGE (CFS)
RIVER MILE 22.5

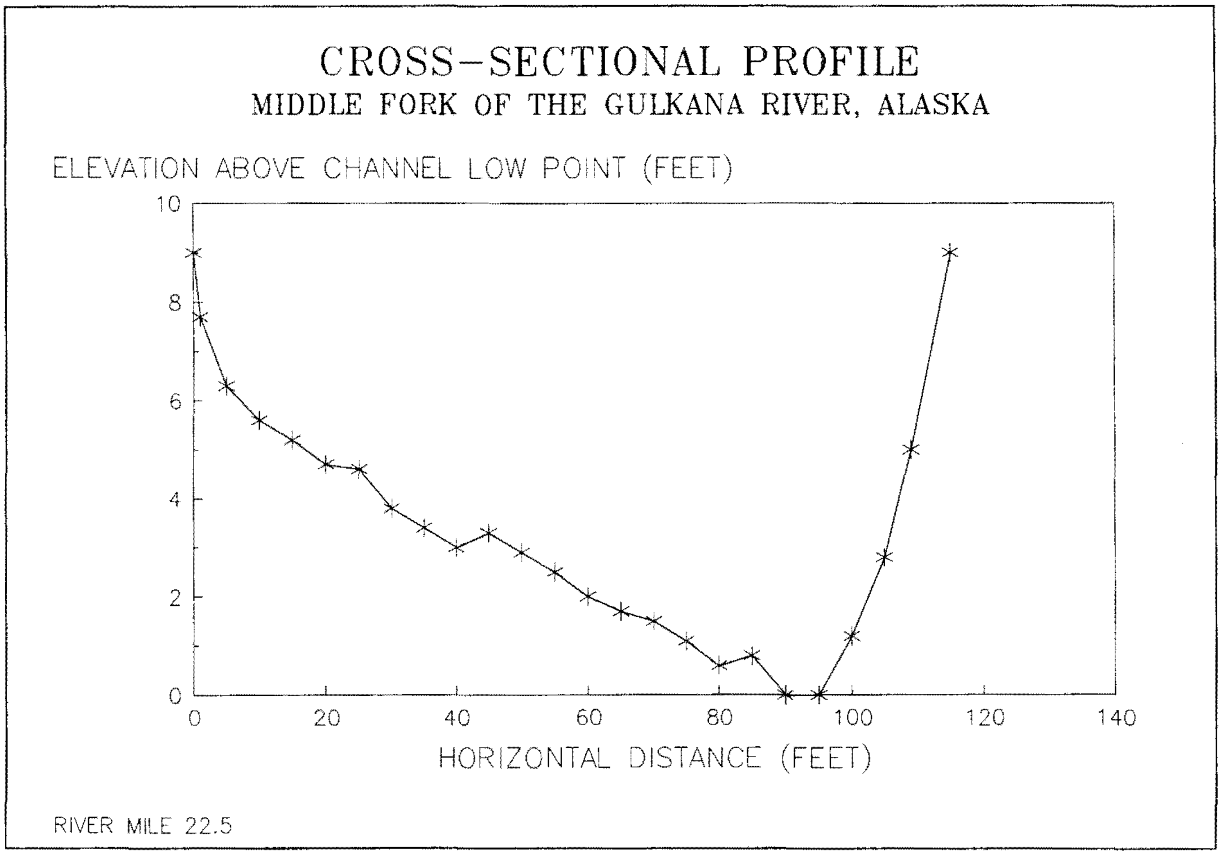

DISCHARGE VS. CROSS-SECTIONAL AREA
MIDDLE FORK OF THE GULKANA RIVER, ALASKA
CROSS-SECTIONAL AREA (SQUARE FEET)
800
700
600
500
400
300
200
100
0
0
100
200
300
400
500
600
DISCHARGE (CFS)
RIVER MILE 22.5

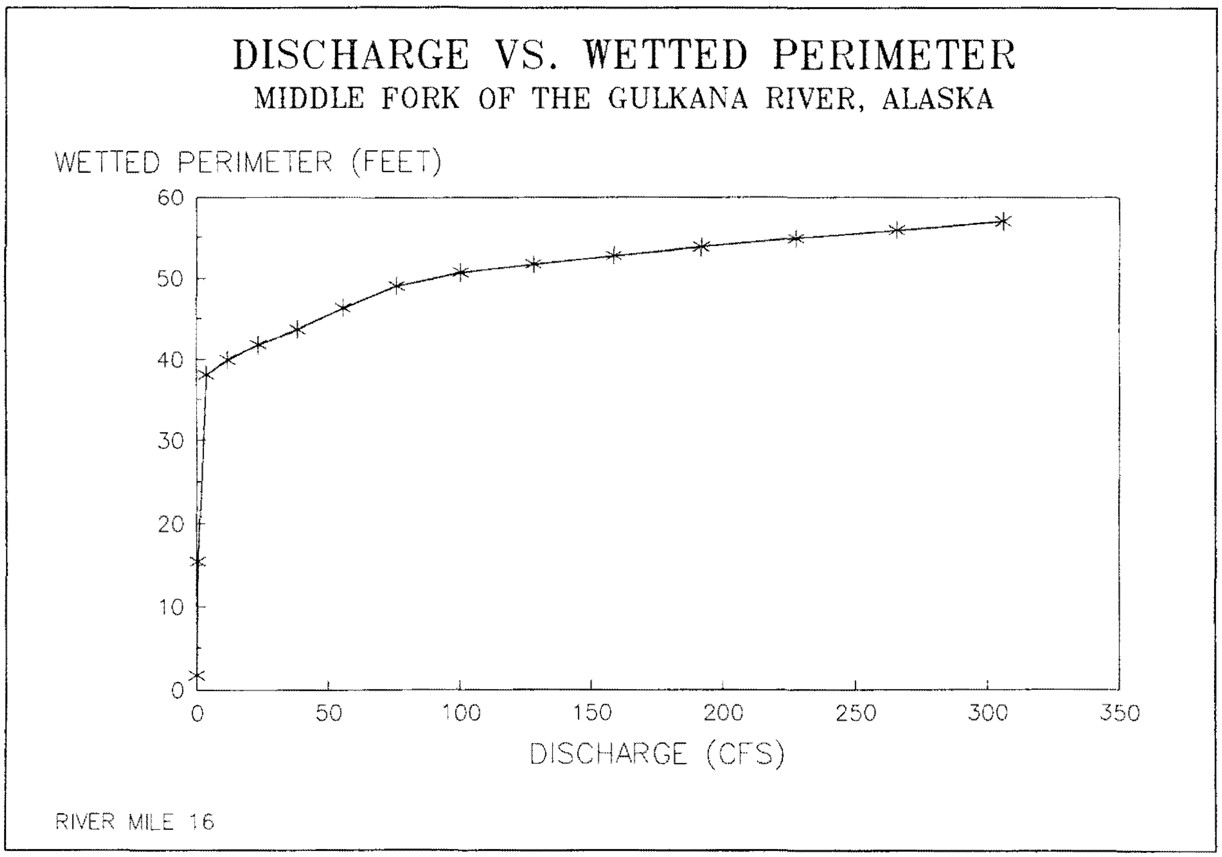


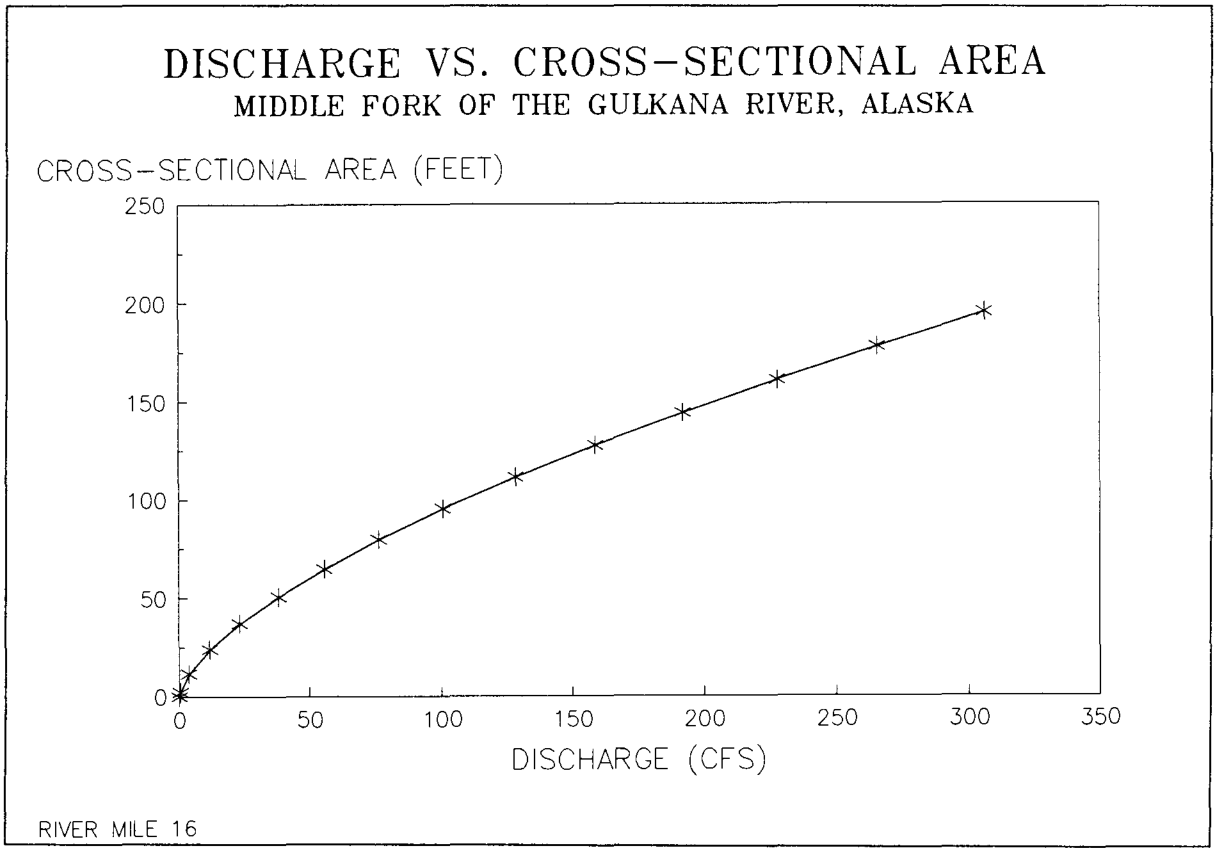
DISCHARGE VS. VELOCITY
MIDDLE FORK OF THE GULKANA RIVER, ALASKA
VELOCITY (FT/S)
0.8
0.6
0.4
0.2
0
0
100
200
300
400
500
600
DISCHARGE (CFS)
RIVER MILE 22.5

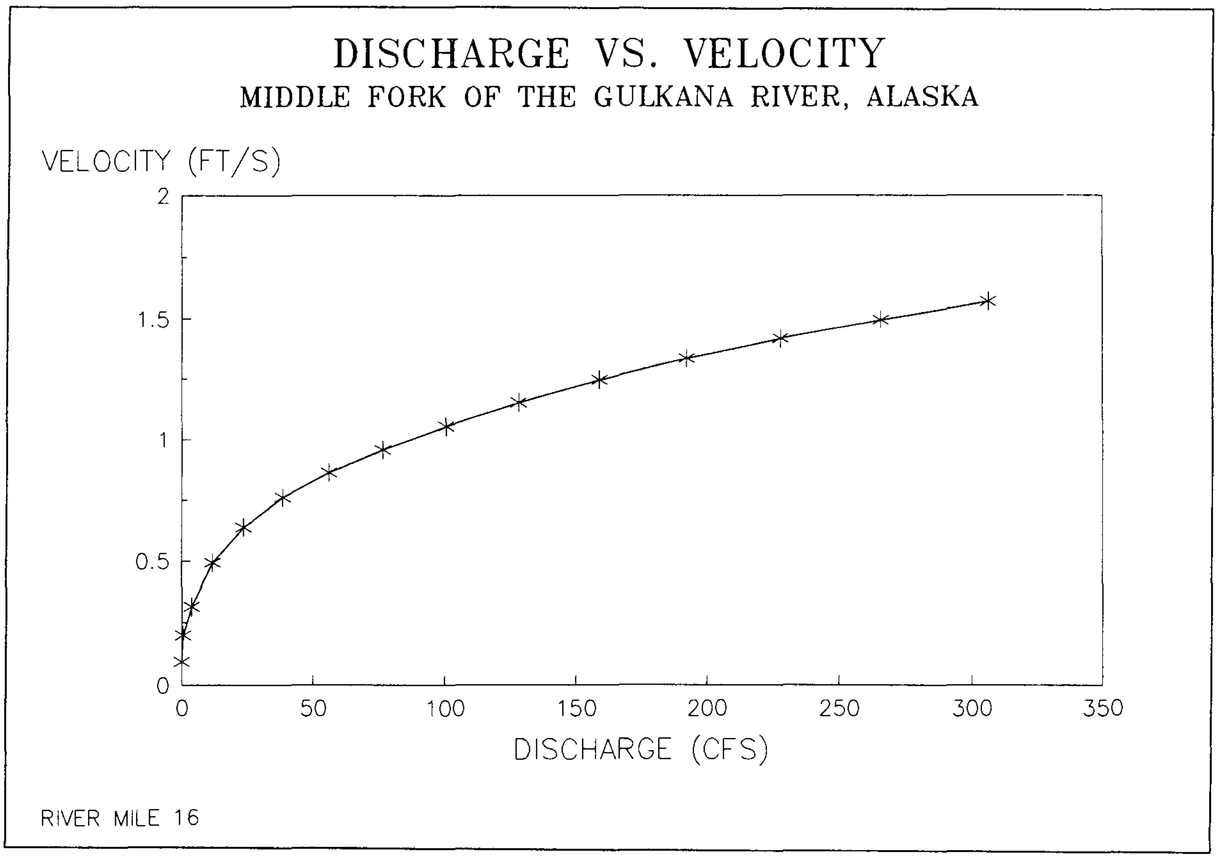


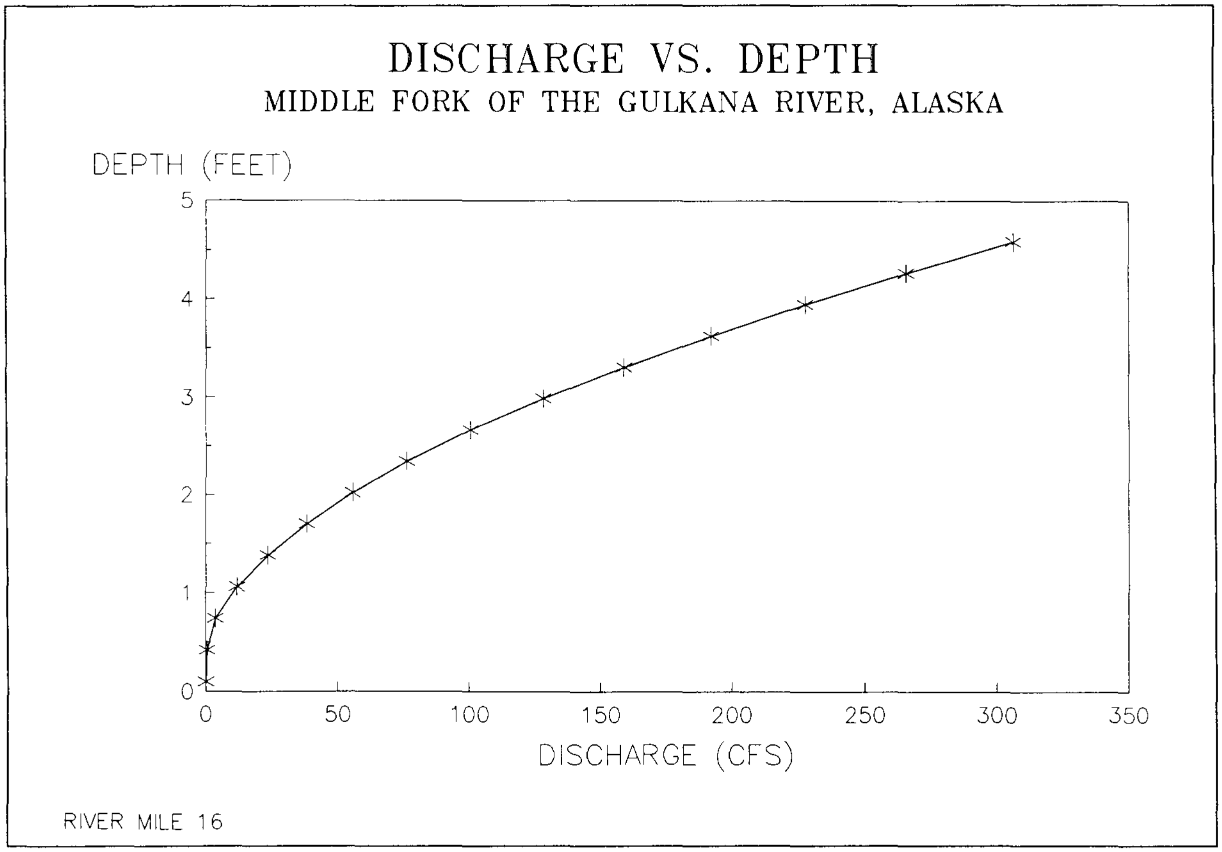
DISCHARGE VS. DEPTH
MIDDLE FORK OF THE GULKANA RIVER, ALASKA
DEPTH (FEET)
10
8
6
4
2
0
0
100
200
300
400
500
600
DISCHARGE (CFS)
RIVER MILE 22.5

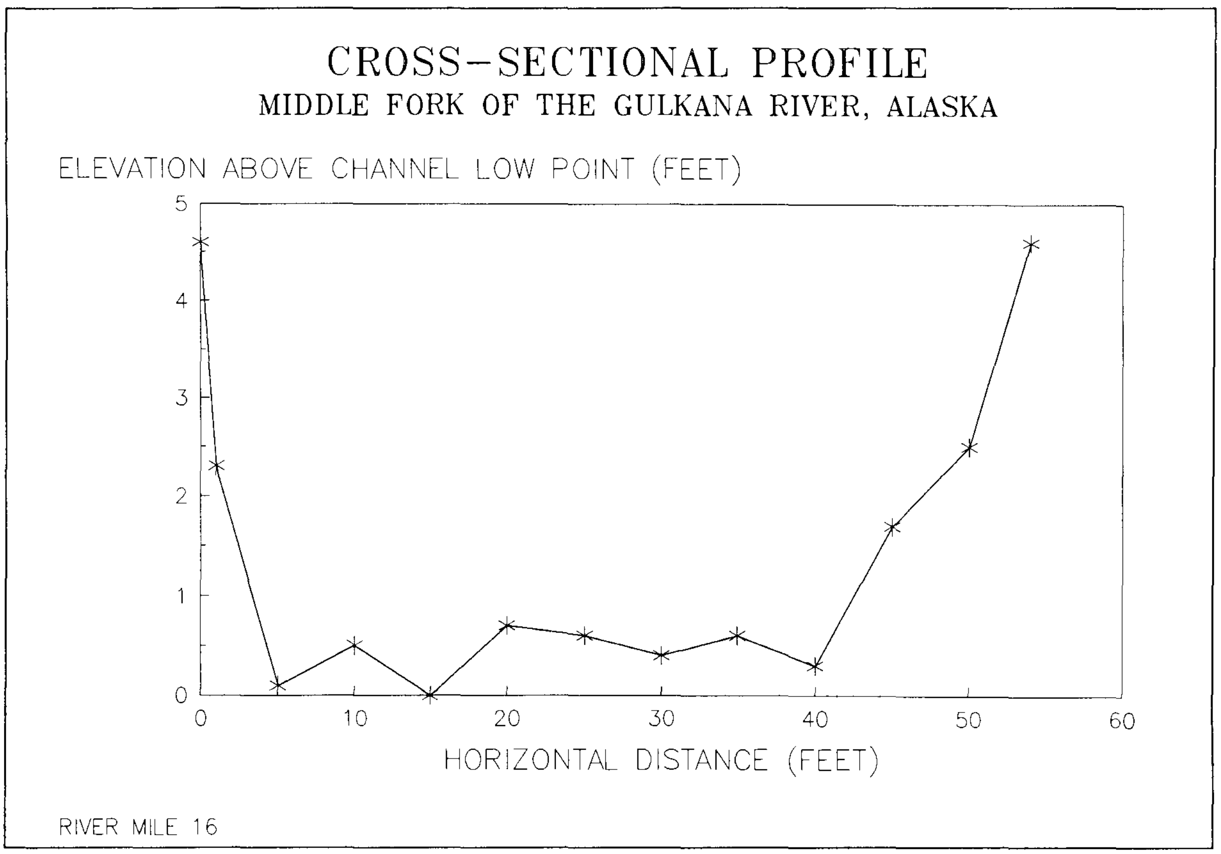

CROSS-SECTIONAL PROFILE
MIDDLE FORK OF THE GULKANA RIVER, ALASKA
ELEVATION ABOVE CHANNEL LOW POINT (FEET)
10
8
6
4
2
0
0
20
40
60
80
100
120
140
HORIZONTAL DISTANCE (FEET)
RIVER MILE 22.5

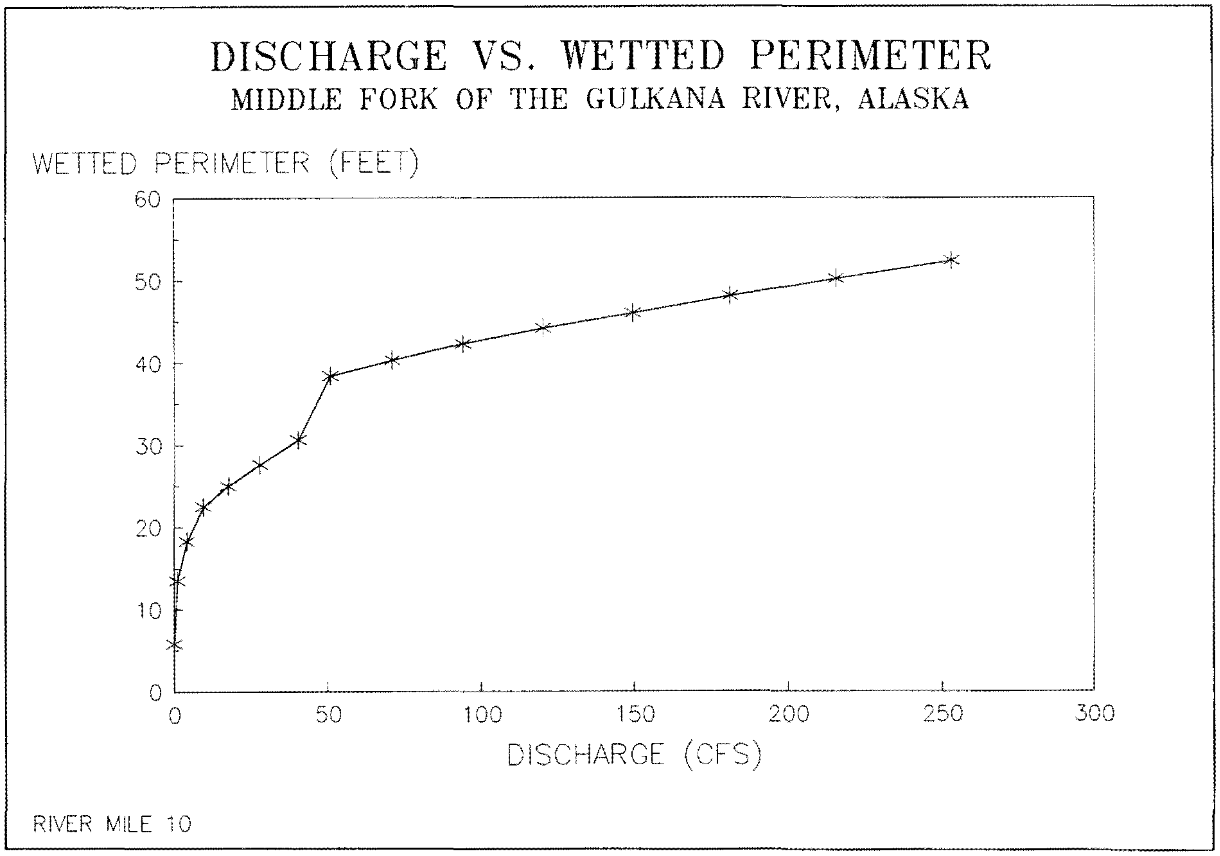

DISCHARGE VS. WETTED PERIMETER
MIDDLE FORK OF THE GULKANA RIVER, ALASKA
WETTED PERIMETER (FEET)
60
50
40
30
20
10
0
0
50
100
150
200
250
300
350
DISCHARGE (CFS)
RIVER MILE 16

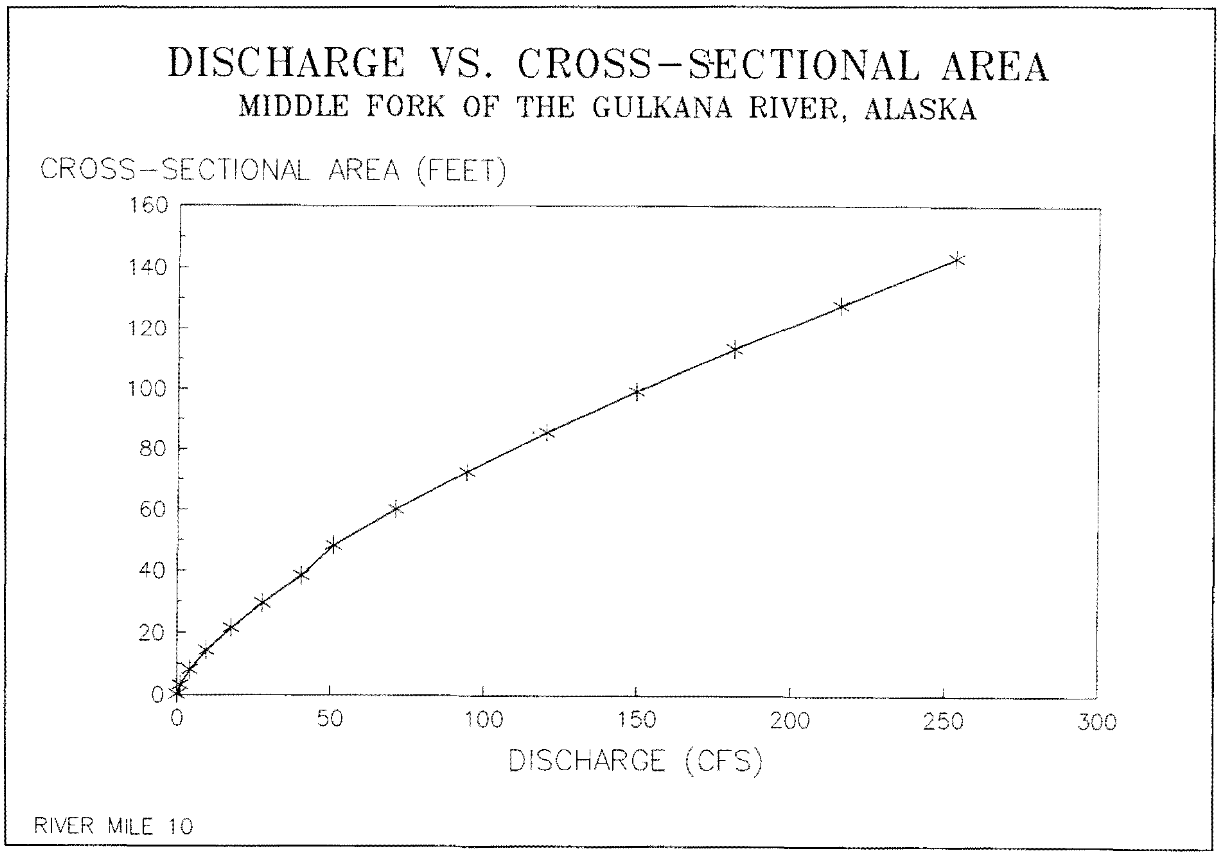

DISCHARGE VS. CROSS-SECTIONAL AREA
MIDDLE FORK OF THE GULKANA RIVER, ALASKA
CROSS-SECTIONAL AREA (FEET)
250
200
150
100
50
0
0
50
100
150
200
250
300
350
DISCHARGE (CFS)
RIVER MILE 16

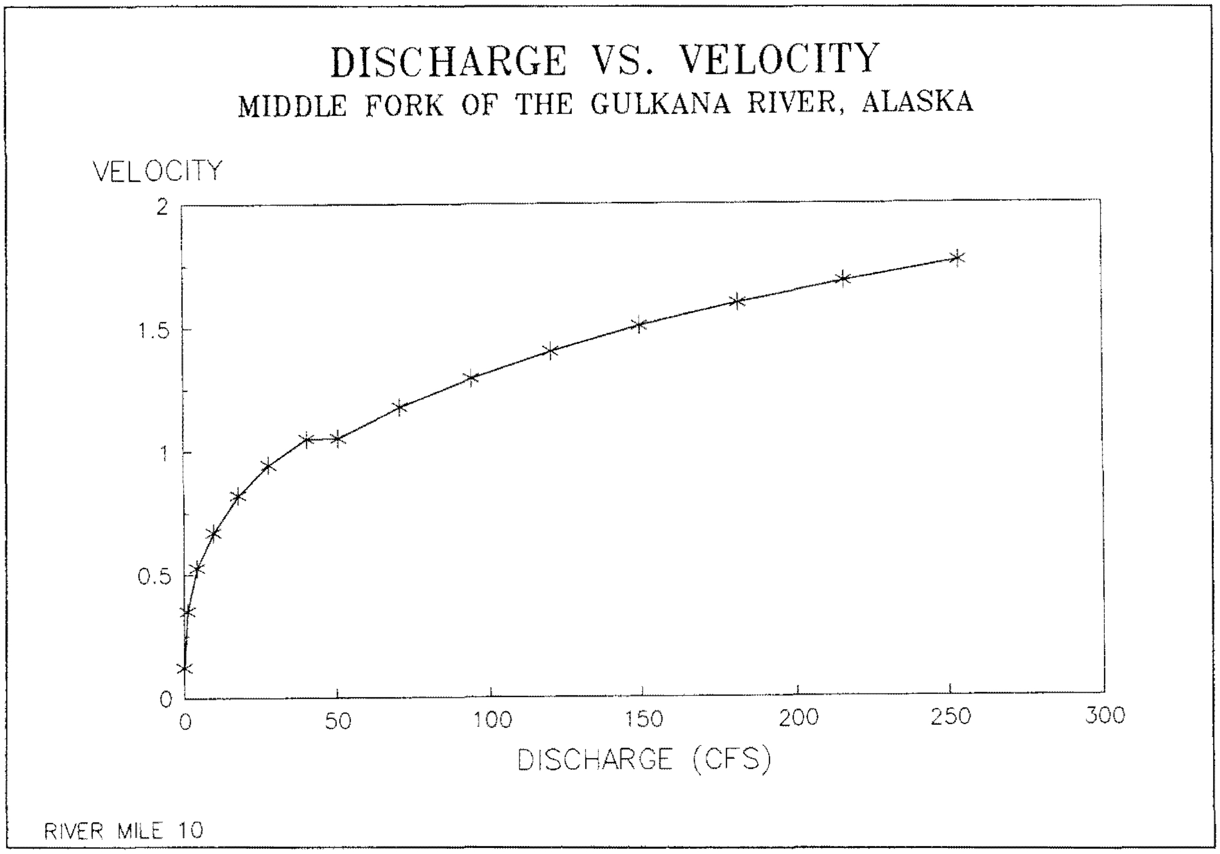

DISCHARGE VS. VELOCITY
MIDDLE FORK OF THE GULKANA RIVER, ALASKA
VELOCITY (FT/S)
2
1.5
1
0.5
0
0
50
100
150
200
250
300
350
DISCHARGE (CFS)
RIVER MILE 16

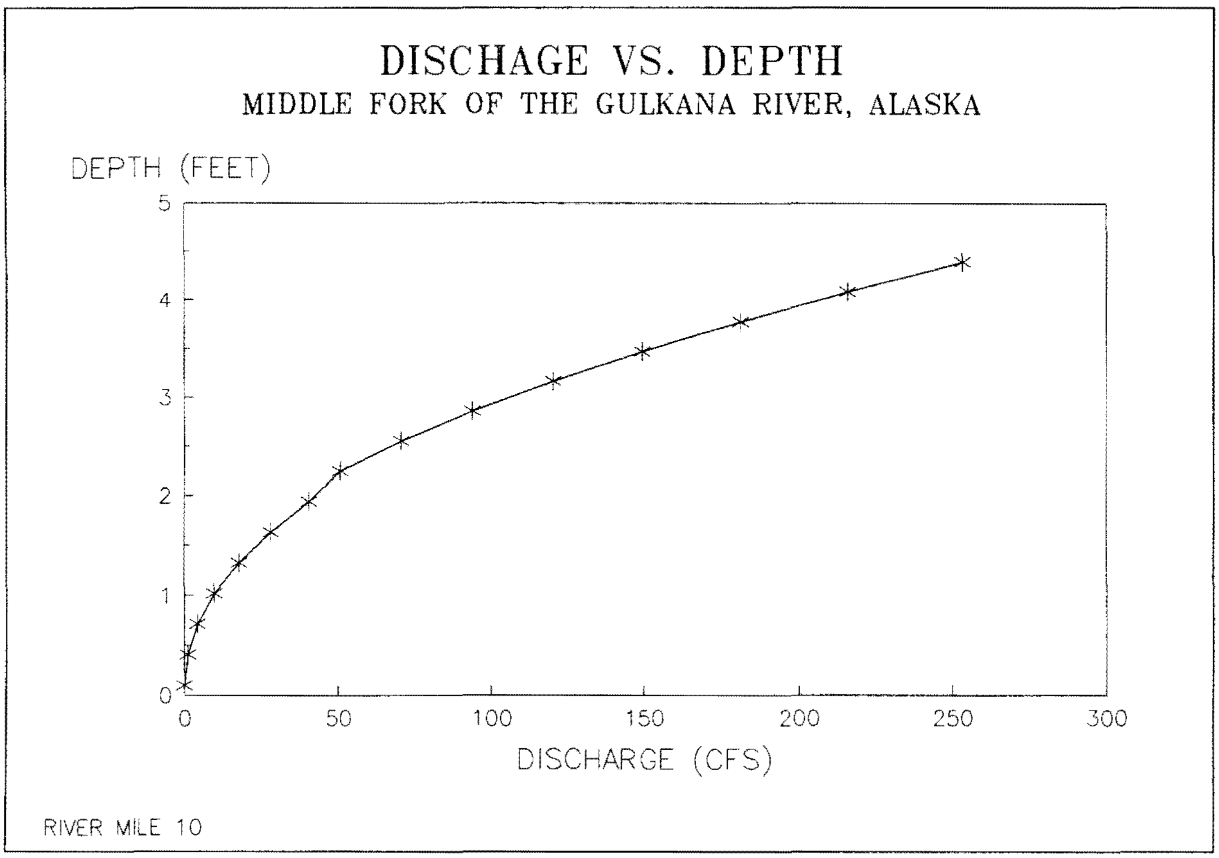

DISCHARGE VS. DEPTH
MIDDLE FORK OF THE GULKANA RIVER, ALASKA
DEPTH (FEET)
5
4
3
2
1
0
0
50
100
150
200
250
300
350
DISCHARGE (CFS)
RIVER MILE 16

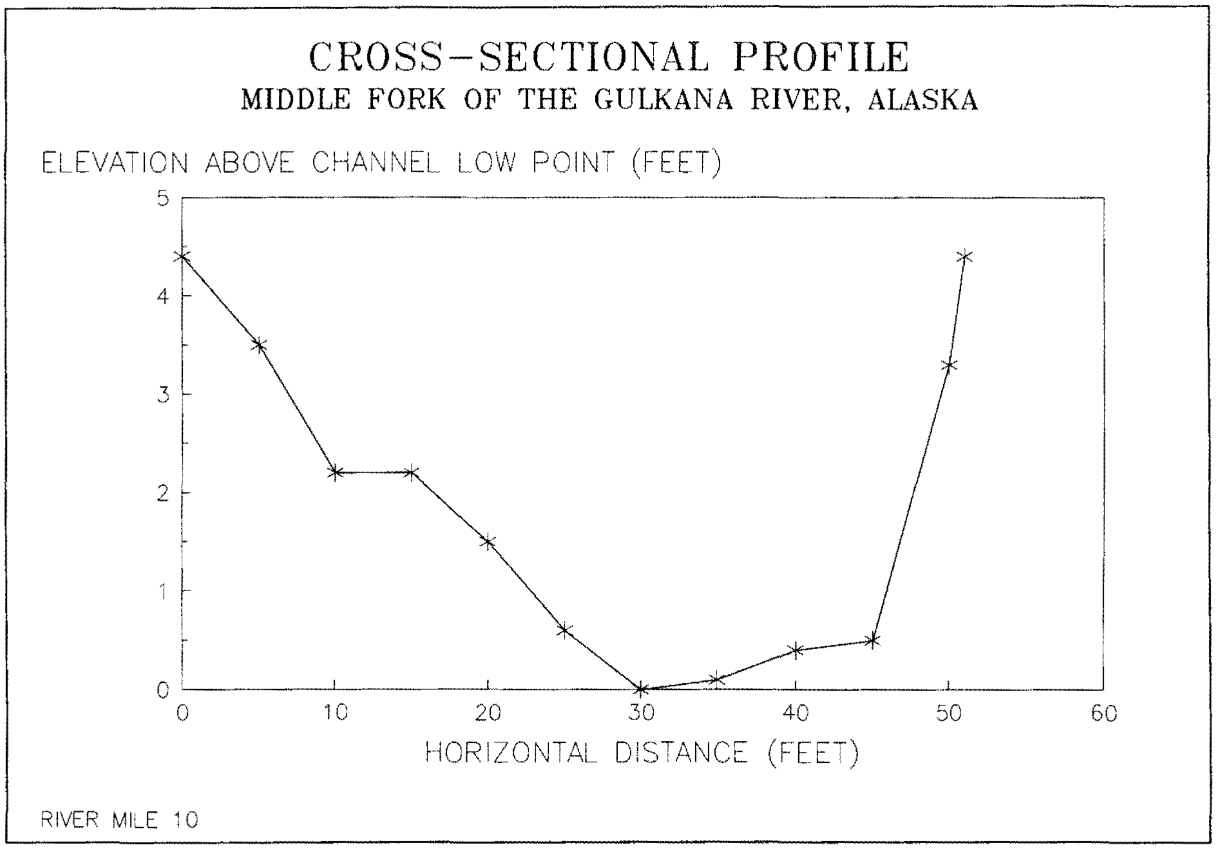

CROSS-SECTIONAL PROFILE
MIDDLE FORK OF THE GULKANA RIVER, ALASKA
ELEVATION ABOVE CHANNEL LOW POINT (FEET)
5
4
3
2
1
0
0
10
20
30
40
50
60
HORIZONTAL DISTANCE (FEET)
RIVER MILE 16

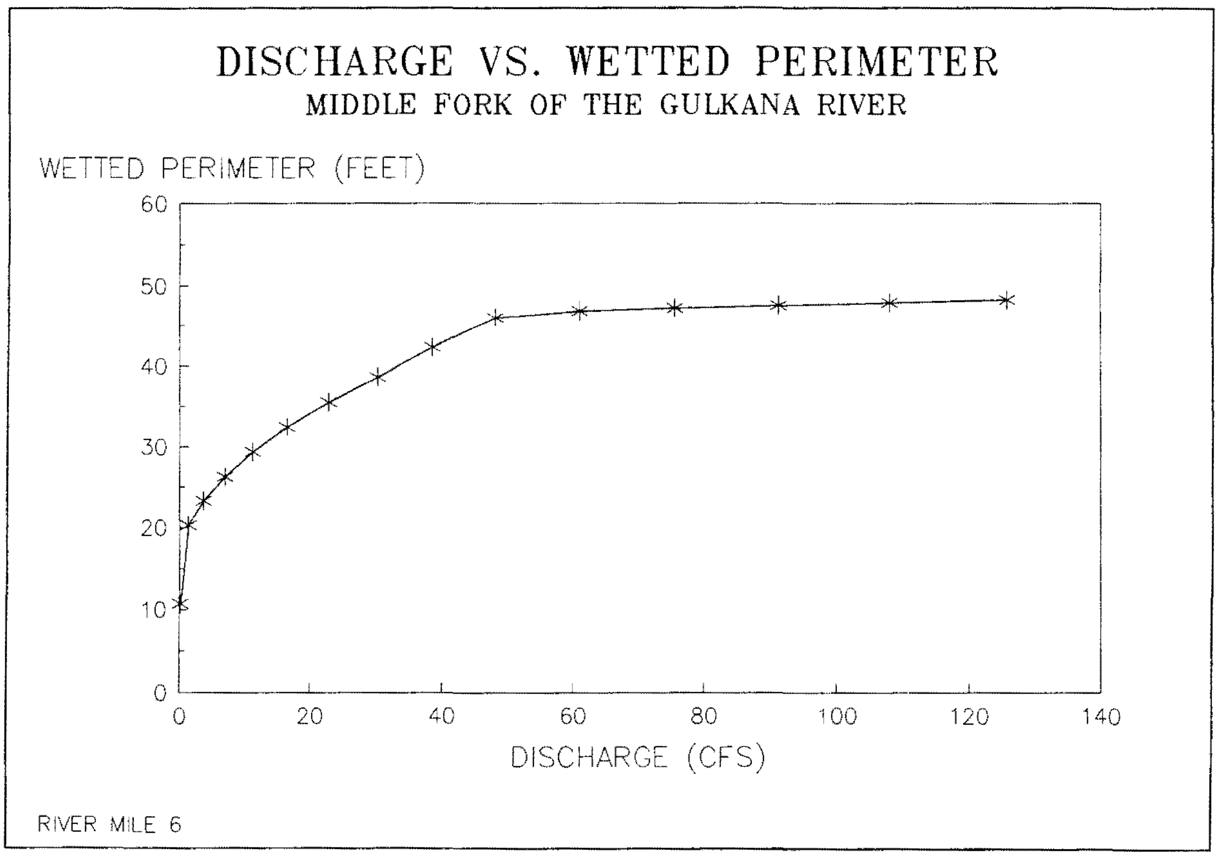

DISCHARGE VS. WETTED PERIMETER
MIDDLE FORK OF THE GULKANA RIVER, ALASKA
WETTED PERIMETER (FEET)
60
50
40
30
20
10
0
0
50
100
150
200
250
300
DISCHARGE (CFS)
RIVER MILE 10

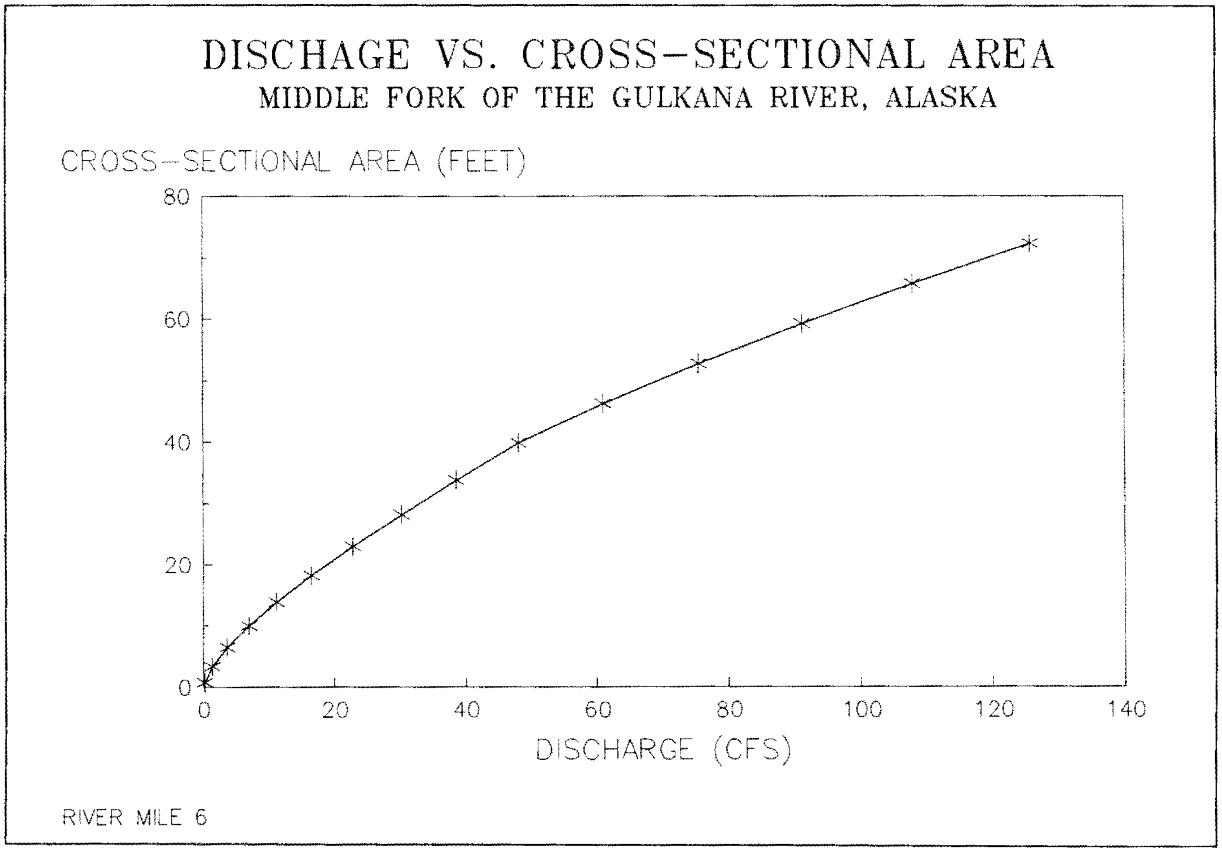

DISCHARGE VS. CROSS-SECTIONAL AREA
MIDDLE FORK OF THE GULKANA RIVER, ALASKA
CROSS-SECTIONAL AREA (FEET)
160
140
120
100
80
60
40
20
0
0
50
100
150
200
250
300
DISCHARGE (CFS)
RIVER MILE 10

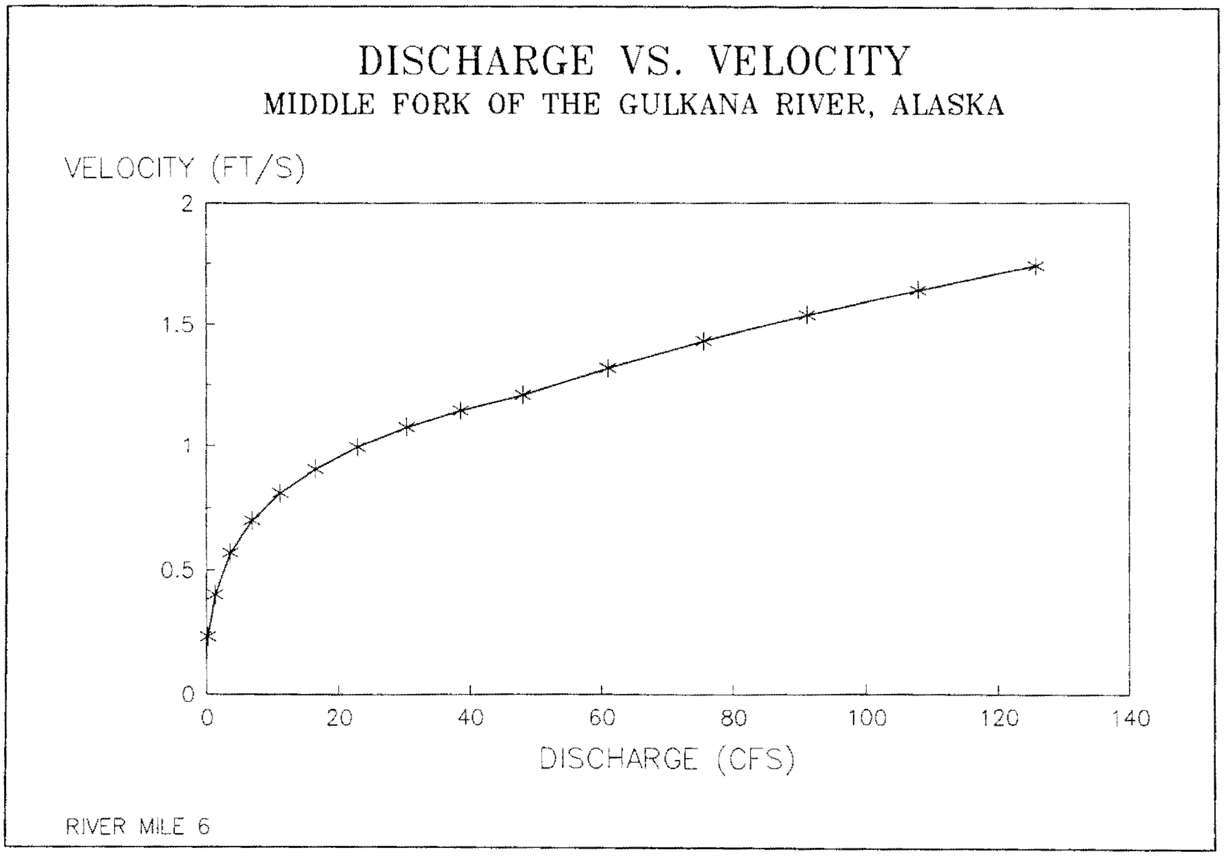

DISCHARGE VS. VELOCITY
MIDDLE FORK OF THE GULKANA RIVER, ALASKA
VELOCITY
2
1.5
1
0.5
0
0
50
100
150
200
250
300
DISCHARGE (CFS)
RIVER MILE 10

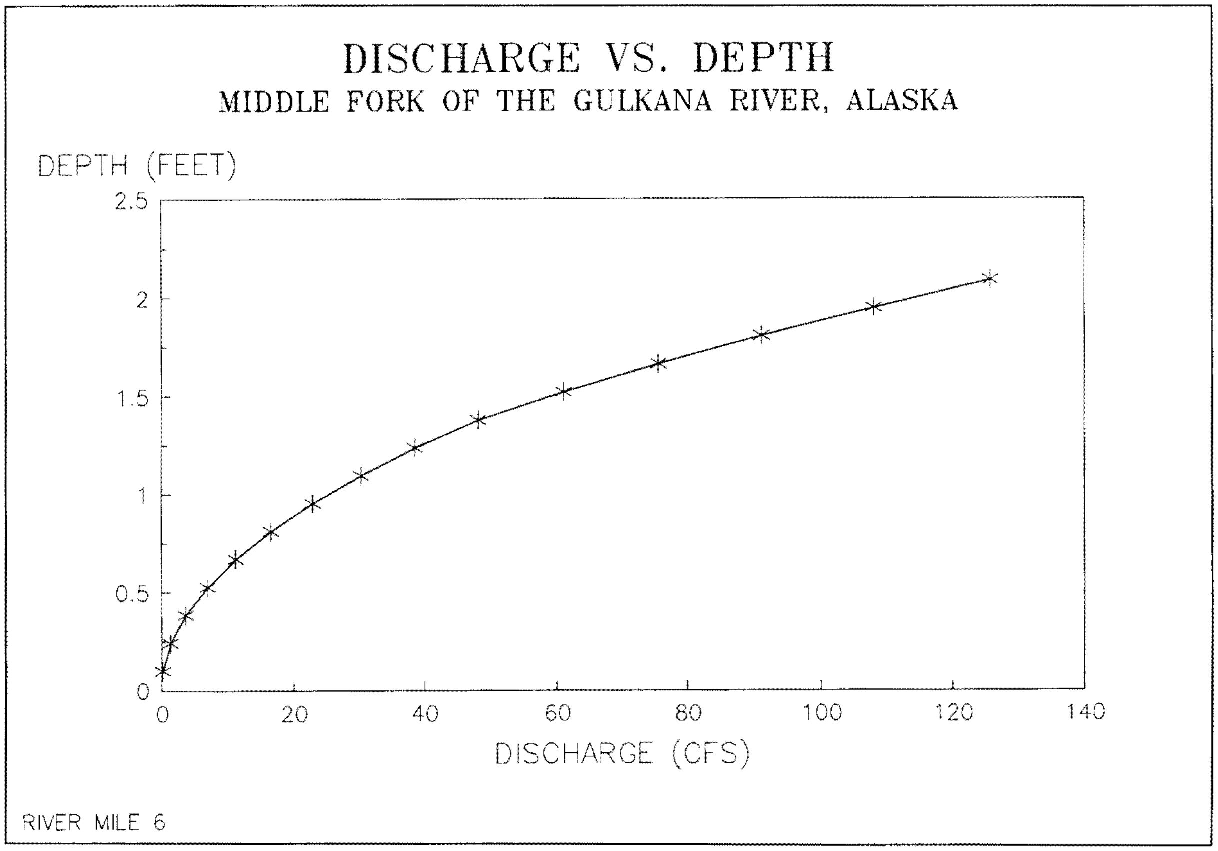

DISCHAGE VS. DEPTH
MIDDLE FORK OF THE GULKANA RIVER, ALASKA
DEPTH (FEET)
5
4
3
2
1
0
0
50
100
150
200
250
300
DISCHARGE (CFS)
RIVER MILE 10

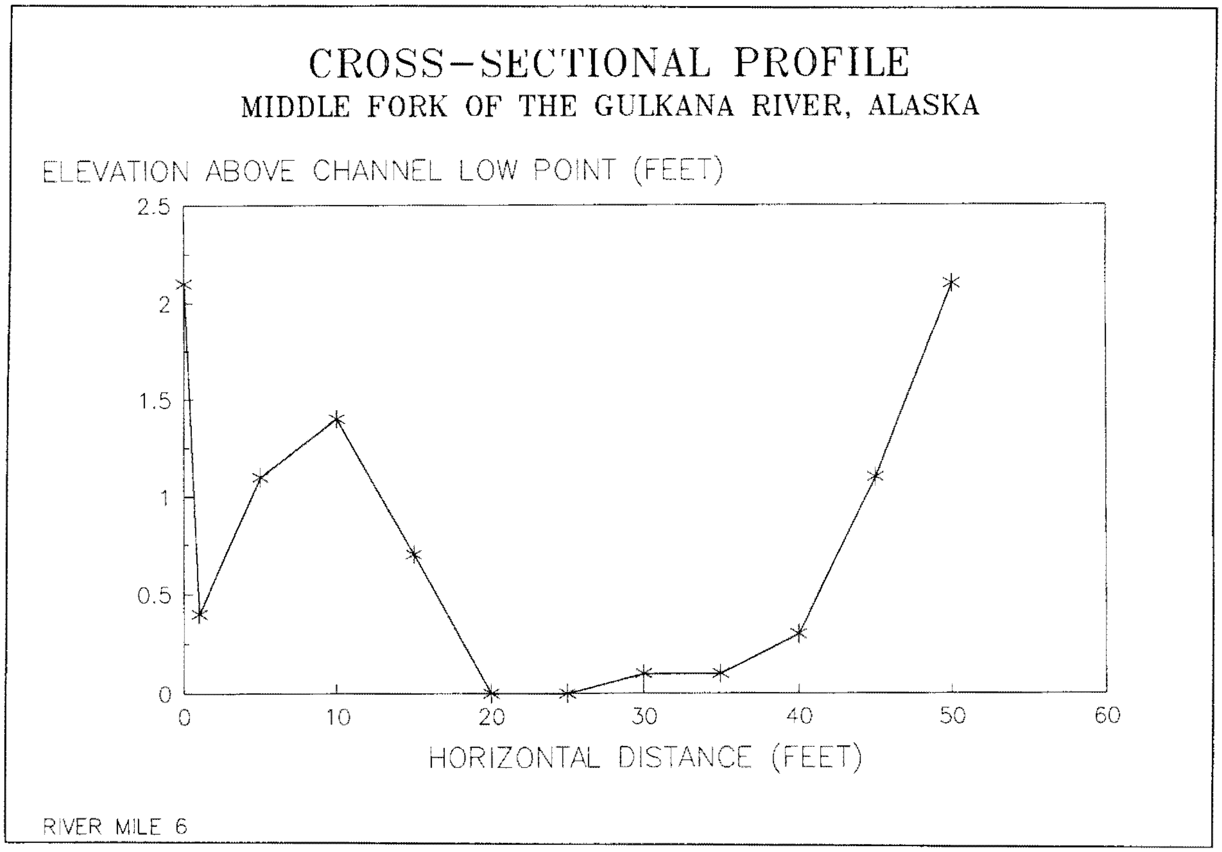

CROSS-SECTIONAL PROFILE
MIDDLE FORK OF THE GULKANA RIVER, ALASKA
ELEVATION ABOVE CHANNEL LOW POINT (FEET)
5
4
3
2
1
0
0
10
20
30
40
50
60
HORIZONTAL DISTANCE (FEET)
RIVER MILE 10

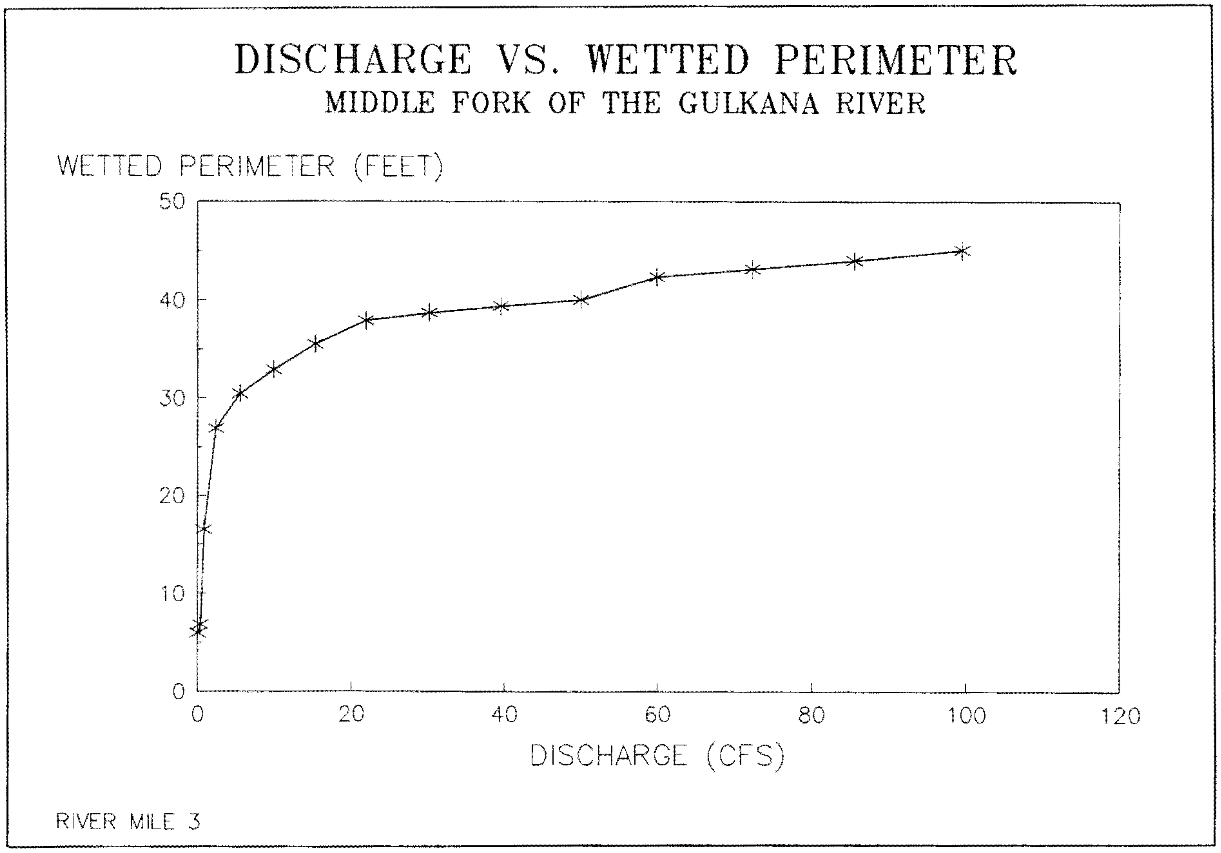

DISCHARGE VS. WETTED PERIMETER
MIDDLE FORK OF THE GULKANA RIVER
WETTED PERIMETER (FEET)
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
DISCHARGE (CFS)
RIVER MILE 6

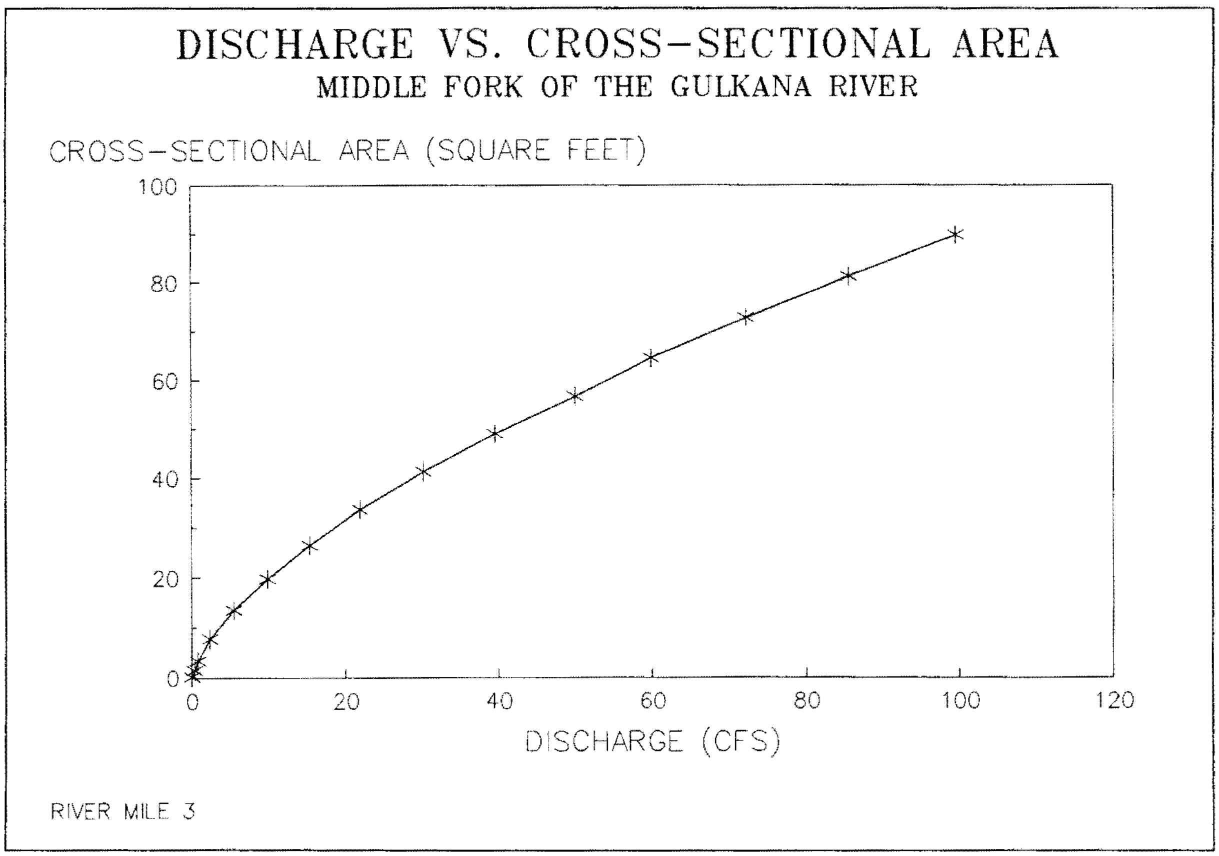

DISCHAGE VS. CROSS-SECTIONAL AREA
MIDDLE FORK OF THE GULKANA RIVER, ALASKA
CROSS-SECTIONAL AREA (FEET)
80
60
40
20
0
0
20
40
60
80
100
120
140
DISCHARGE (CFS)
RIVER MILE 6

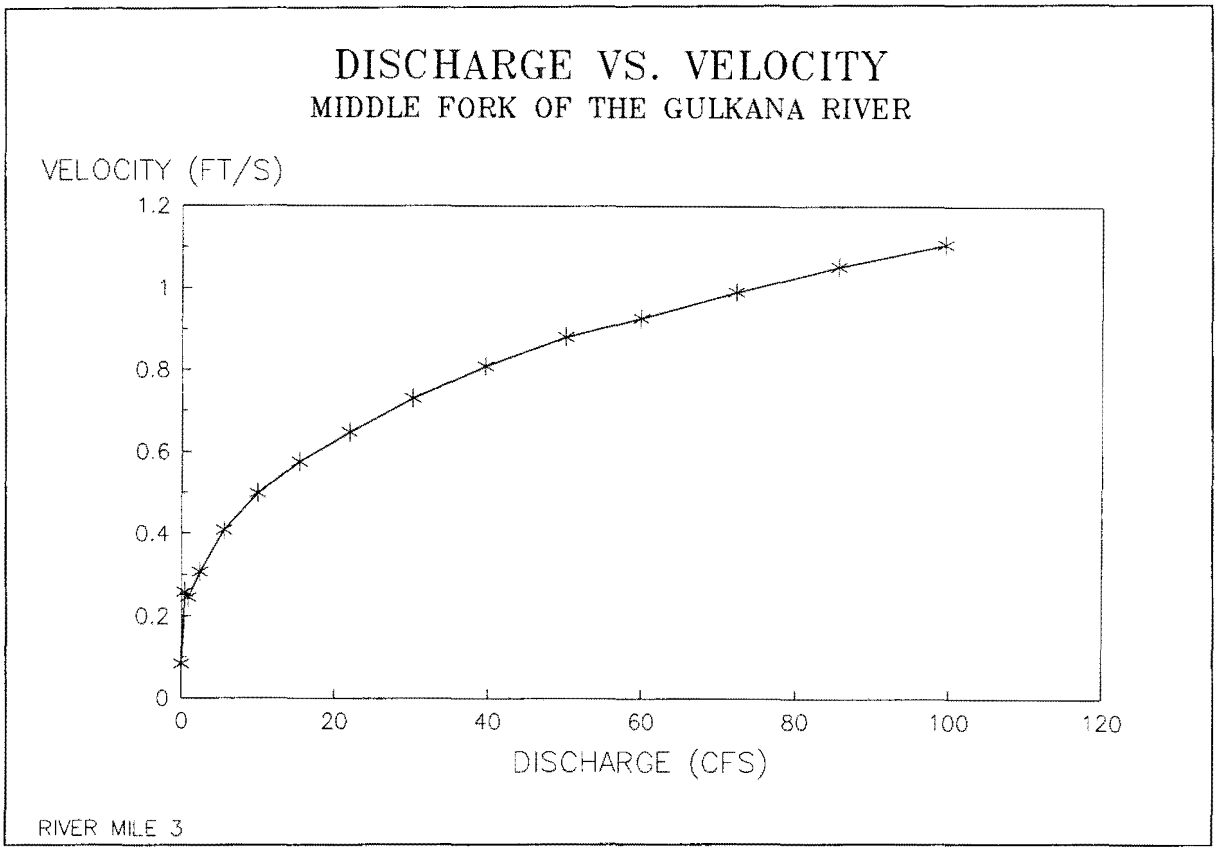

DISCHARGE VS. VELOCITY
MIDDLE FORK OF THE GULKANA RIVER, ALASKA
VELOCITY (FT/S)
2
1.5
1
0.5
0
0
20
40
60
80
100
120
140
DISCHARGE (CFS)
RIVER MILE 6

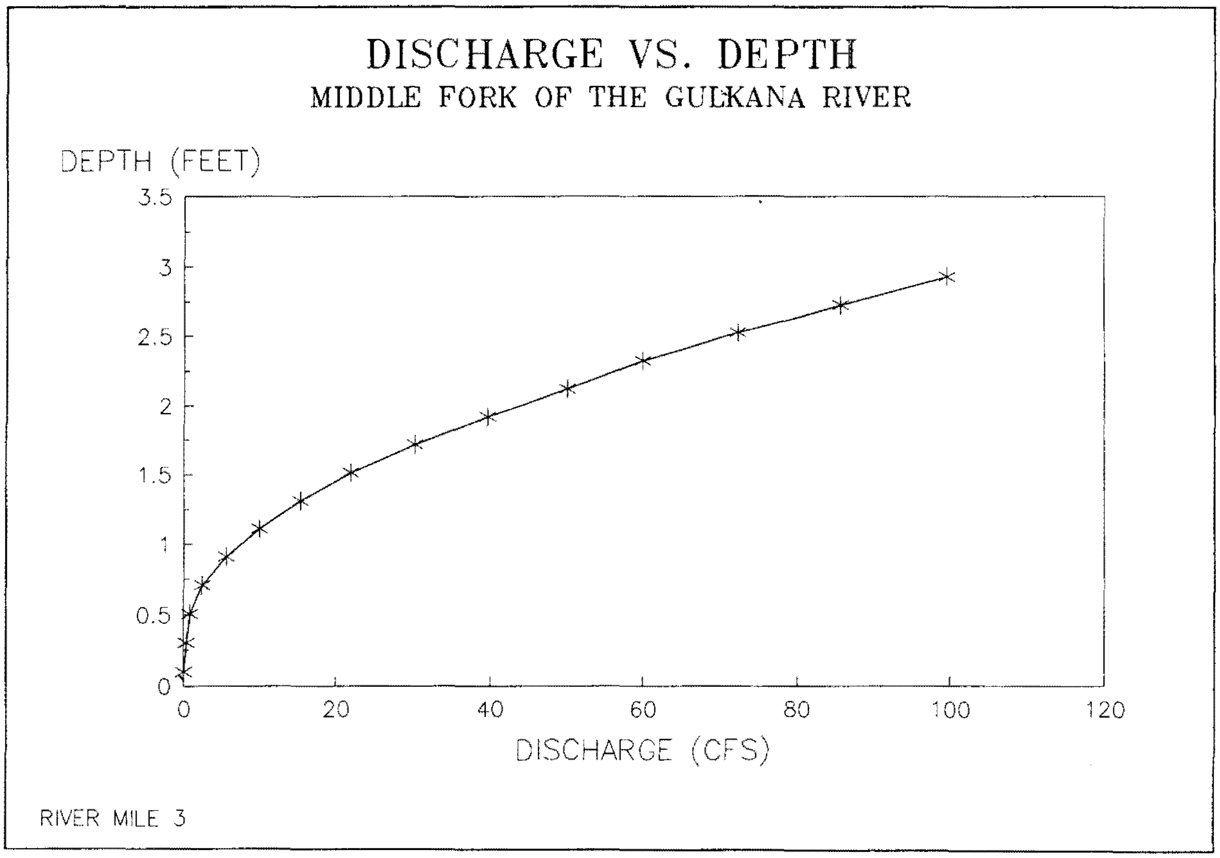

DISCHARGE VS. DEPTH
MIDDLE FORK OF THE GULKANA RIVER, ALASKA
DEPTH (FEET)
2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
120
140
DISCHARGE (CFS)
RIVER MILE 6

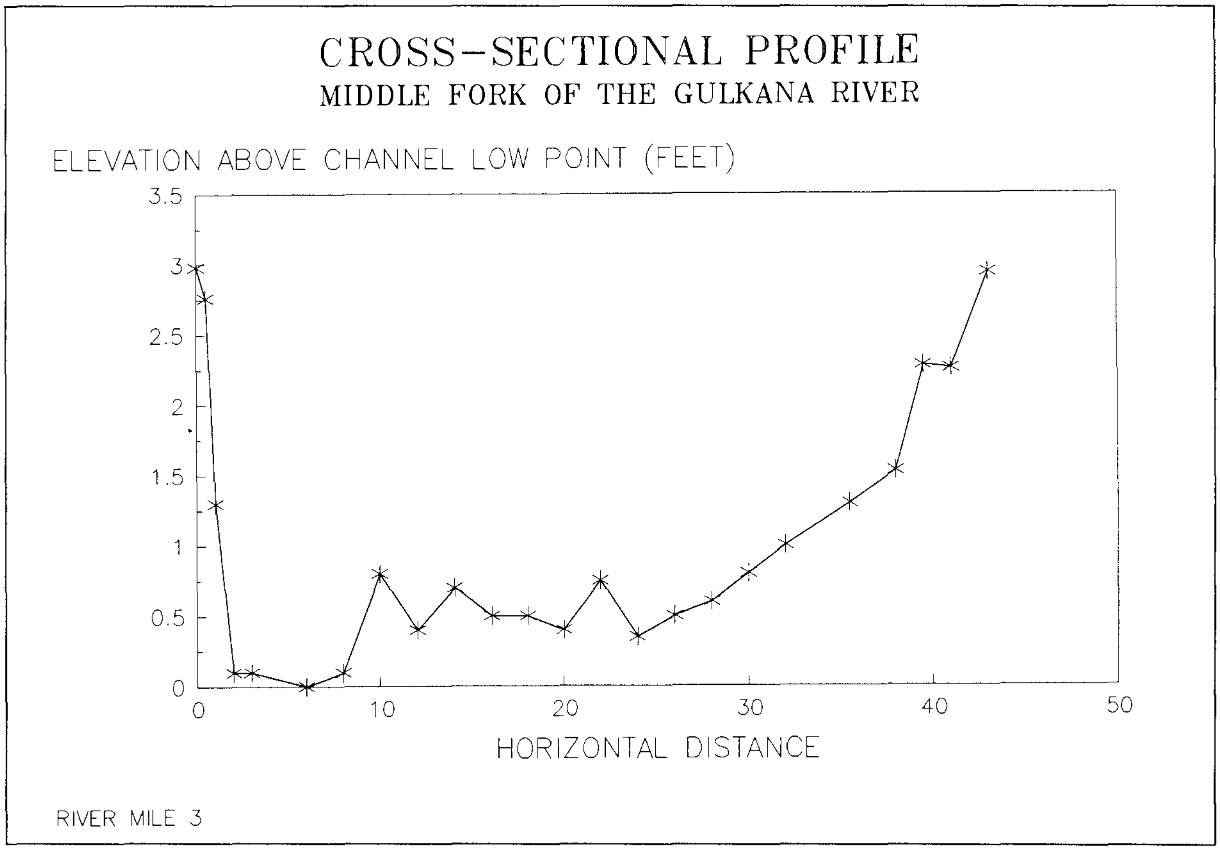

CROSS-SECTIONAL PROFILE
MIDDLE FORK OF THE GULKANA RIVER, ALASKA
ELEVATION ABOVE CHANNEL LOW POINT (FEET)
2.5
2
1.5
1
0.5
0
0
10
20
30
40
50
60
HORIZONTAL DISTANCE (FEET)
RIVER MILE 6

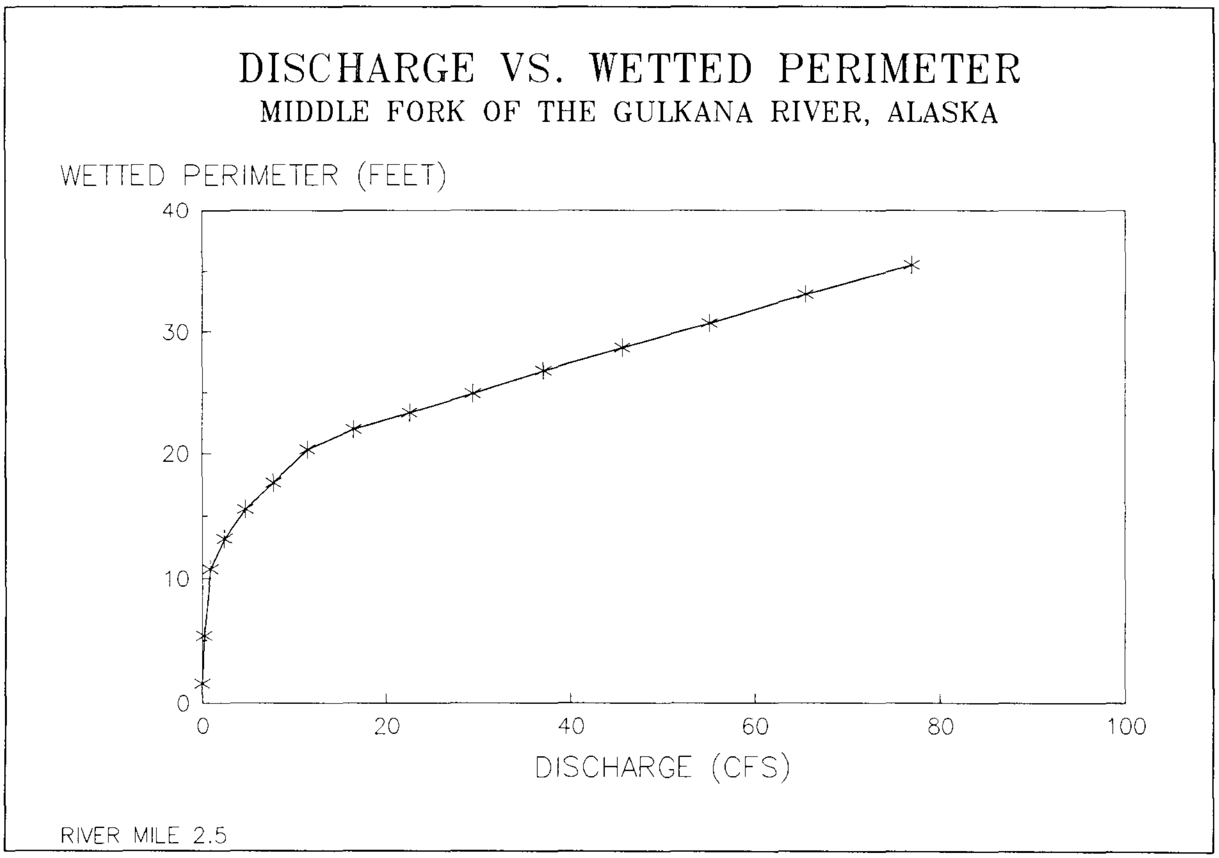

DISCHARGE VS. WETTED PERIMETER
MIDDLE FORK OF THE GULKANA RIVER
WETTED PERIMETER (FEET)
50
40
30
20
10
0
0
20
40
60
80
100
120
DISCHARGE (CFS)
RIVER MILE 3

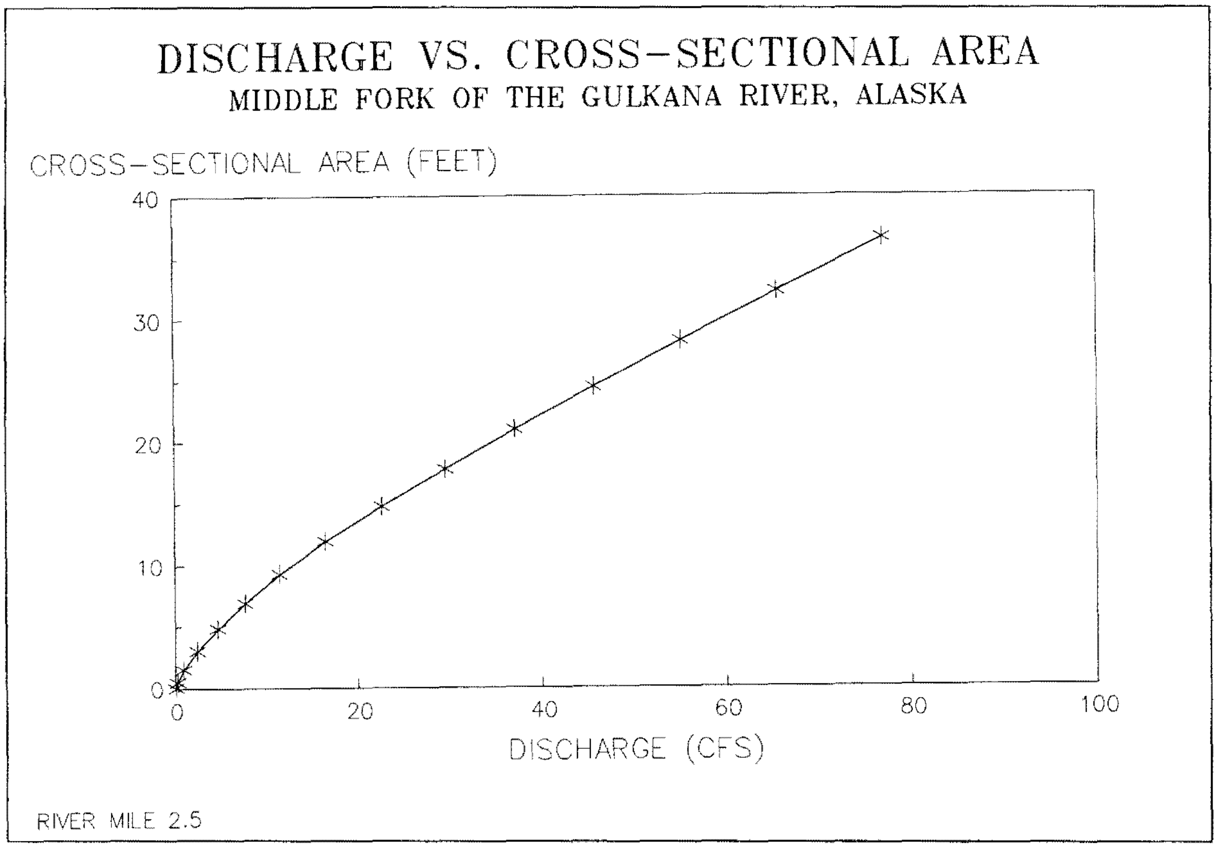

DISCHARGE VS. CROSS-SECTIONAL AREA
MIDDLE FORK OF THE GULKANA RIVER
CROSS-SECTIONAL AREA (SQUARE FEET)
100
80
60
40
20
0
0
20
40
60
80
100
120
DISCHARGE (CFS)
RIVER MILE 3

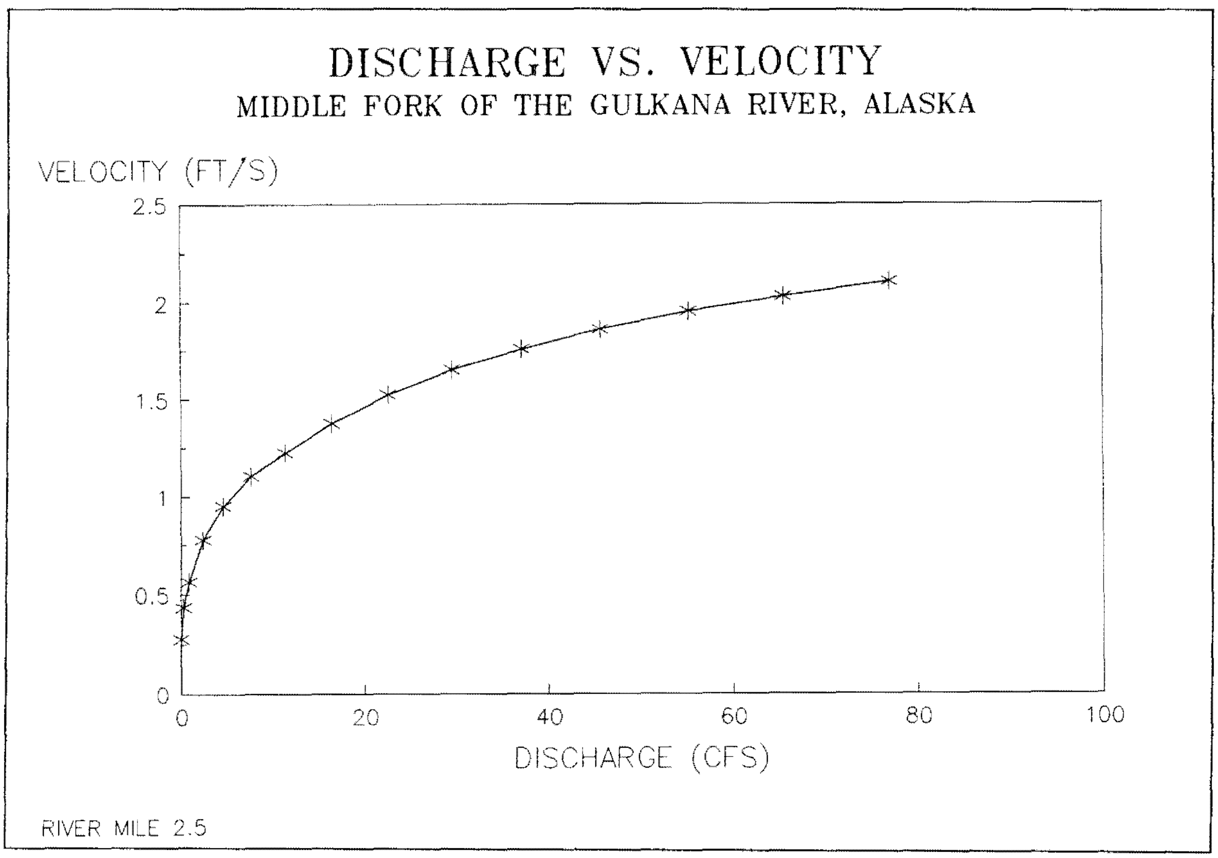

DISCHARGE VS. VELOCITY
MIDDLE FORK OF THE GULKANA RIVER
VELOCITY (FT/S)
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
120
DISCHARGE (CFS)
RIVER MILE 3

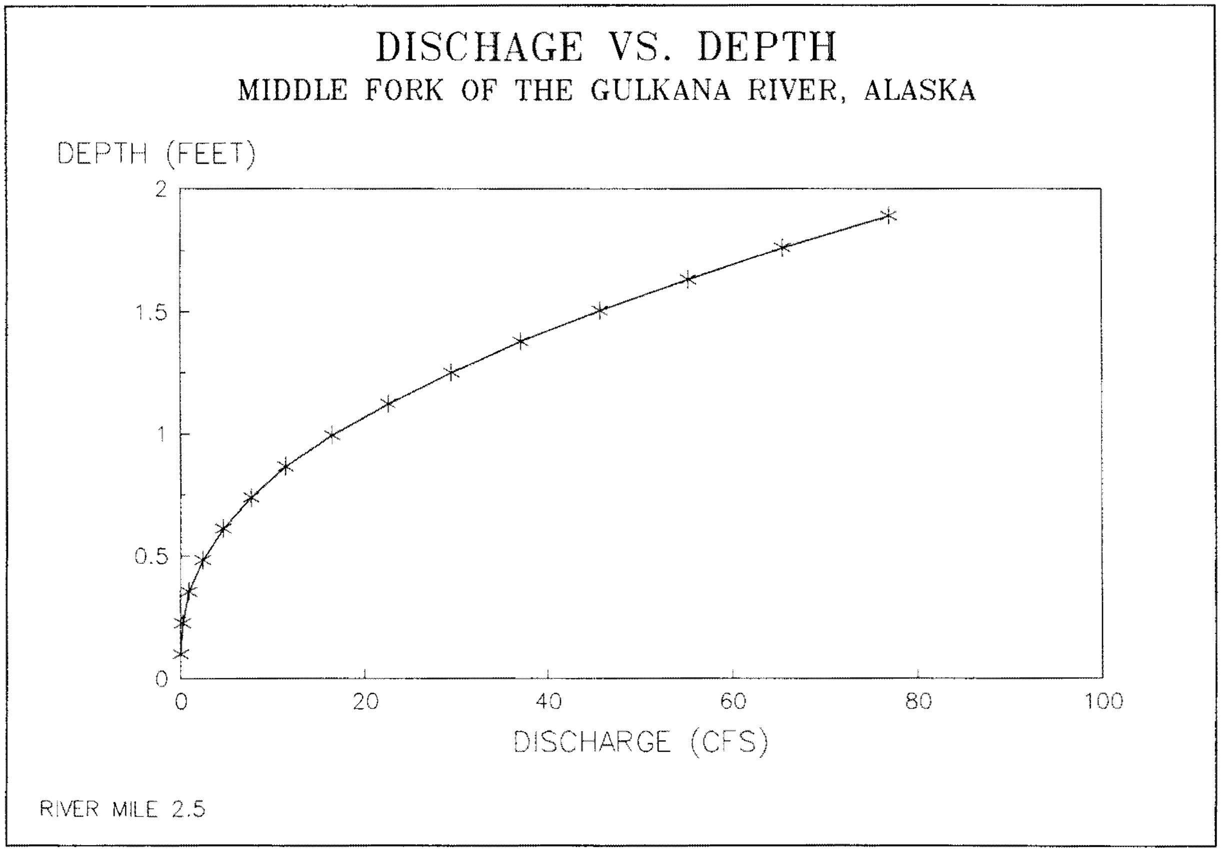

DISCHARGE VS. DEPTH
MIDDLE FORK OF THE GULKANA RIVER
DEPTH (FEET)
3.5
3
2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
120
DISCHARGE (CFS)
RIVER MILE 3

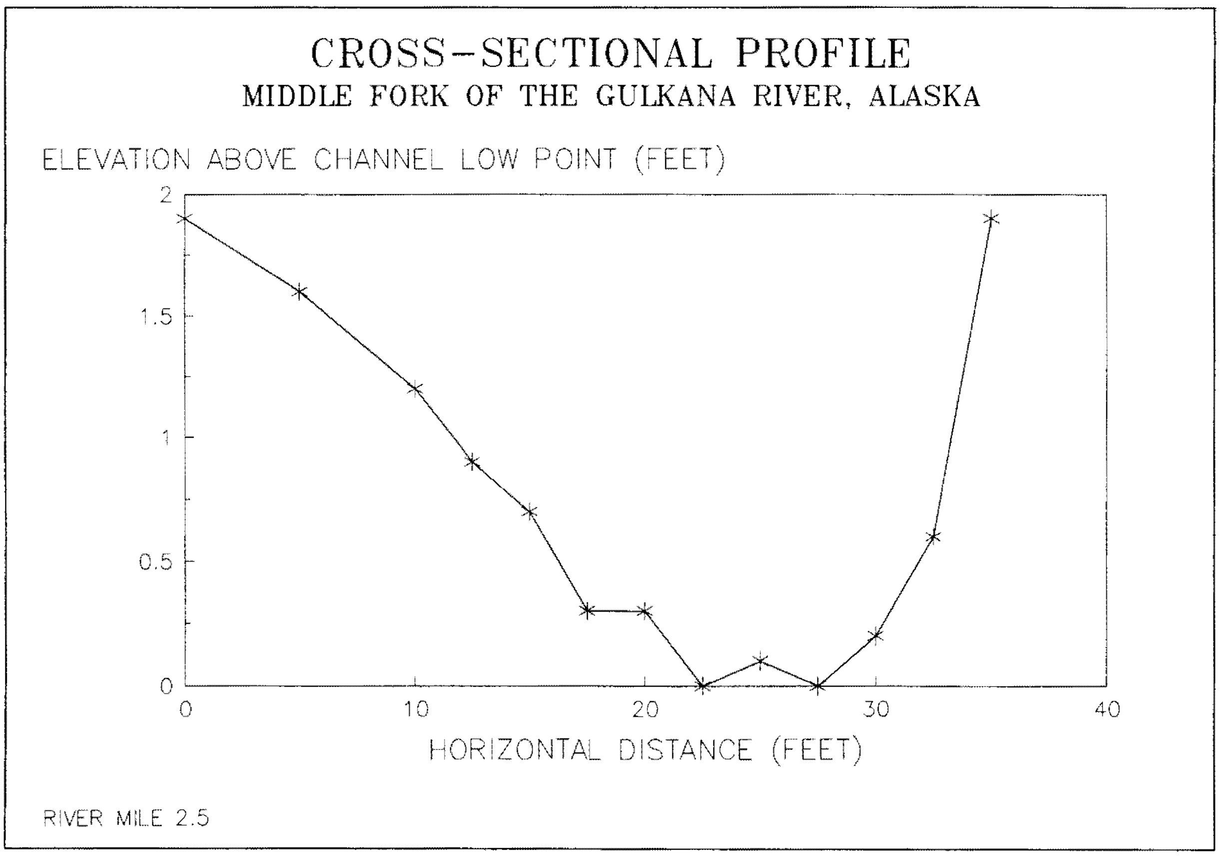

CROSS-SECTIONAL PROFILE
MIDDLE FORK OF THE GULKANA RIVER
ELEVATION ABOVE CHANNEL LOW POINT (FEET)
3.5
3
2.5
2
1.5
1
0.5
0
0
10
20
30
40
50
HORIZONTAL DISTANCE
RIVER MILE 3

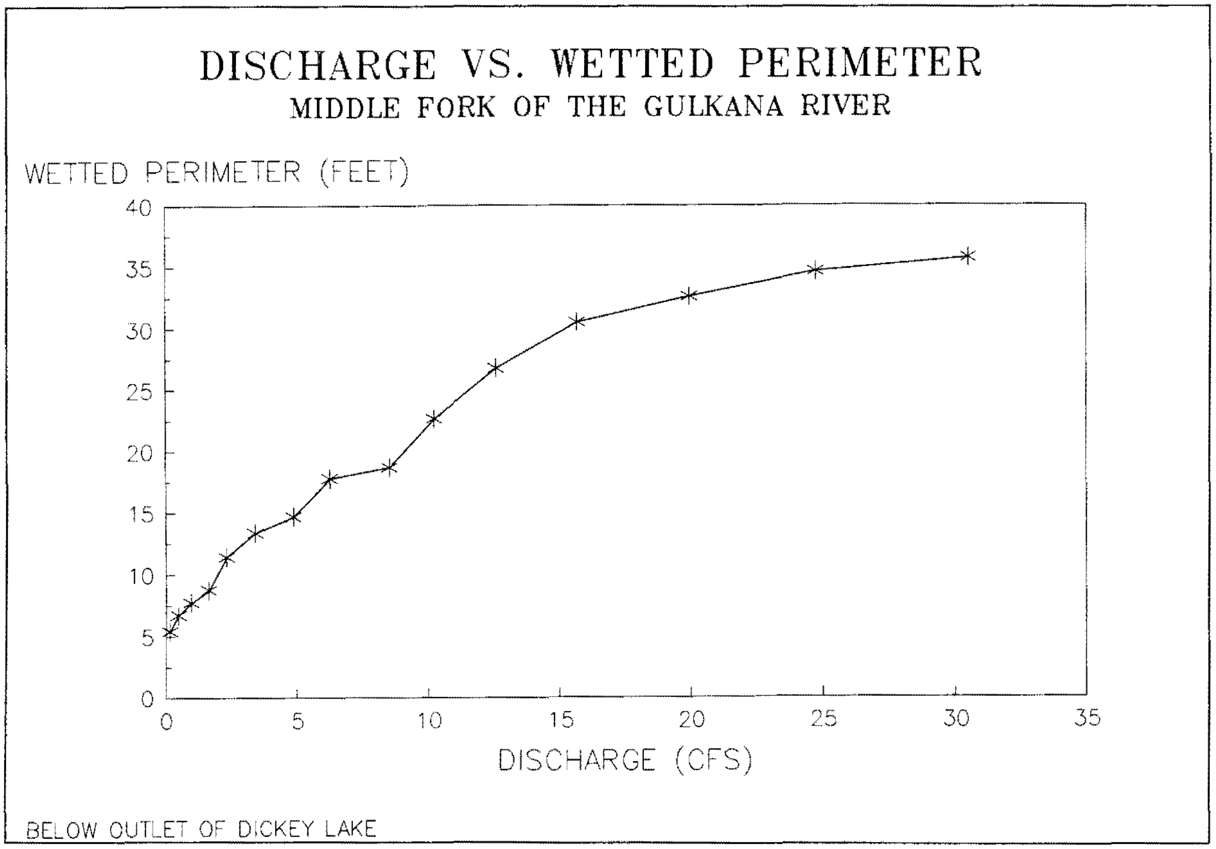

DISCHARGE VS. WETTED PERIMETER
MIDDLE FORK OF THE GULKANA RIVER, ALASKA
WETTED PERIMETER (FEET)
40
30
20
10
0
0
20
40
60
80
100
DISCHARGE (CFS)
RIVER MILE 2.5

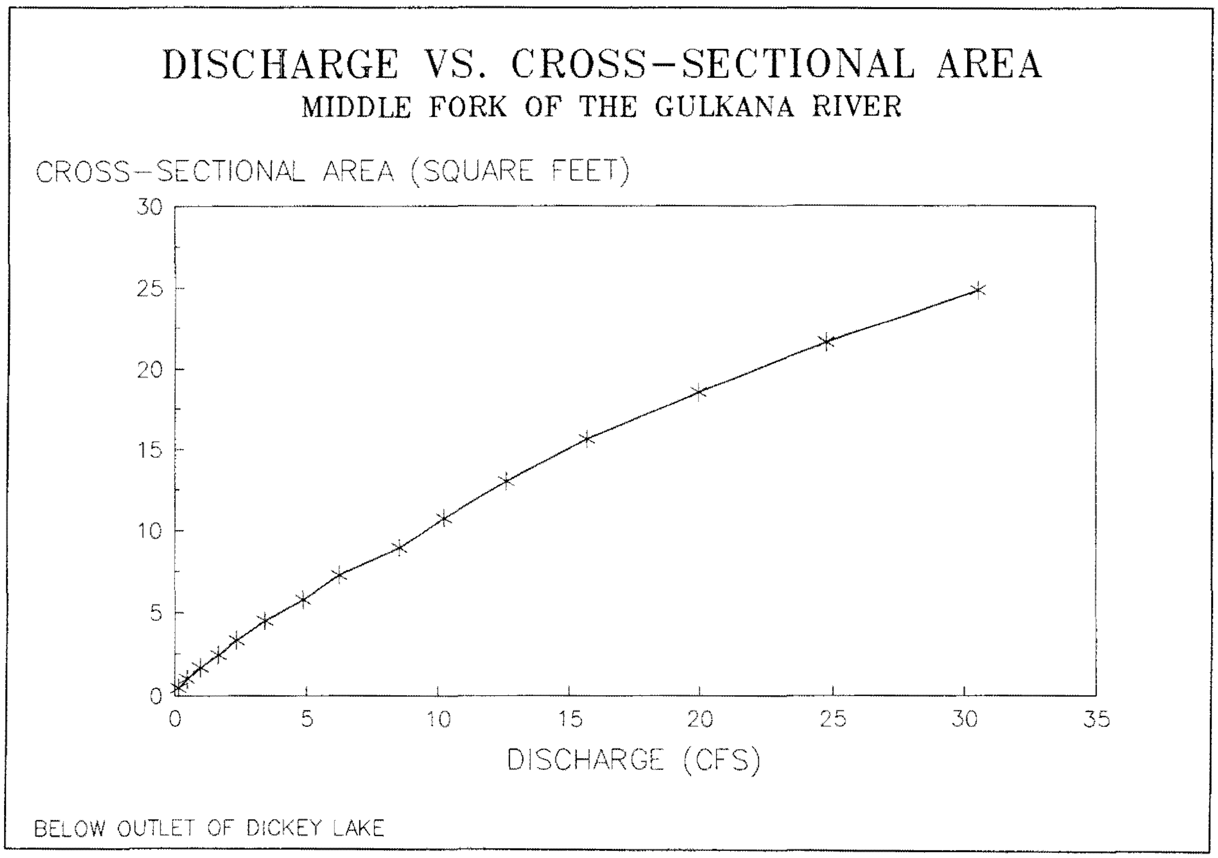

DISCHARGE VS. CROSS-SECTIONAL AREA
MIDDLE FORK OF THE GULKANA RIVER, ALASKA
CROSS-SECTIONAL AREA (FEET)
40
30
20
10
0
0
20
40
60
80
100
DISCHARGE (CFS)
RIVER MILE 2.5

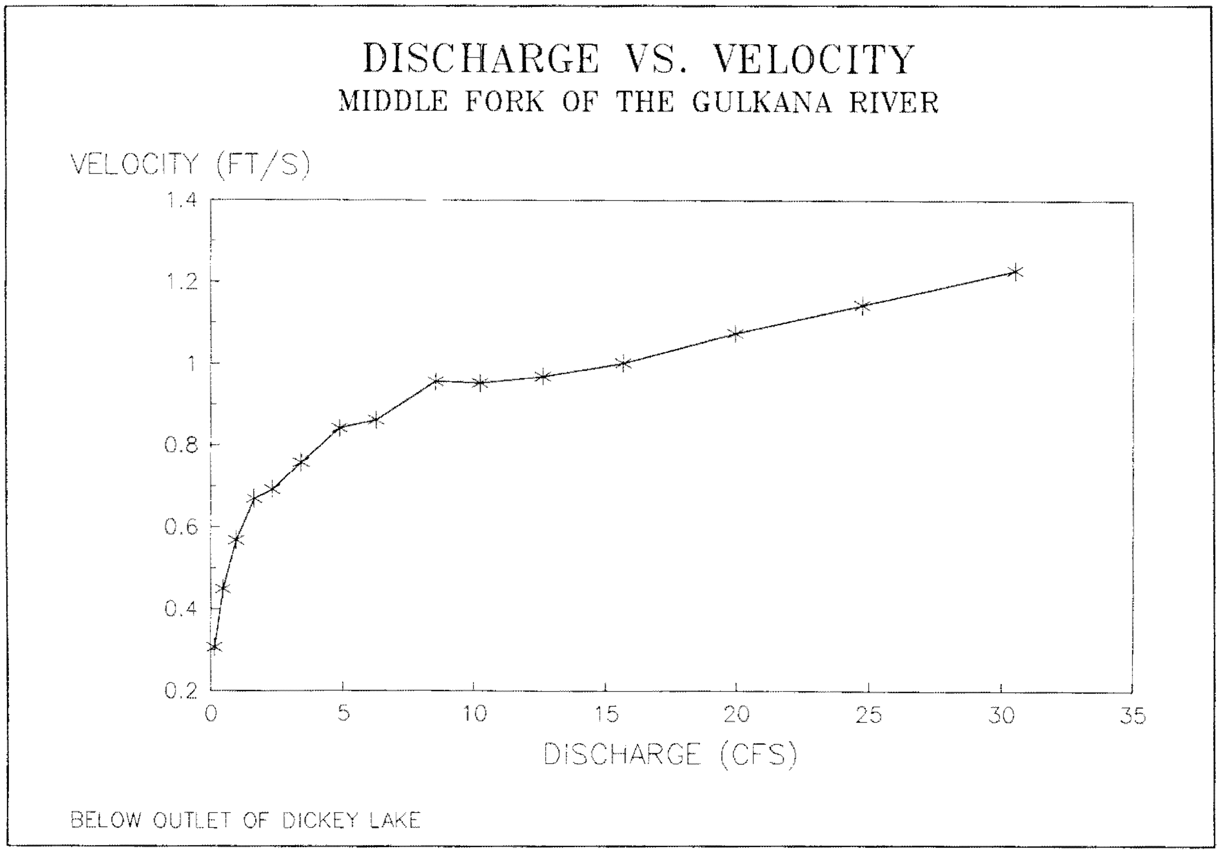

DISCHARGE VS. VELOCITY
MIDDLE FORK OF THE GULKANA RIVER, ALASKA
VELOCITY (FT/S)
2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
DISCHARGE (CFS)
RIVER MILE 2.5

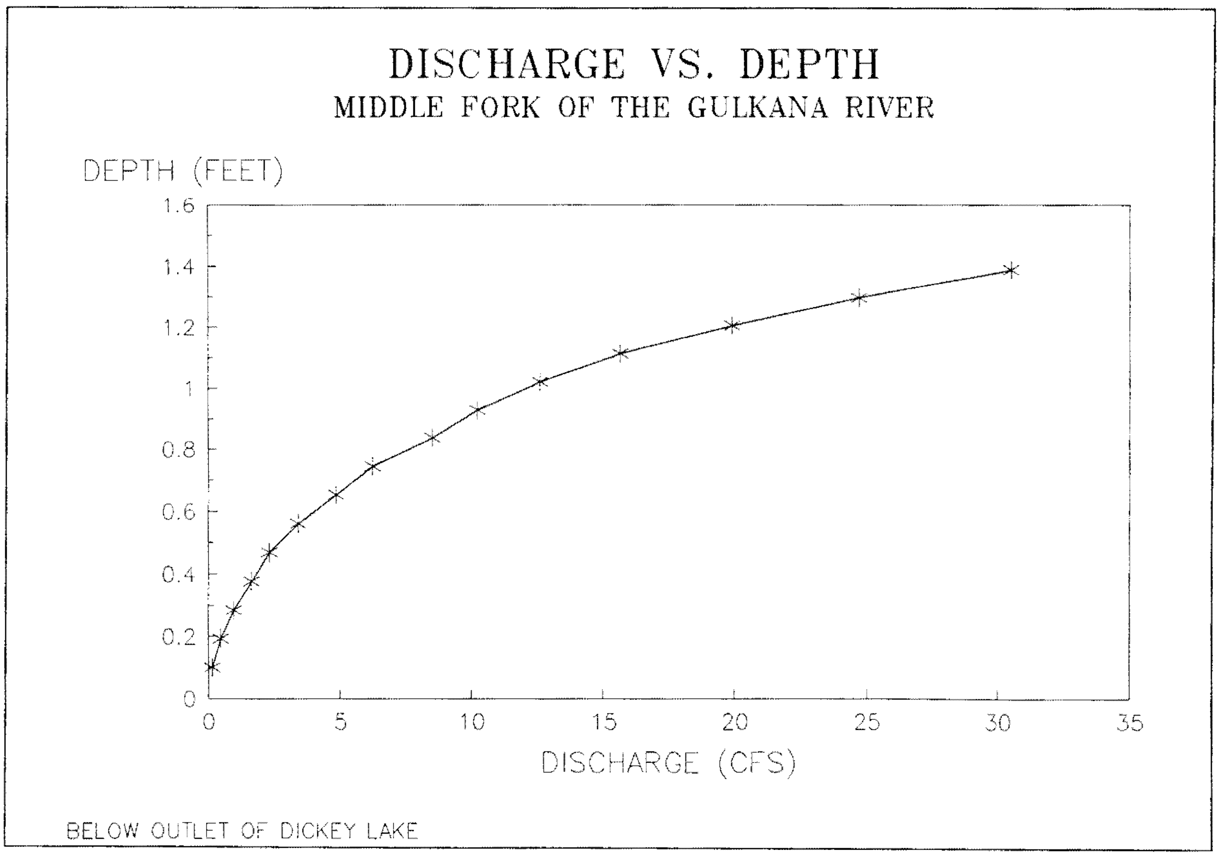

DISCHAGE VS. DEPTH
MIDDLE FORK OF THE GULKANA RIVER, ALASKA
DEPTH (FEET)
2
1.5
1
0.5
0
0
20
40
60
80
100
DISCHARGE (CFS)
RIVER MILE 2.5

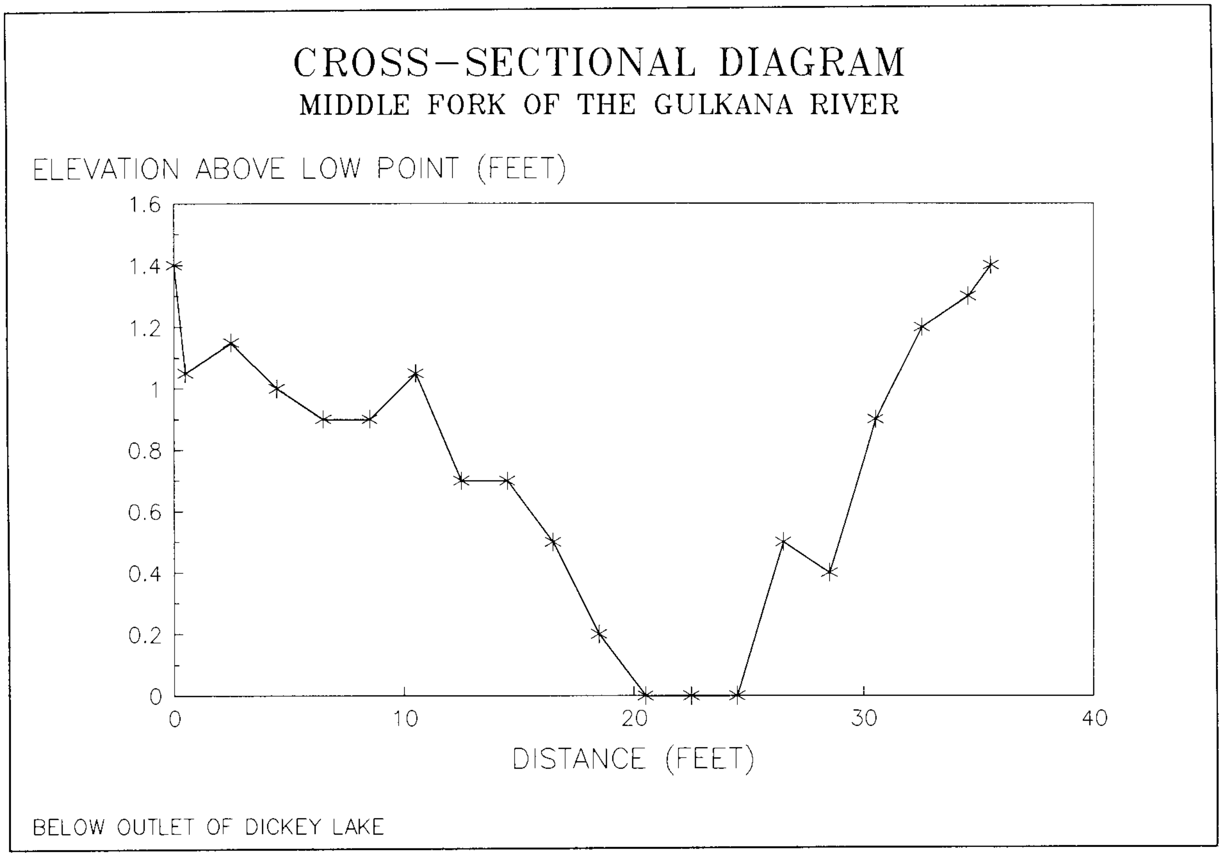

CROSS-SECTIONAL PROFILE
MIDDLE FORK OF THE GULKANA RIVER, ALASKA
ELEVATION ABOVE CHANNEL LOW POINT (FEET)
2
1.5
1
0.5
0
0
10
20
30
40
HORIZONTAL DISTANCE (FEET)
RIVER MILE 2.5

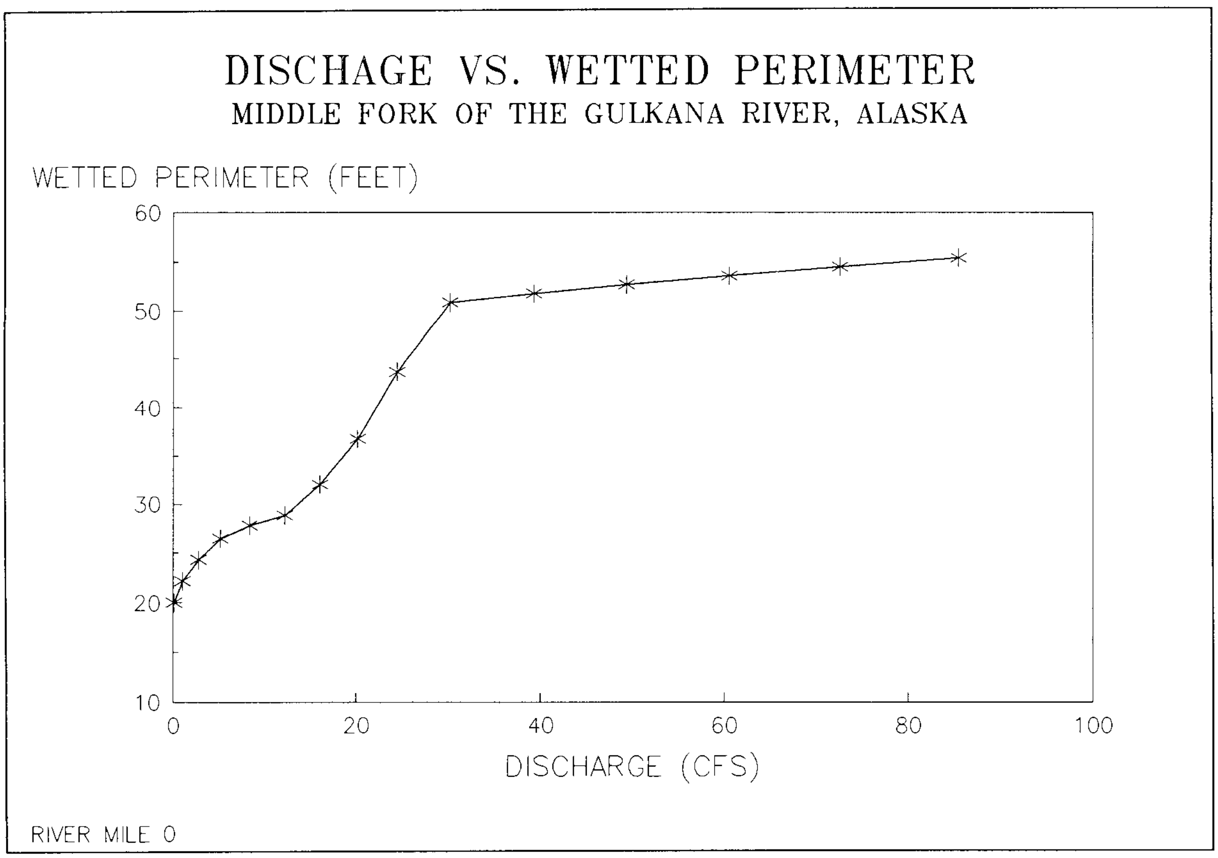

DISCHARGE VS. WETTED PERIMETER
MIDDLE FORK OF THE GULKANA RIVER
WETTED PERIMETER (FEET)
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
DISCHARGE (CFS)
BELOW OUTLET OF DICKEY LAKE

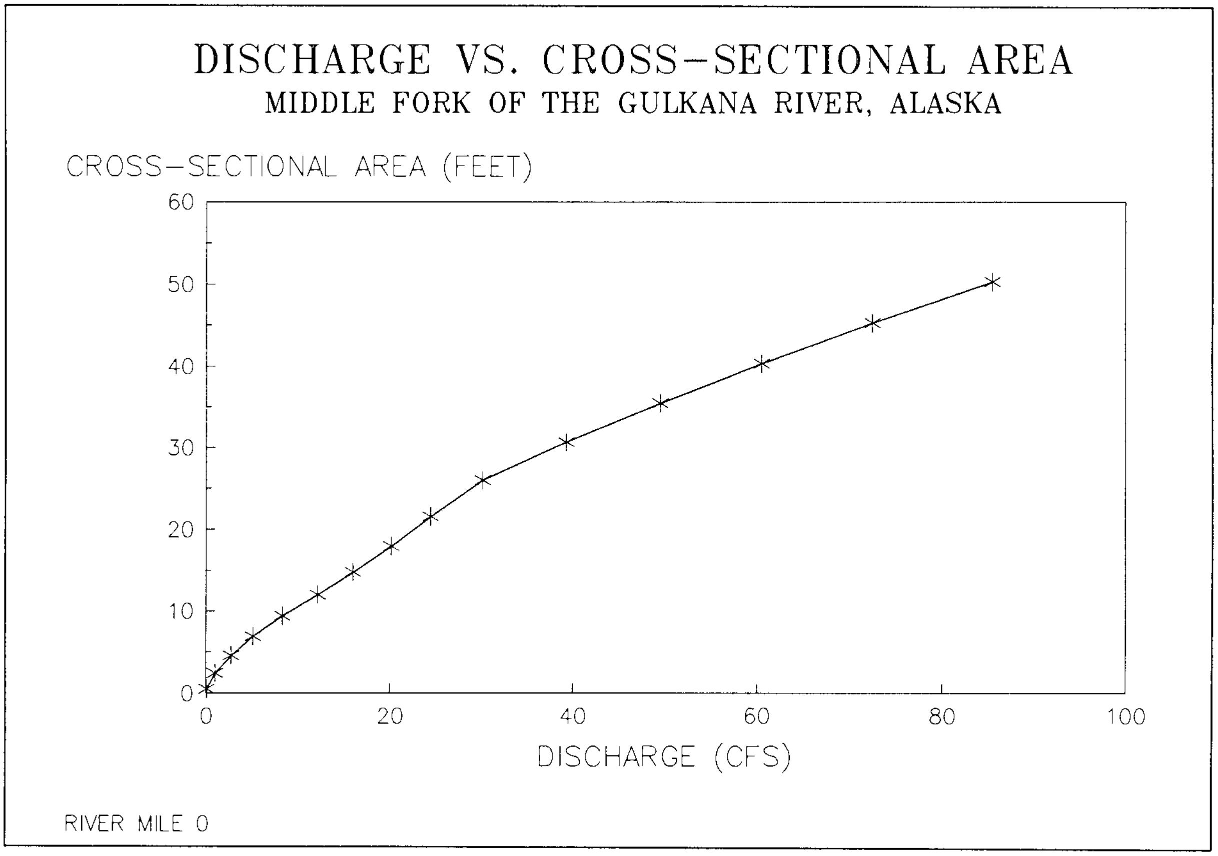

DISCHARGE VS. CROSS-SECTIONAL AREA
MIDDLE FORK OF THE GULKANA RIVER
CROSS-SECTIONAL AREA (SQUARE FEET)
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
DISCHARGE (CFS)
BELOW OUTLET OF DICKEY LAKE

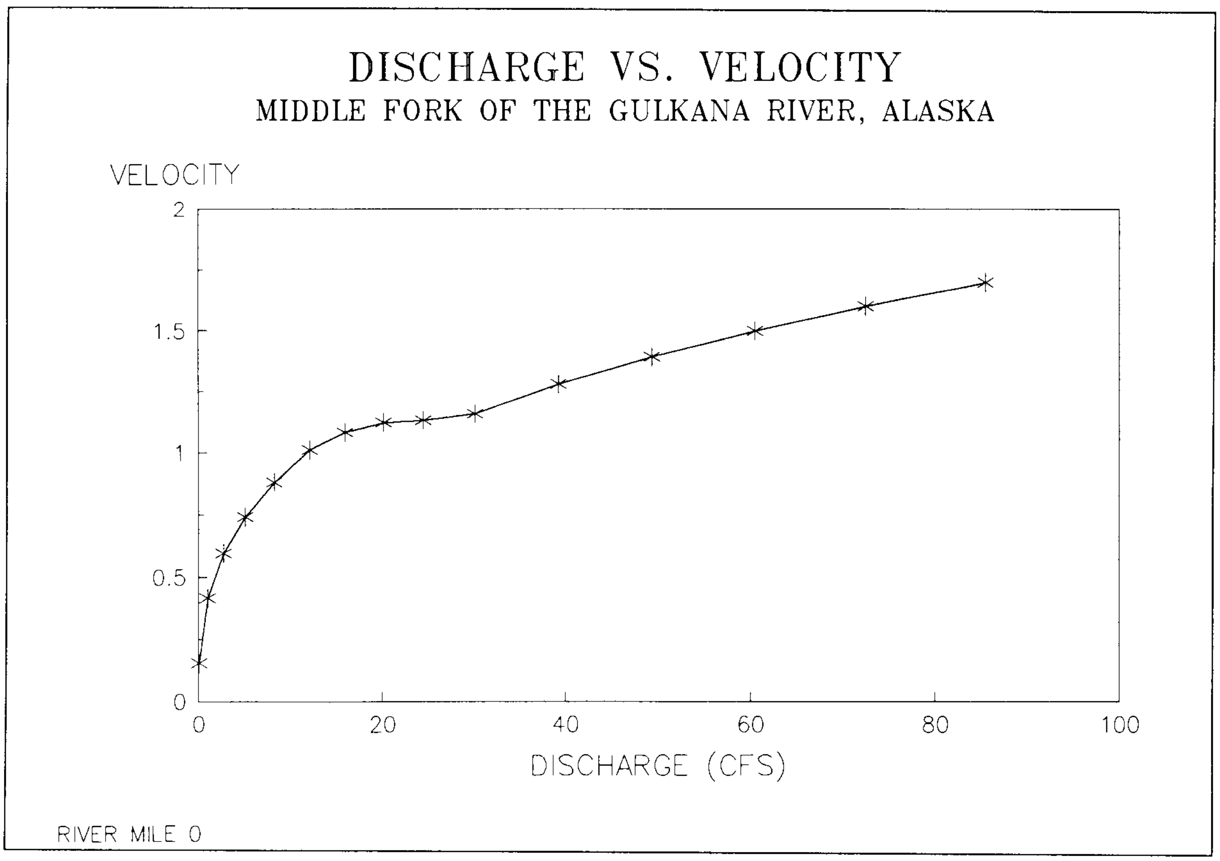

DISCHARGE VS. VELOCITY
MIDDLE FORK OF THE GULKANA RIVER
VELOCITY (FT/S)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
5
10
15
20
25
30
35
DISCHARGE (CFS)
BELOW OUTLET OF DICKEY LAKE

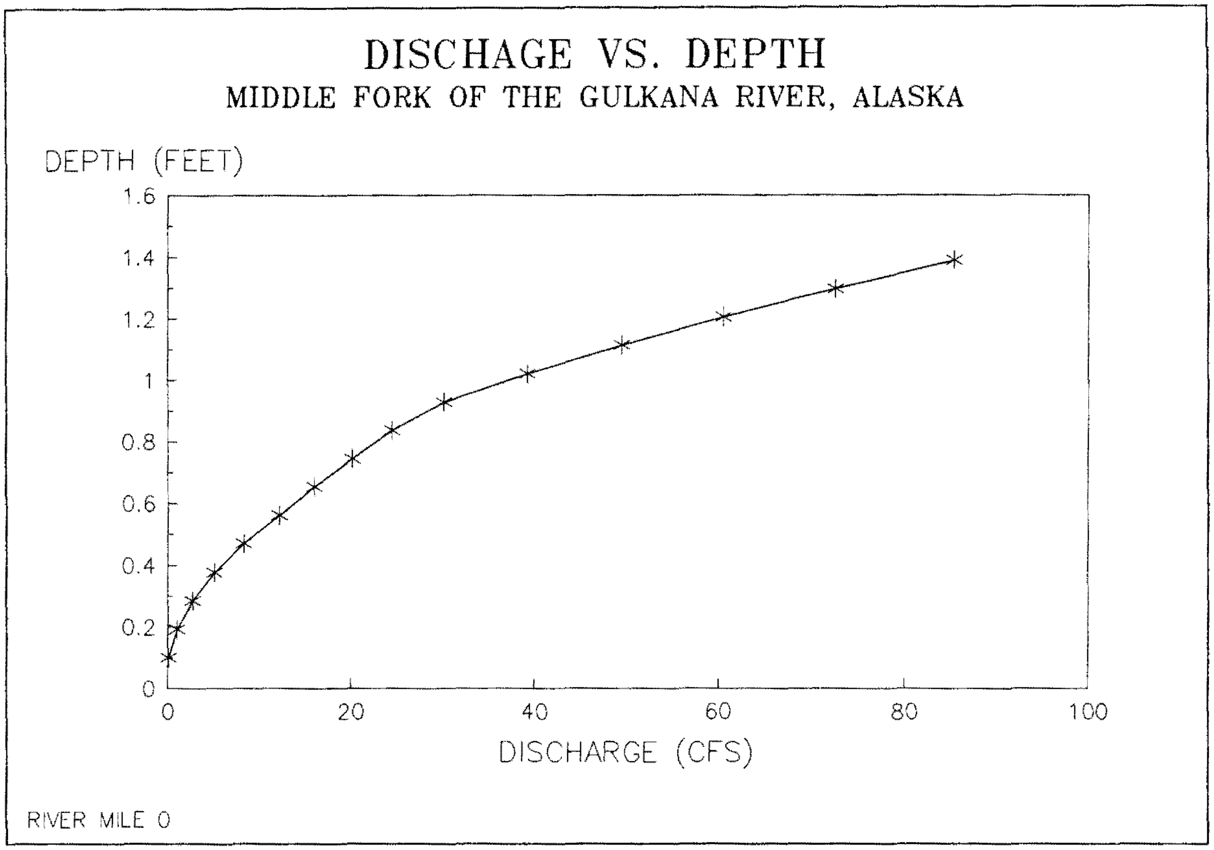

DISCHARGE VS. DEPTH
MIDDLE FORK OF THE GULKANA RIVER
DEPTH (FEET)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
35
DISCHARGE (CFS)
BELOW OUTLET OF DICKEY LAKE

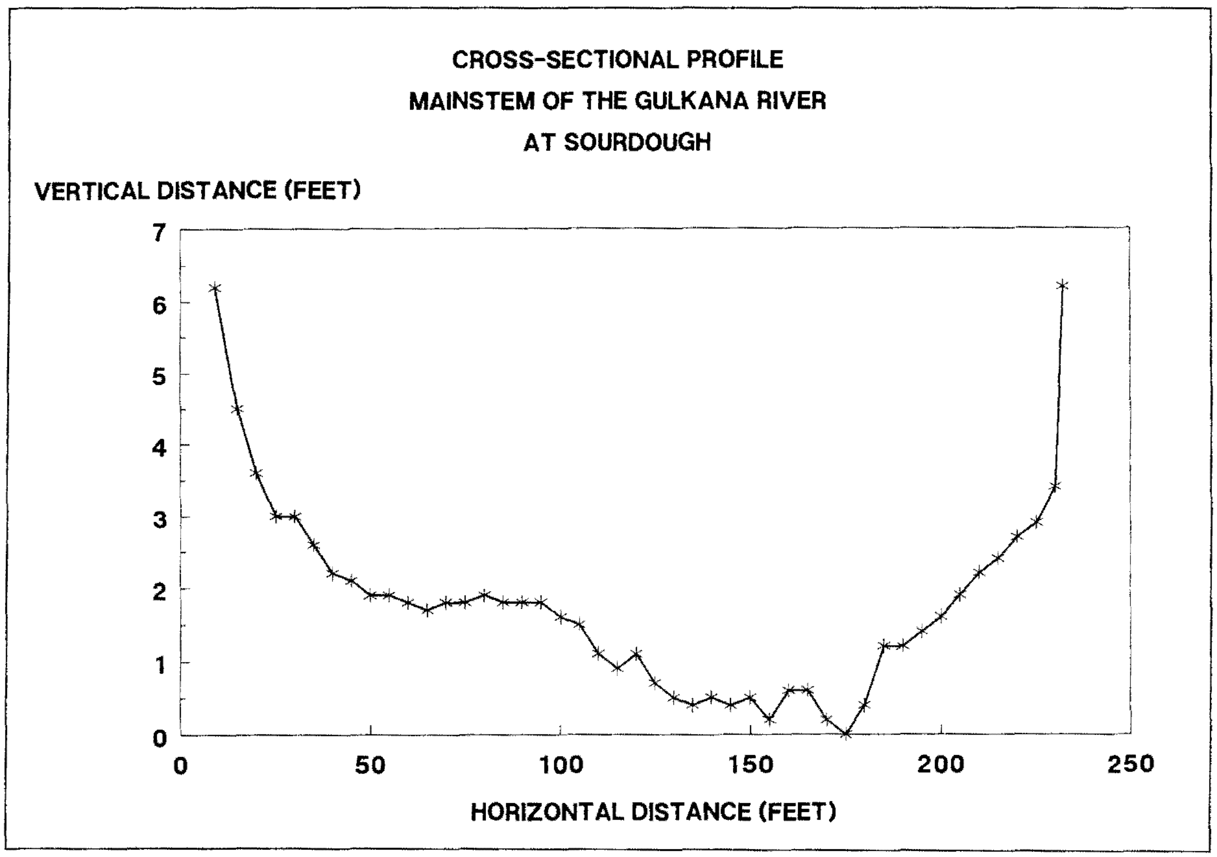

CROSS-SECTIONAL DIAGRAM
MIDDLE FORK OF THE GULKANA RIVER
ELEVATION ABOVE LOW POINT (FEET)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
10
20
30
40
DISTANCE (FEET)
BELOW OUTLET OF DICKEY LAKE

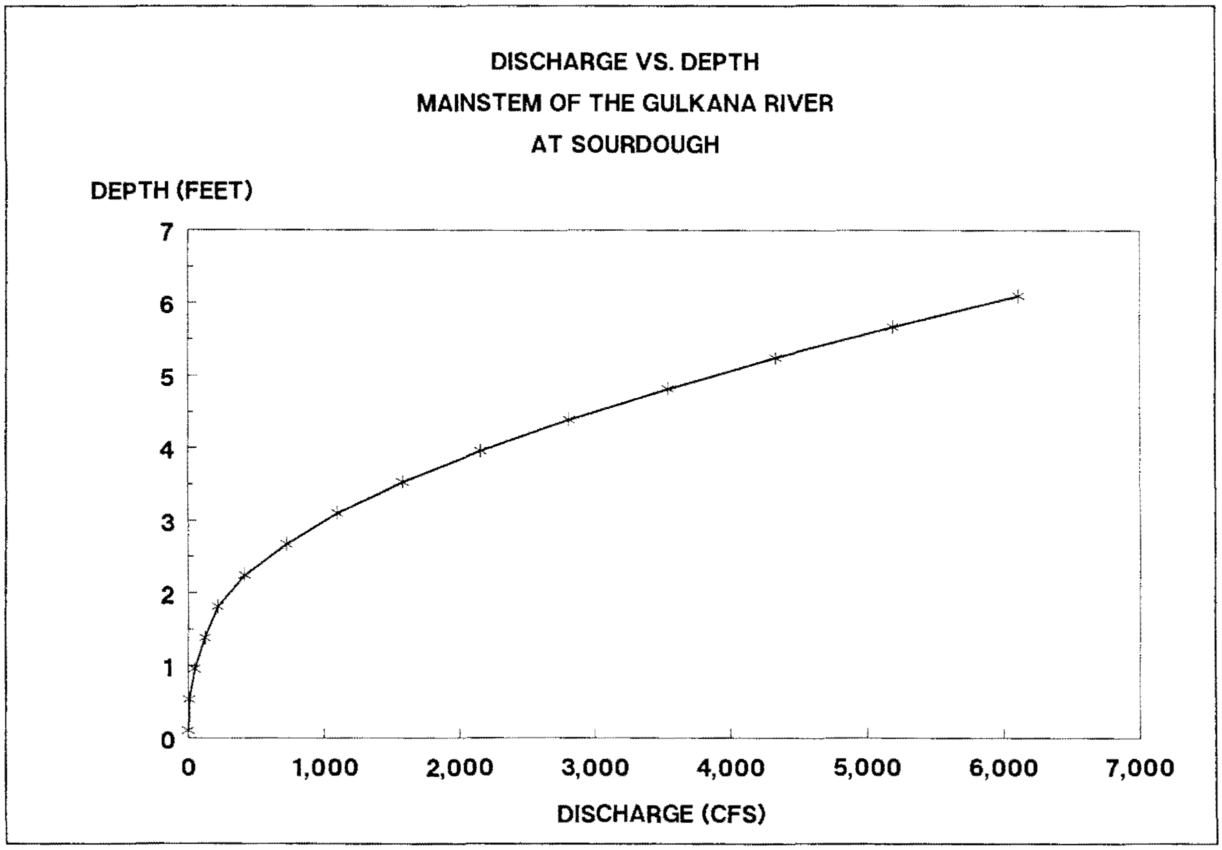

DISCHAGE VS. WETTED PERIMETER
MIDDLE FORK OF THE GULKANA RIVER, ALASKA
WETTED PERIMETER (FEET)
60
50
40
30
20
10
0
20
40
60
80
100
DISCHARGE (CFS)
RIVER MILE 0


DISCHARGE VS. CROSS-SECTIONAL AREA
MIDDLE FORK OF THE GULKANA RIVER, ALASKA
CROSS-SECTIONAL AREA (FEET)
60
50
40
30
20
10
0
0
20
40
60
80
100
DISCHARGE (CFS)
RIVER MILE 0

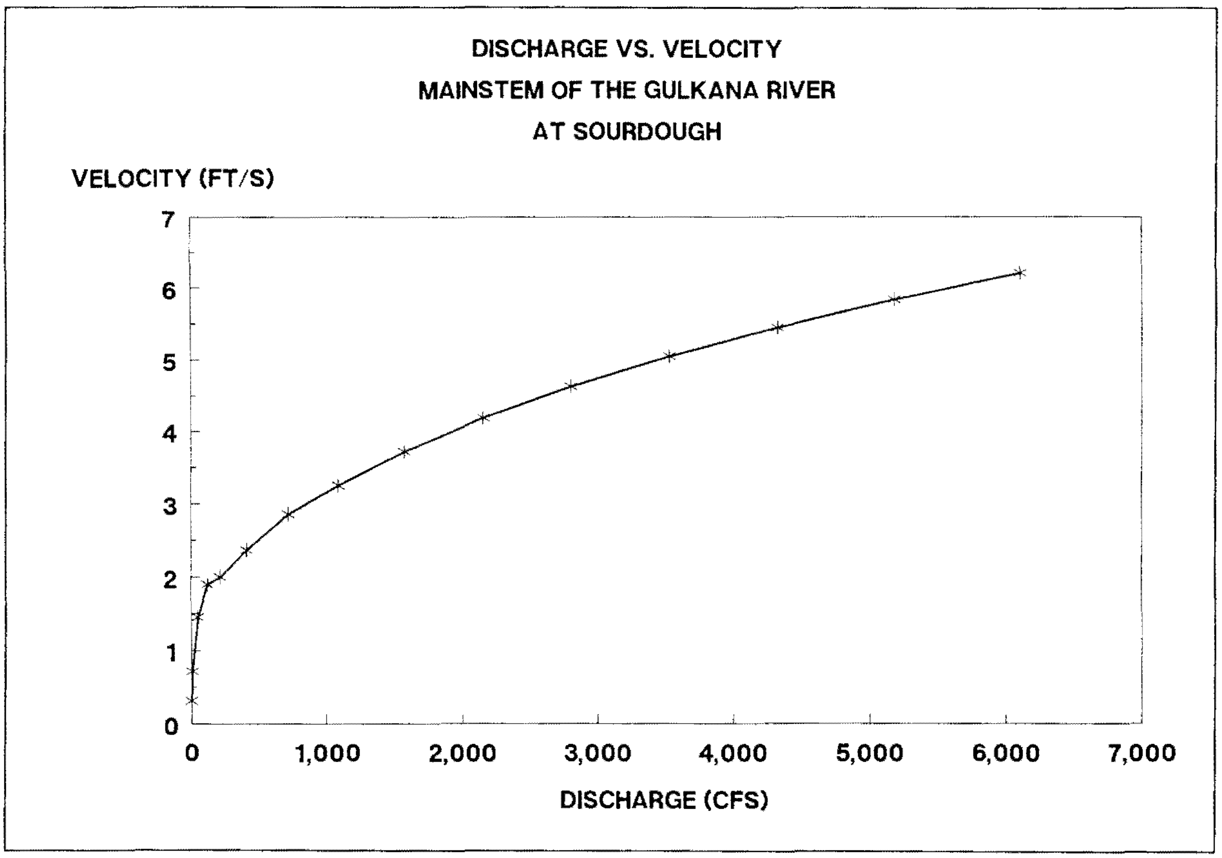

DISCHARGE VS. VELOCITY
MIDDLE FORK OF THE GULKANA RIVER, ALASKA
VELOCITY
2
1.5
1
0.5
0
0
20
40
60
80
100
DISCHARGE (CFS)
RIVER MILE 0


DISCHAGE VS. DEPTH
MIDDLE FORK OF THE GULKANA RIVER, ALASKA
DEPTH (FEET)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
DISCHARGE (CFS)
RIVER MILE 0

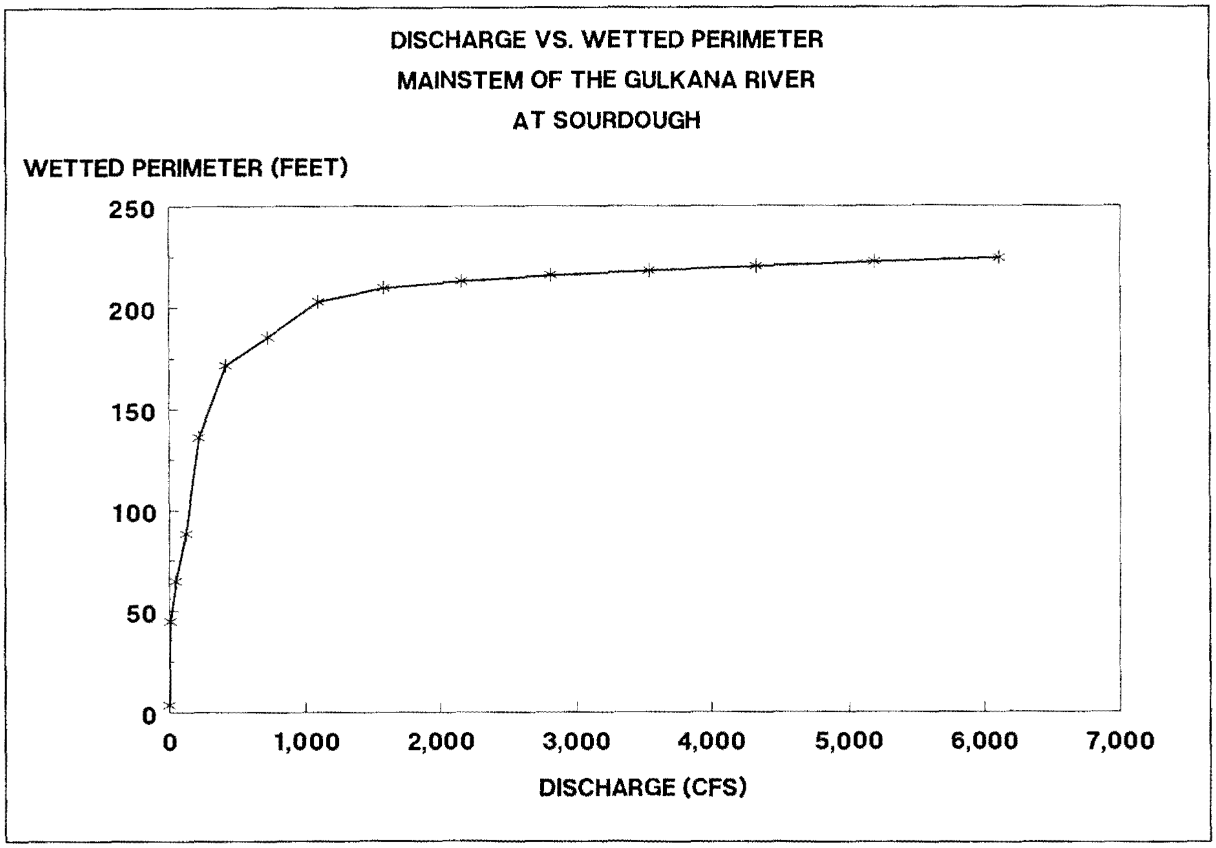

CROSS-SECTIONAL PROFILE
MAINSTEM OF THE GULKANA RIVER
AT SOURDOUGH
VERTICAL DISTANCE (FEET)
7
6
5
4
3
2
1
0
0
50
100
150
200
250
HORIZONTAL DISTANCE (FEET)



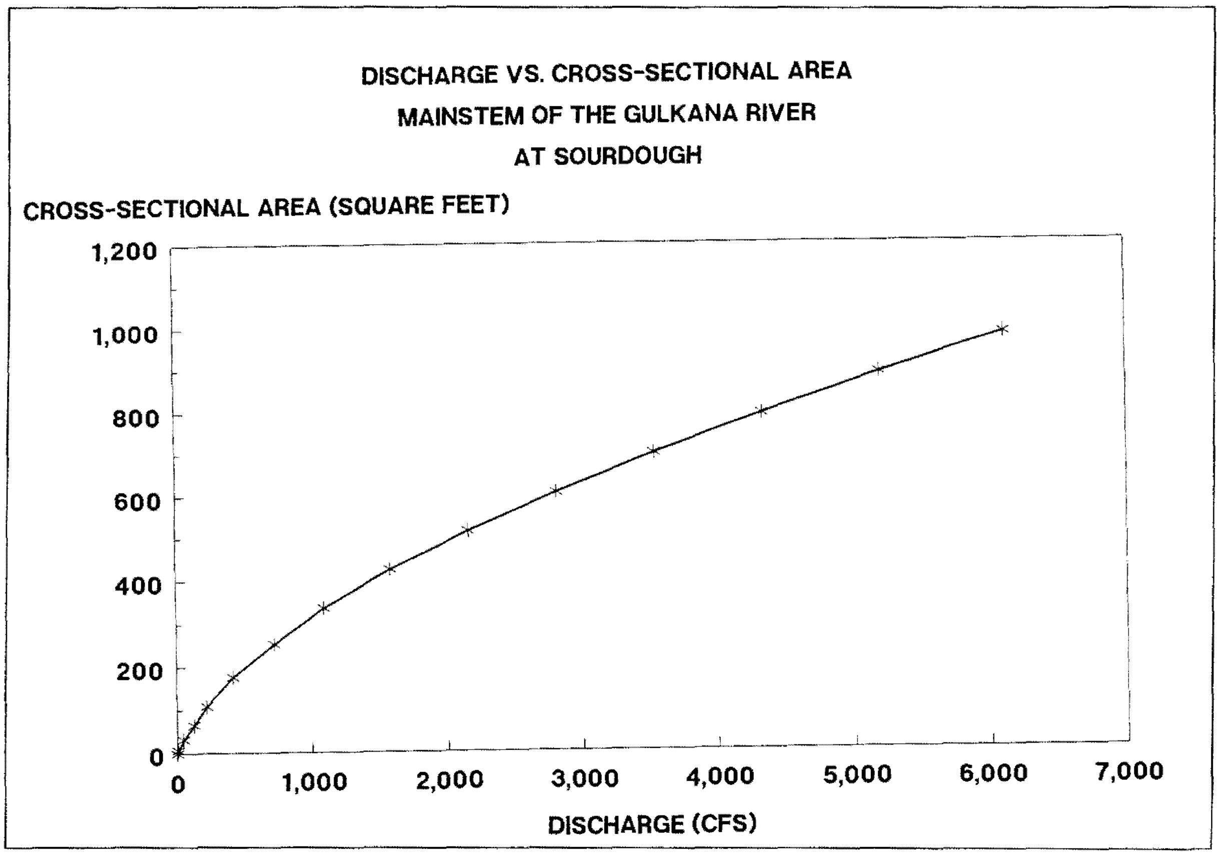
DISCHARGE VS. DEPTH
MAINSTEM OF THE GULKANA RIVER
AT SOURDOUGH
DEPTH (FEET)
7
6
5
4
3
2
1
0
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
DISCHARGE (CFS)



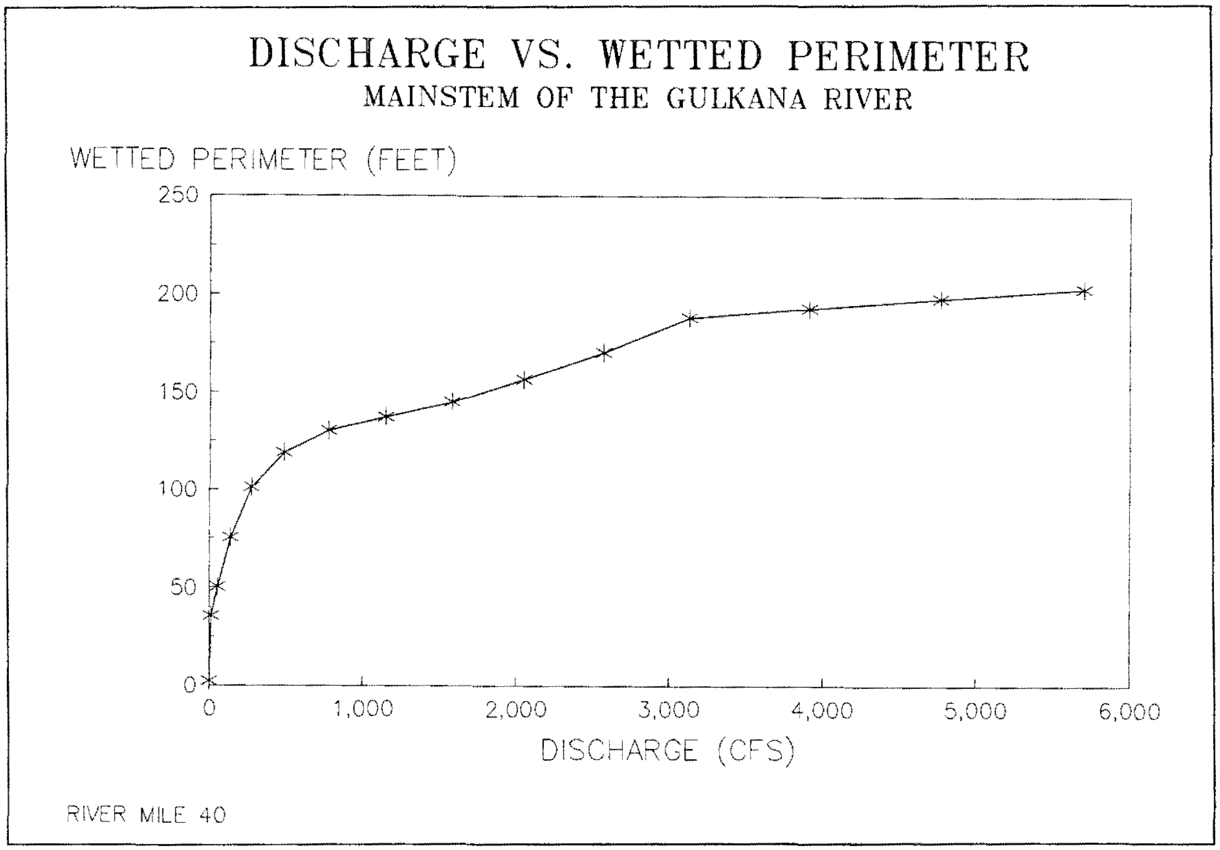
DISCHARGE VS. VELOCITY
MAINSTEM OF THE GULKANA RIVER
AT SOURDOUGH
VELOCITY (FT/S)
7
6
5
4
3
2
1
0
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
DISCHARGE (CFS)

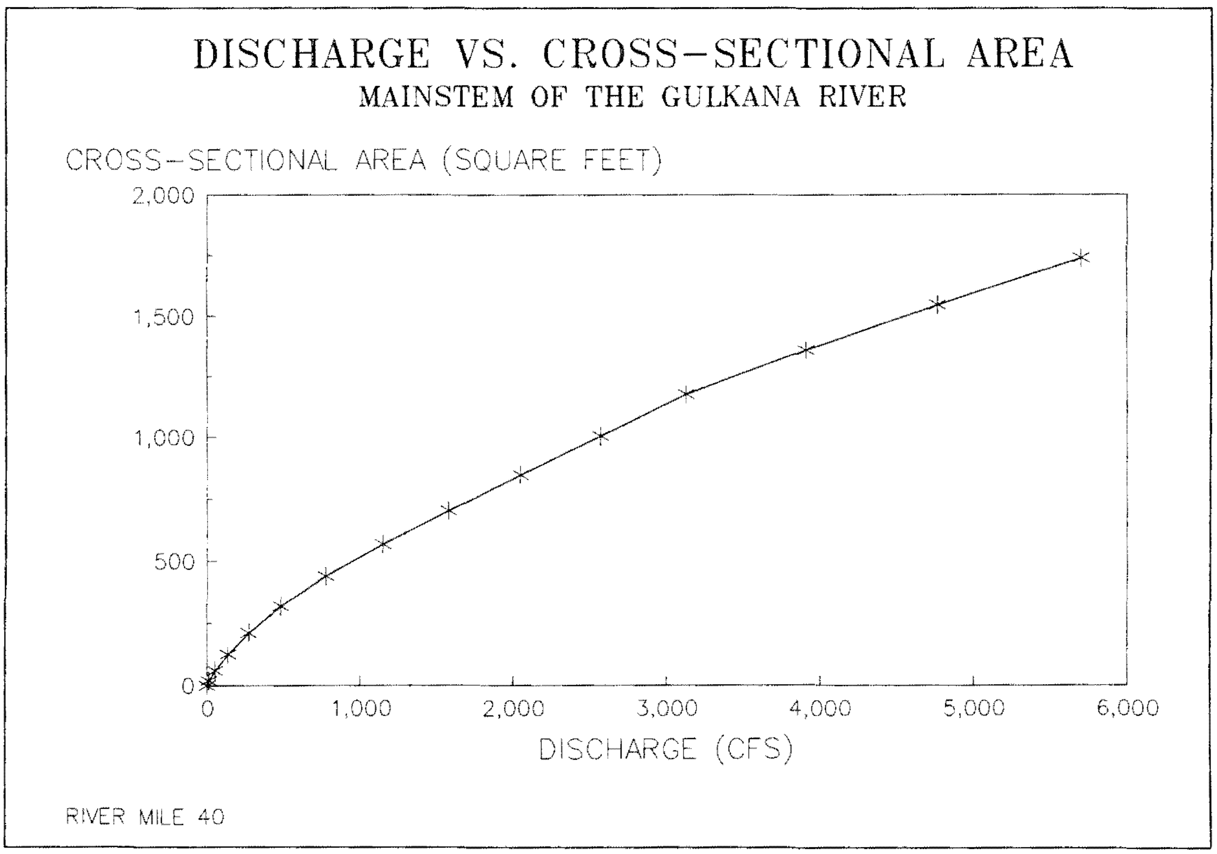


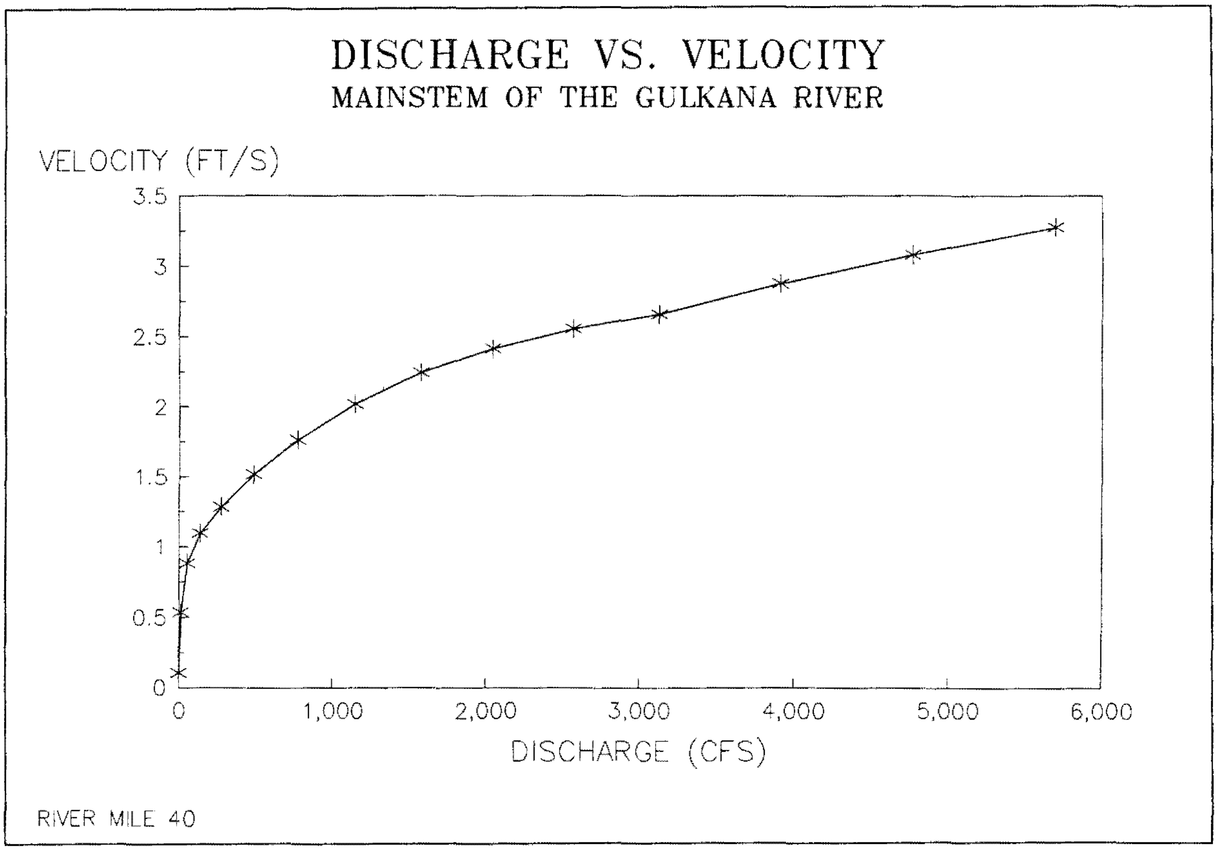
DISCHARGE VS. WETTED PERIMETER
MAINSTEM OF THE GULKANA RIVER
AT SOURDOUGH
WETTED PERIMETER (FEET)
250
200
150
100
50
0
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
DISCHARGE (CFS)

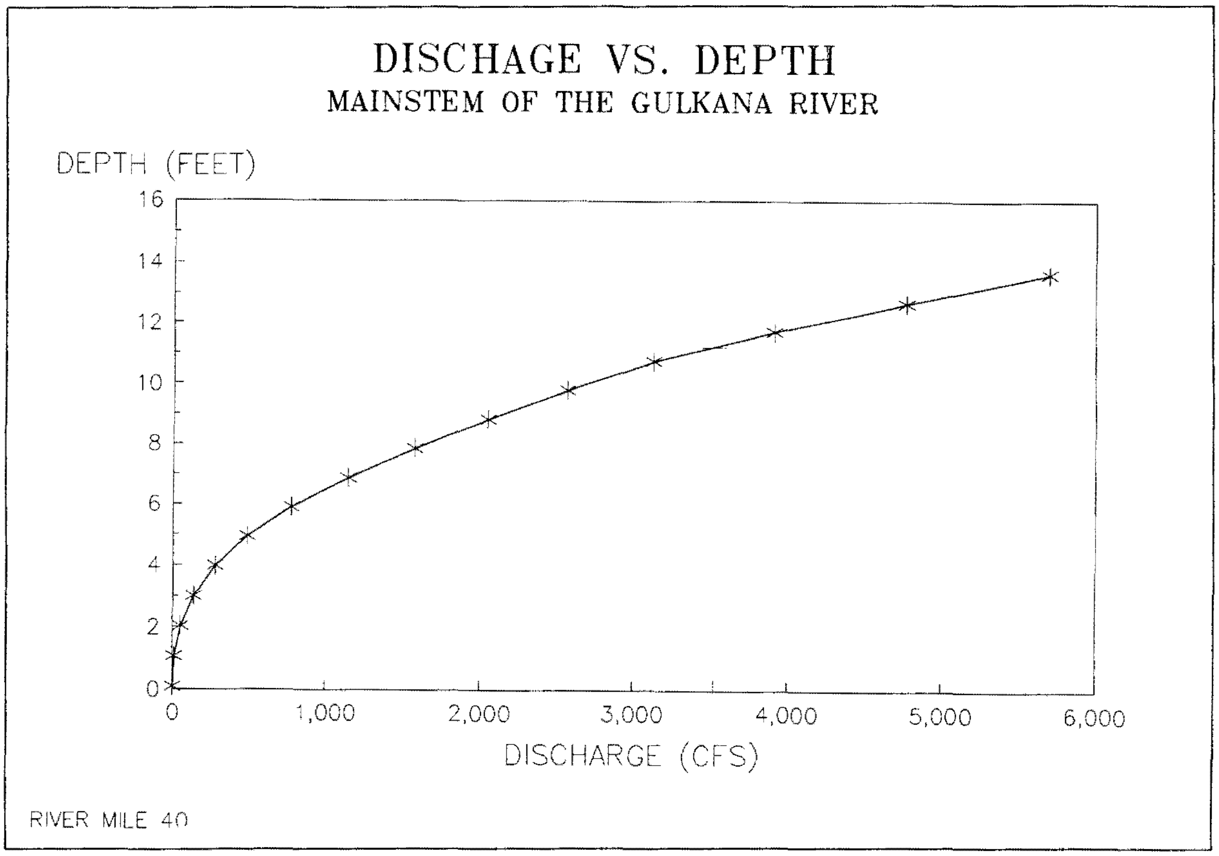


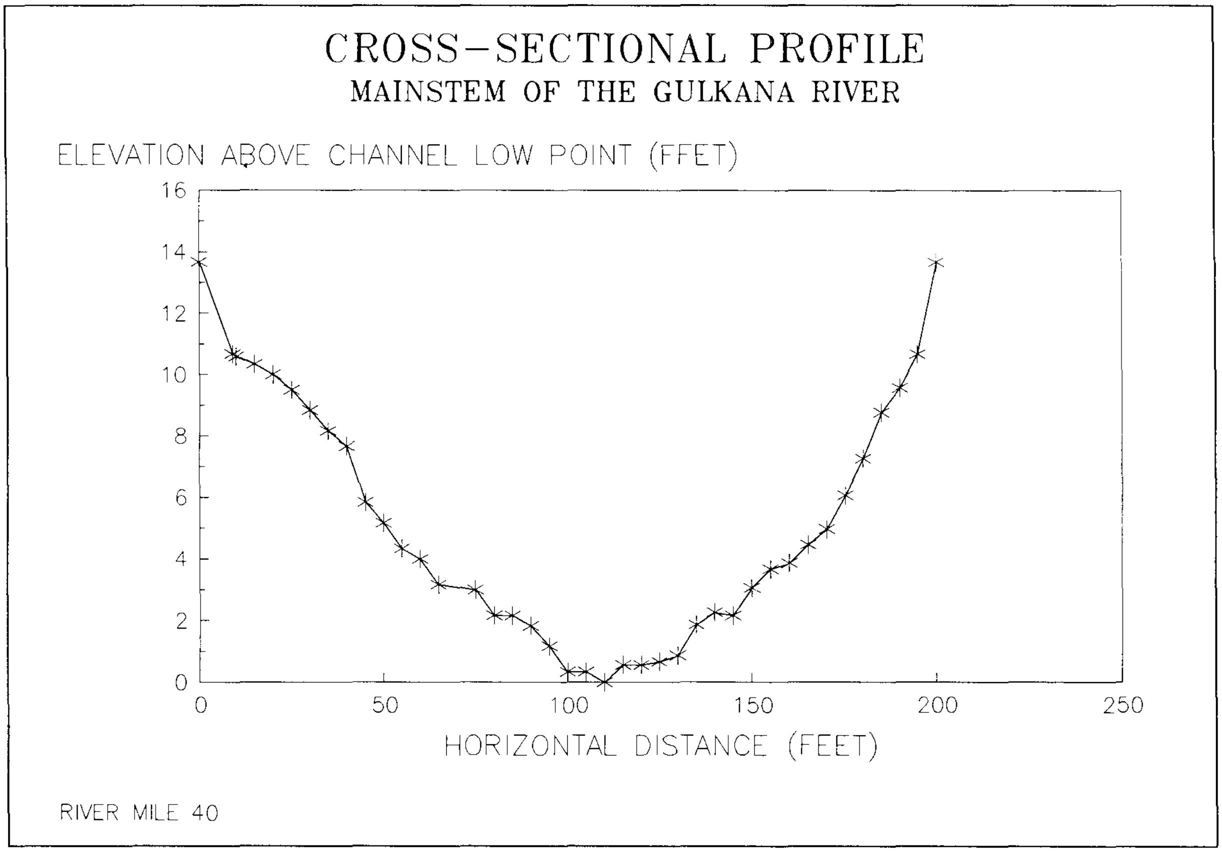
DISCHARGE VS. CROSS-SECTIONAL AREA
MAINSTEM OF THE GULKANA RIVER
AT SOURDOUGH
CROSS-SECTIONAL AREA (SQUARE FEET)
1,200
1,000
800
600
400
200
0
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
DISCHARGE (CFS)

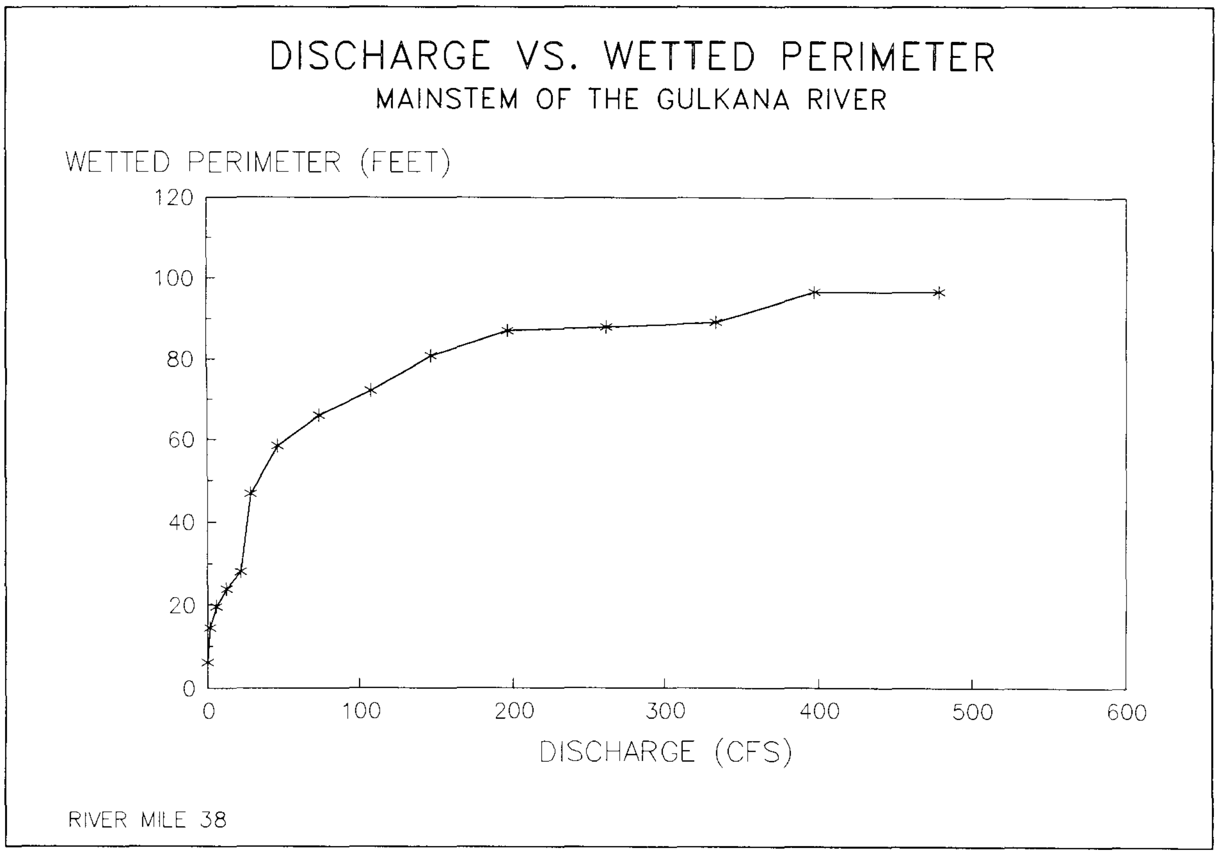

DISCHARGE VS. WETTED PERIMETER
MAINSTEM OF THE GULKANA RIVER
WETTED PERIMETER (FEET)
250
200
150
100
50
0
0
1,000
2,000
3,000
4,000
5,000
6,000
DISCHARGE (CFS)
RIVER MILE 40

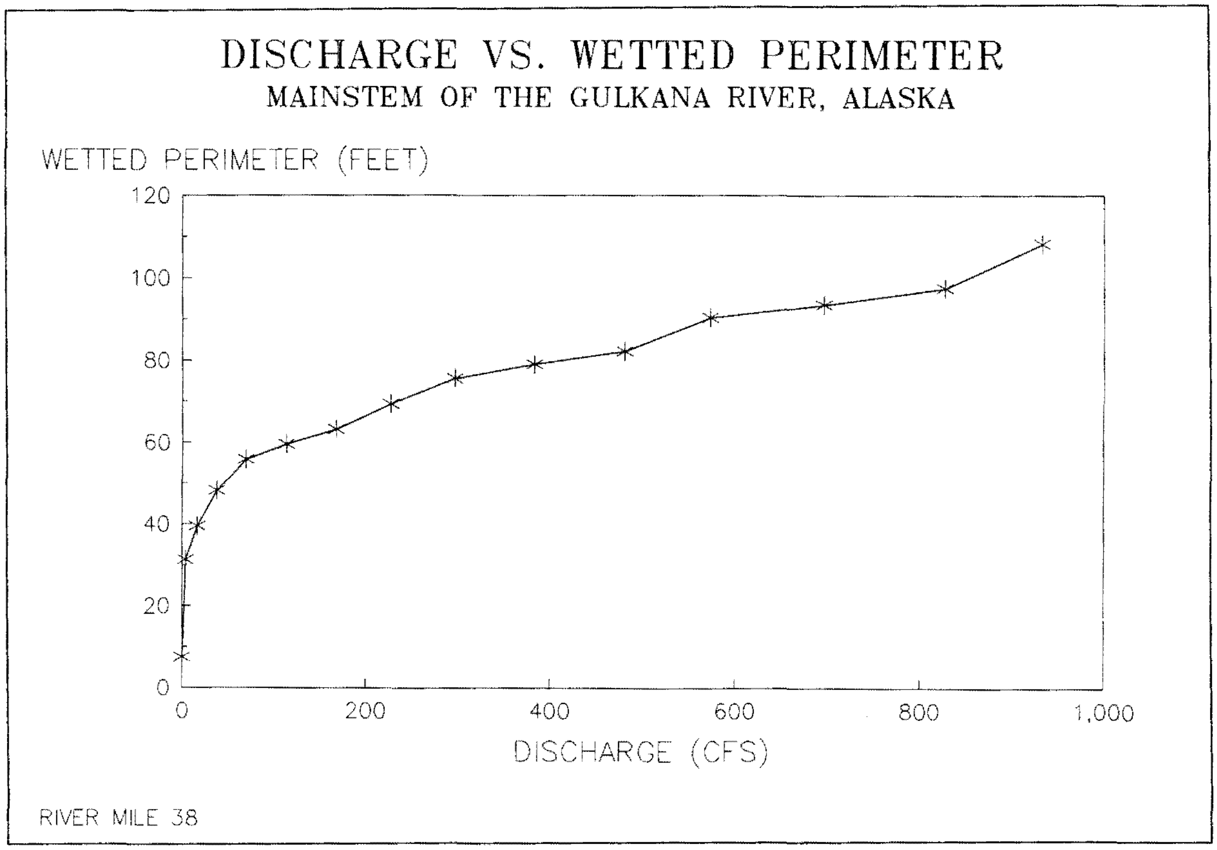

DISCHARGE VS. CROSS-SECTIONAL AREA
MAINSTEM OF THE GULKANA RIVER
CROSS-SECTIONAL AREA (SQUARE FEET)
2,000
1,500
1,000
500
0
0
1,000
2,000
3,000
4,000
5,000
6,000
DISCHARGE (CFS)
RIVER MILE 40

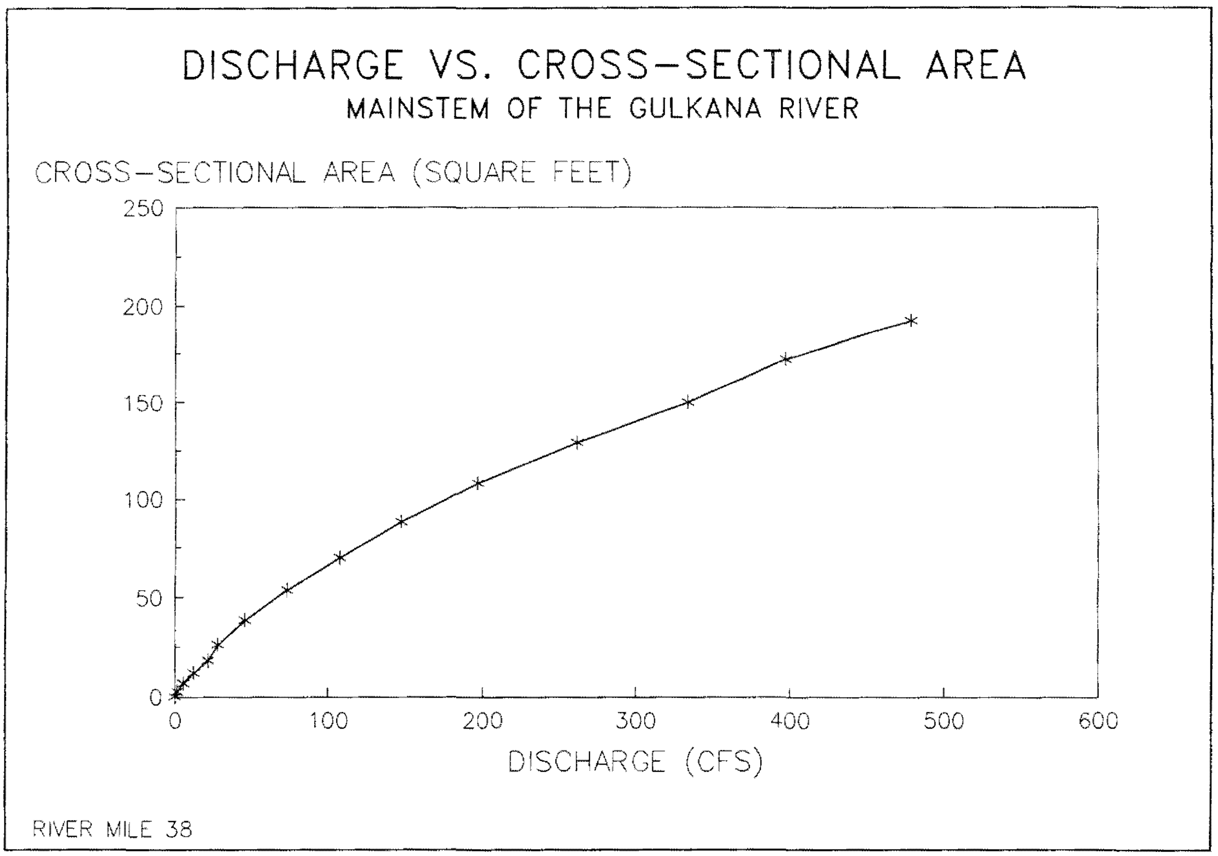

DISCHARGE VS. VELOCITY
MAINSTEM OF THE GULKANA RIVER
VELOCITY (FT/S)
3.5
3
2.5
2
1.5
1
0.5
0
0
1,000
2,000
3,000
4,000
5,000
6,000
DISCHARGE (CFS)
RIVER MILE 40

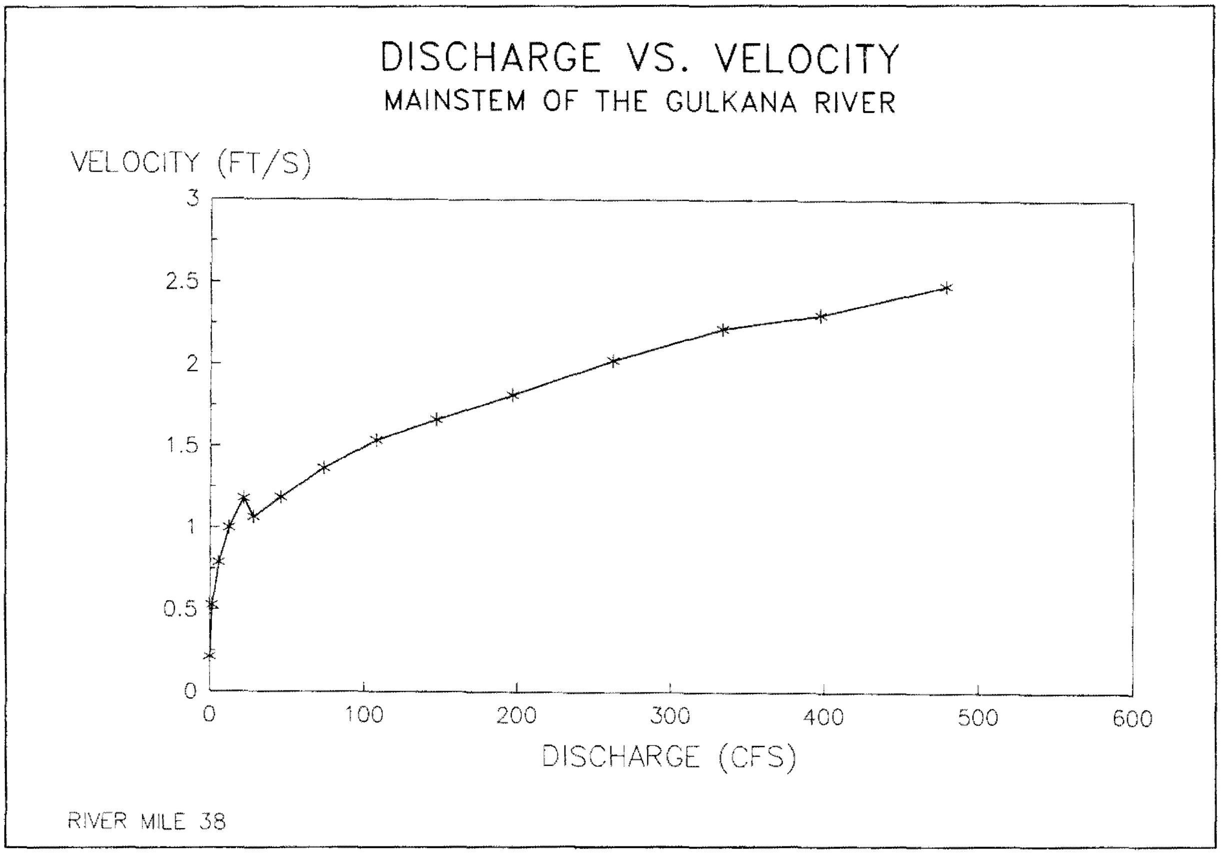

DISCHAGE VS. DEPTH
MAINSTEM OF THE GULKANA RIVER
DEPTH (FEET)
16
14
12
10
8
6
4
2
0
0
1,000
2,000
3,000
4,000
5,000
6,000
DISCHARGE (CFS)
RIVER MILE 40

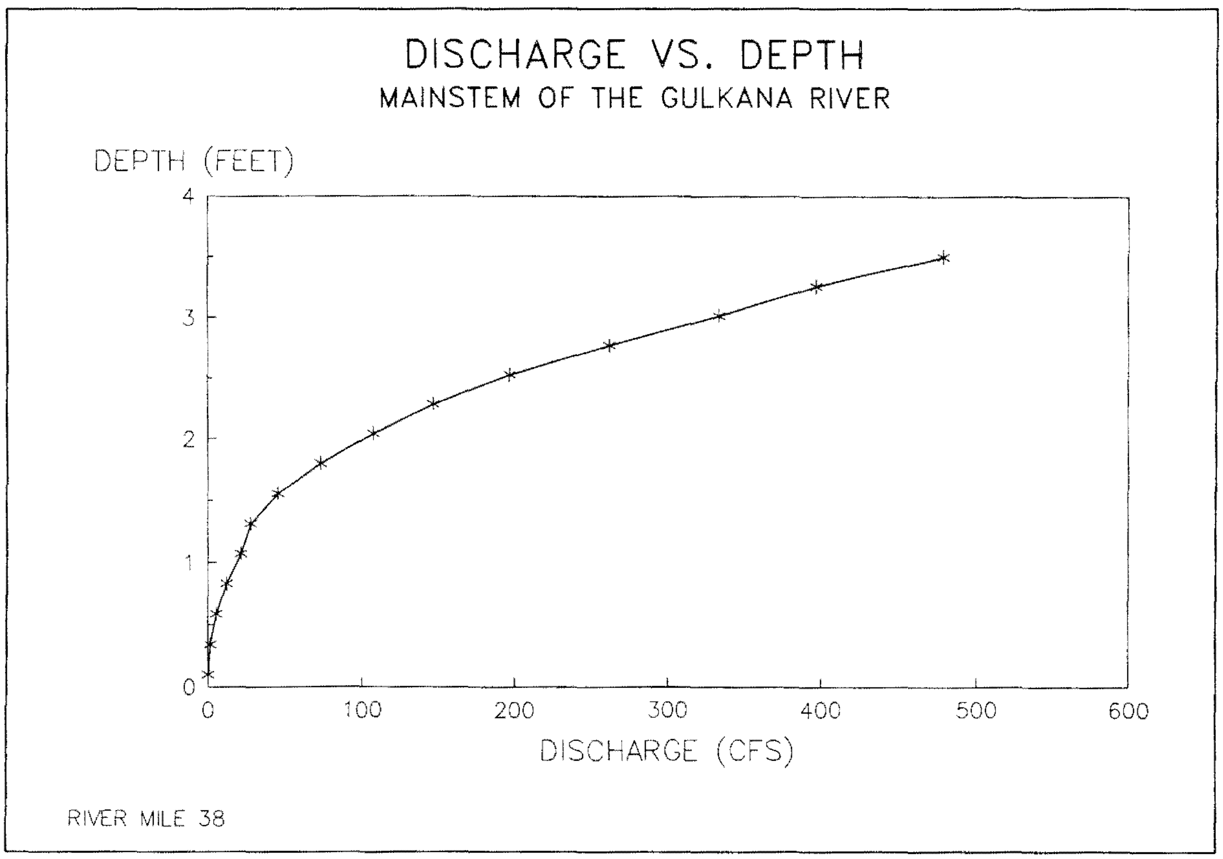

CROSS-SECTIONAL PROFILE
MAINSTEM OF THE GULKANA RIVER
ELEVATION ABOVE CHANNEL LOW POINT (FFET)
0
2
4
6
8
10
12
14
16
0
50
100
150
200
250
HORIZONTAL DISTANCE (FEET)
RIVER MILE 40

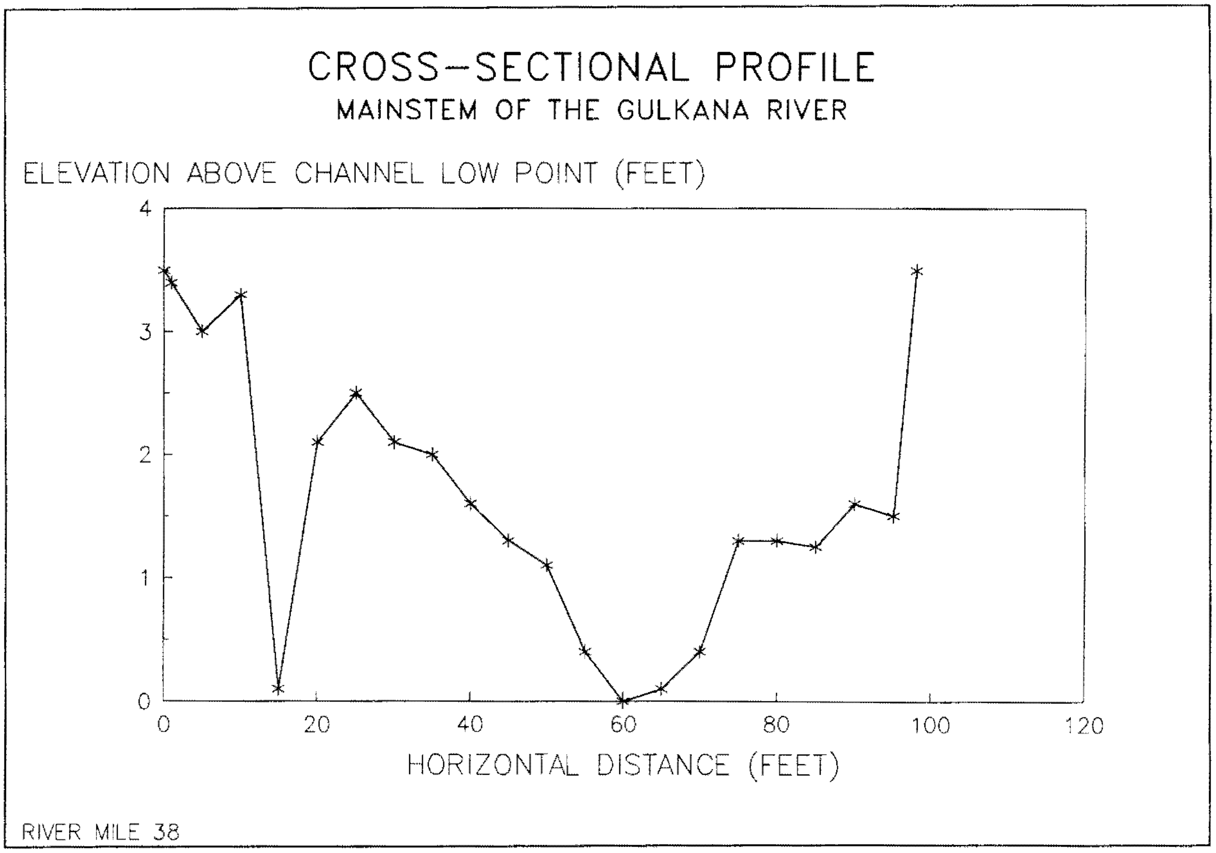

DISCHARGE VS. WETTED PERIMETER
MAINSTEM OF THE GULKANA RIVER
WETTED PERIMETER (FEET)
0
20
40
60
80
100
120
0
100
200
300
400
500
600
DISCHARGE (CFS)
RIVER MILE 38

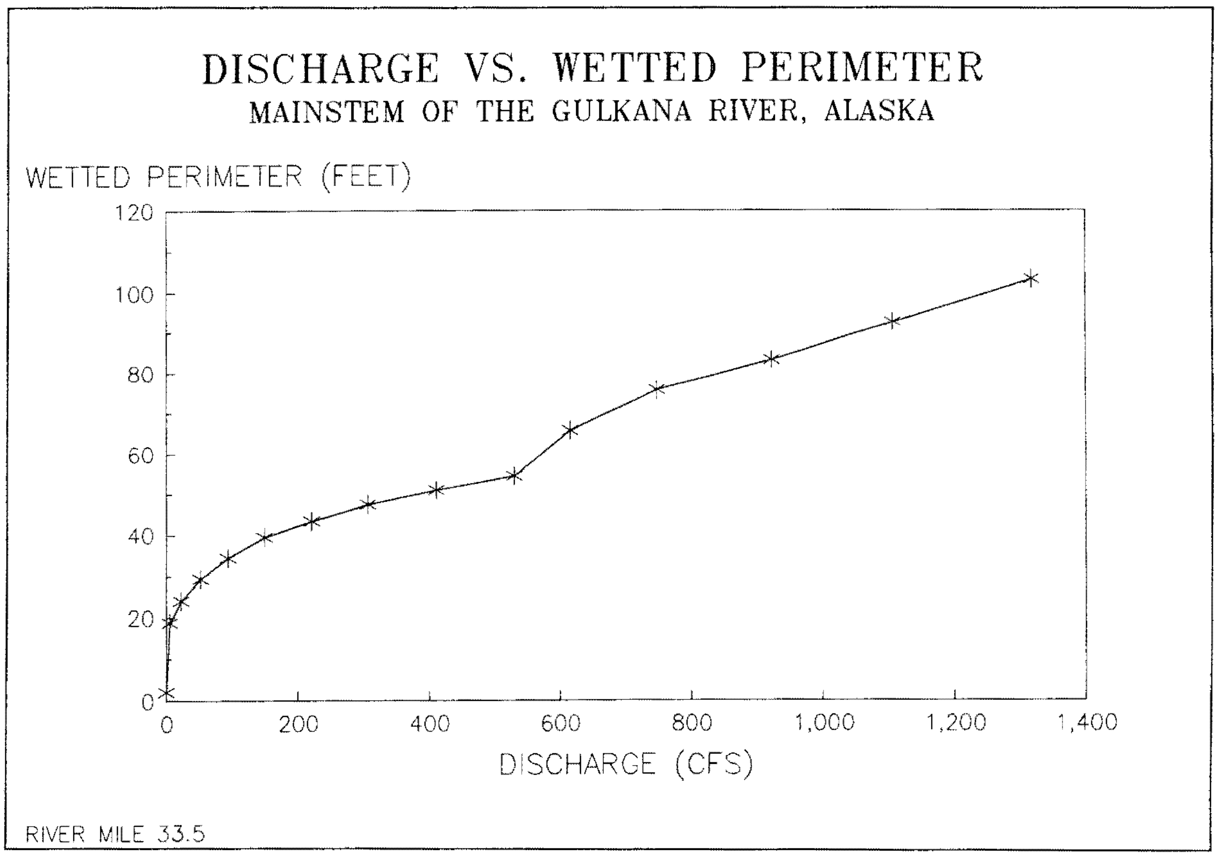

DISCHARGE VS. WETTED PERIMETER
MAINSTEM OF THE GULKANA RIVER, ALASKA
WETTED PERIMETER (FEET)
120
100
80
60
40
20
0
0
200
400
600
800
1,000
DISCHARGE (CFS)
RIVER MILE 38

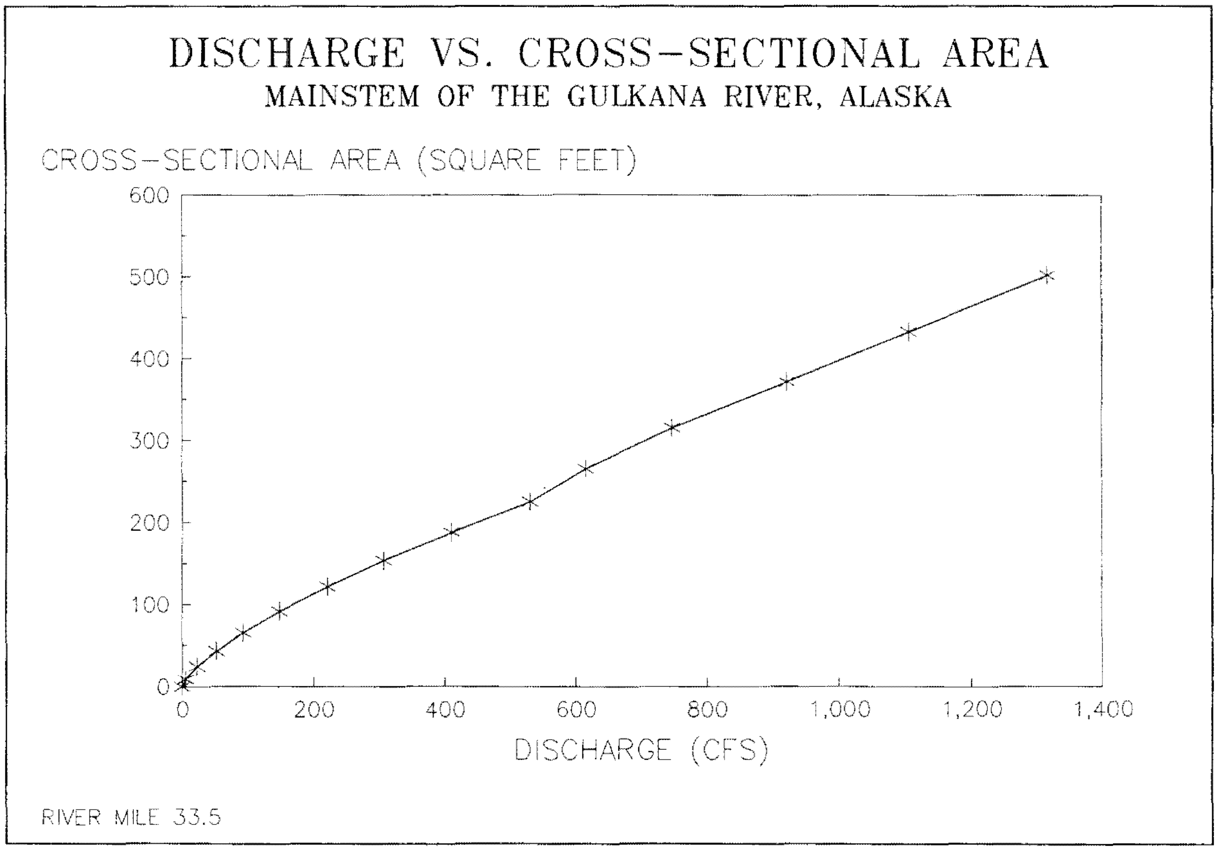

DISCHARGE VS. CROSS-SECTIONAL AREA
MAINSTEM OF THE GULKANA RIVER
CROSS-SECTIONAL AREA (SQUARE FEET)
250
200
150
100
50
0
0
100
200
300
400
500
600
DISCHARGE (CFS)
RIVER MILE 38

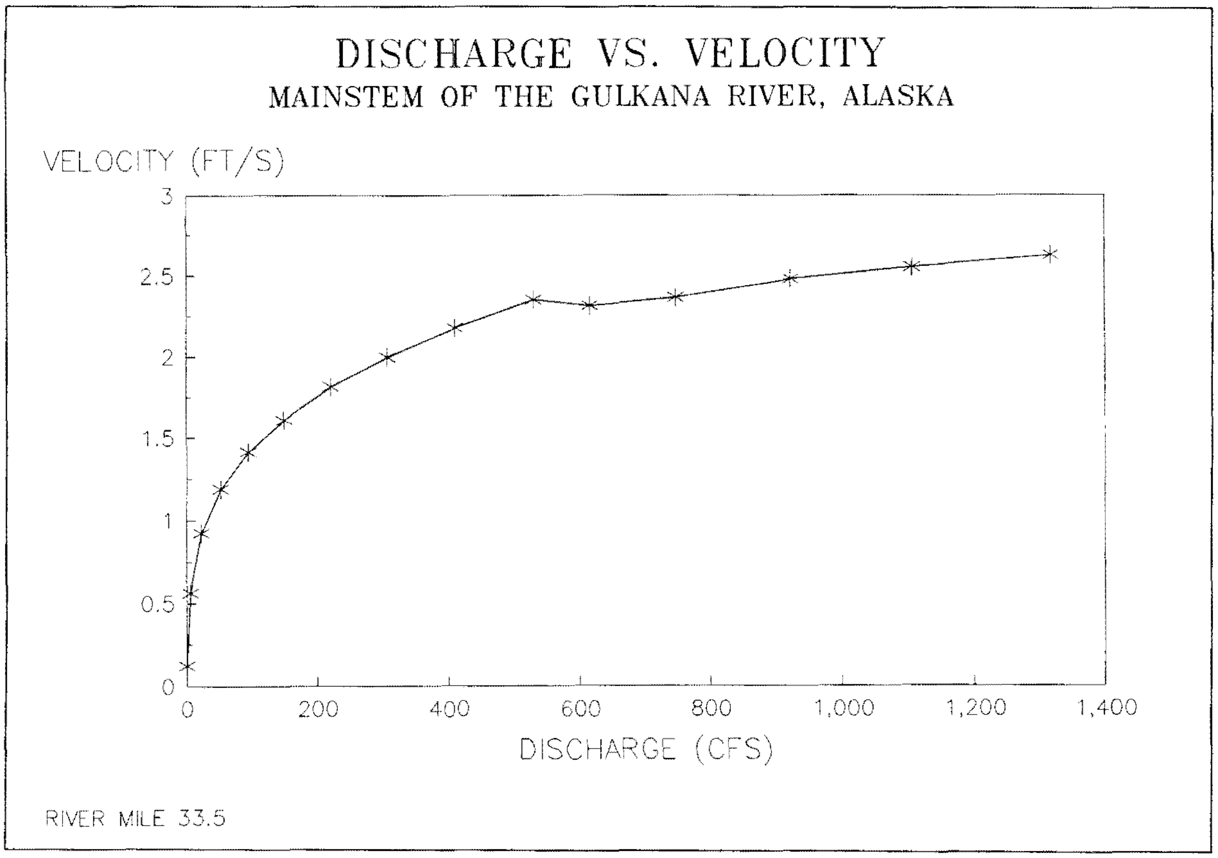

DISCHARGE VS. VELOCITY
MAINSTEM OF THE GULKANA RIVER
VELOCITY (FT/S)
3
2.5
2
1.5
1
0.5
0
0
100
200
300
400
500
600
DISCHARGE (CFS)
RIVER MILE 38

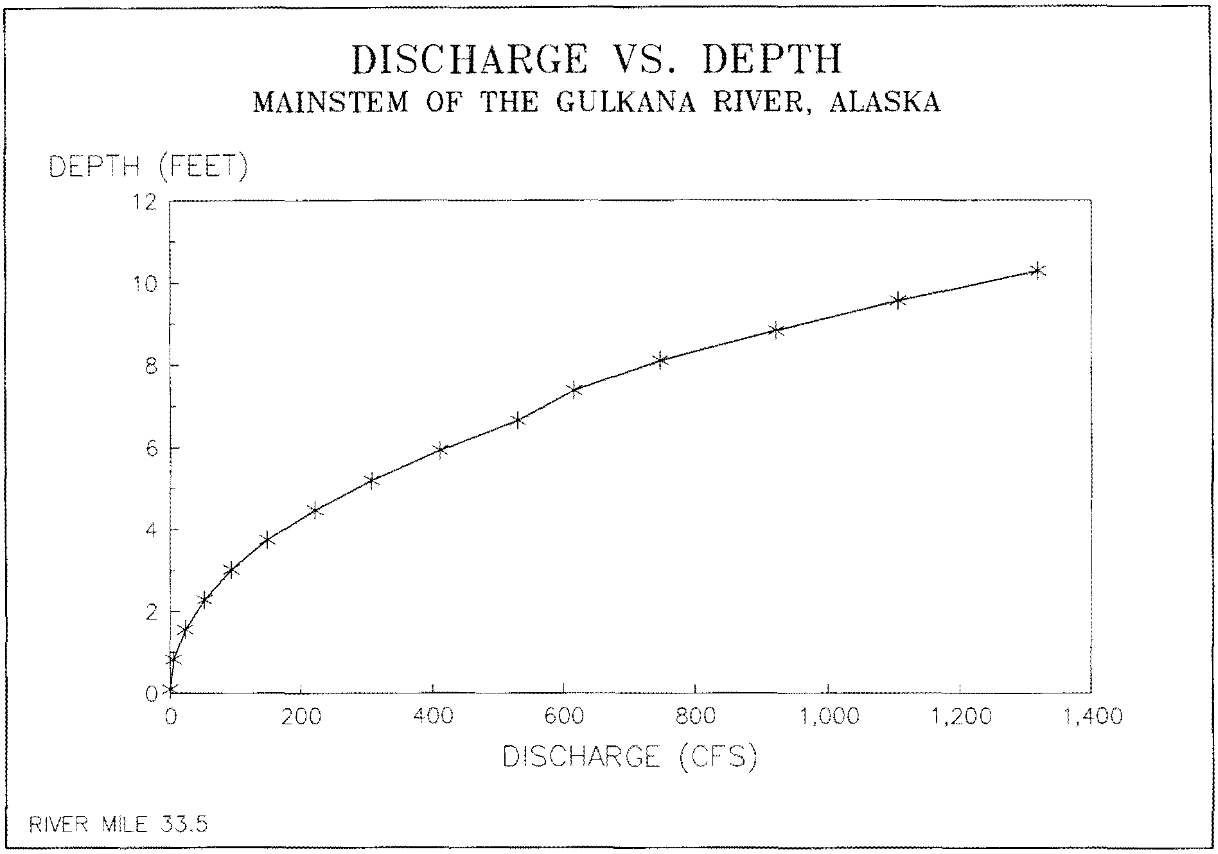

DISCHARGE VS. DEPTH
MAINSTEM OF THE GULKANA RIVER
DEPTH (FEET)
4
3
2
1
0
0
100
200
300
400
500
600
DISCHARGE (CFS)
RIVER MILE 38

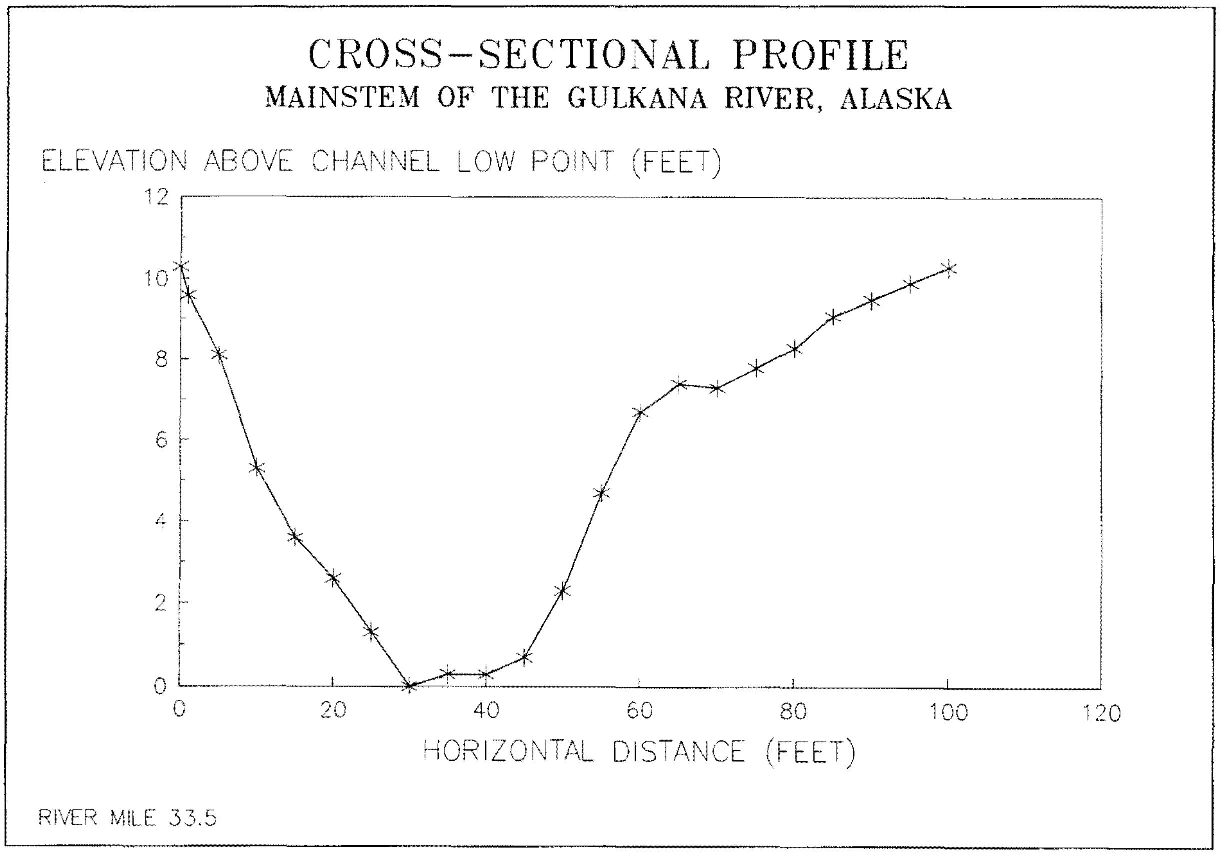

CROSS-SECTIONAL PROFILE
MAINSTEM OF THE GULKANA RIVER
ELEVATION ABOVE CHANNEL LOW POINT (FEET)
4
3
2
1
0
0
20
40
60
80
100
120
HORIZONTAL DISTANCE (FEET)
RIVER MILE 38


DISCHARGE VS. WETTED PERIMETER
MAINSTEM OF THE GULKANA RIVER, ALASKA
WETTED PERIMETER (FEET)
120
100
80
60
40
20
0
0
200
400
600
800
1,000
1,200
1,400
DISCHARGE (CFS)
RIVER MILE 33.5

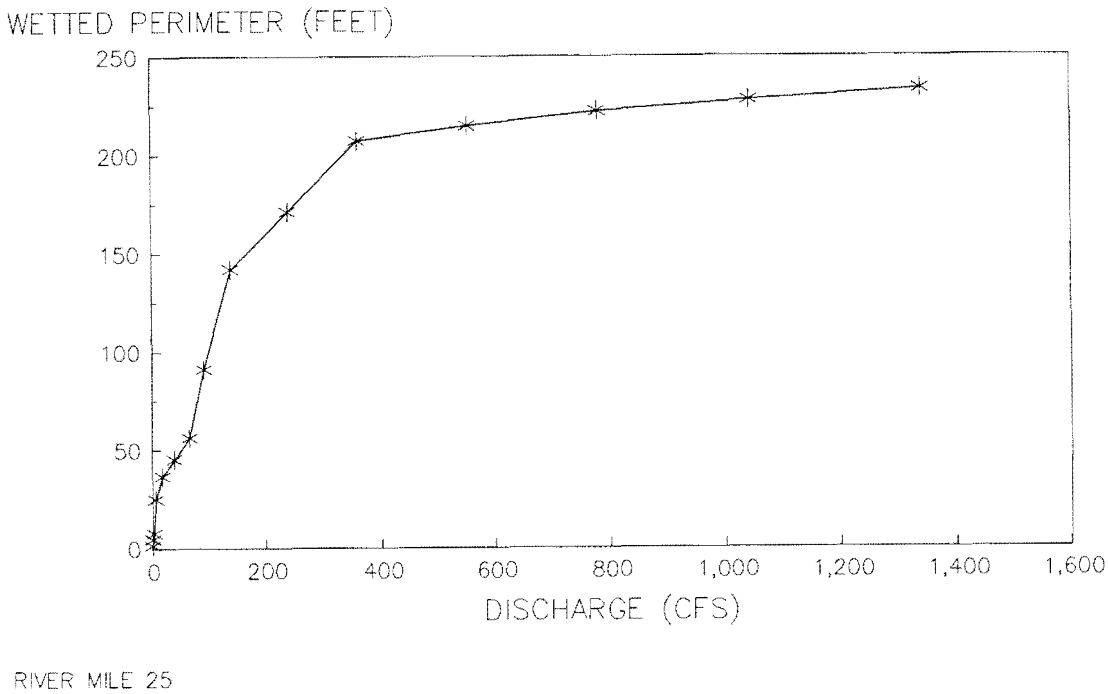

DISCHARGE VS. CROSS-SECTIONAL AREA
MAINSTEM OF THE GULKANA RIVER, ALASKA
CROSS-SECTIONAL AREA (SQUARE FEET)
600
500
400
300
200
100
0
0
200
400
600
800
1,000
1,200
1,400
DISCHARGE (CFS)
RIVER MILE 33.5


DISCHARGE VS. VELOCITY
MAINSTEM OF THE GULKANA RIVER, ALASKA
VELOCITY (FT/S)
3
2.5
2
1.5
1
0.5
0
0
200
400
600
800
1,000
1,200
1,400
DISCHARGE (CFS)
RIVER MILE 33.5

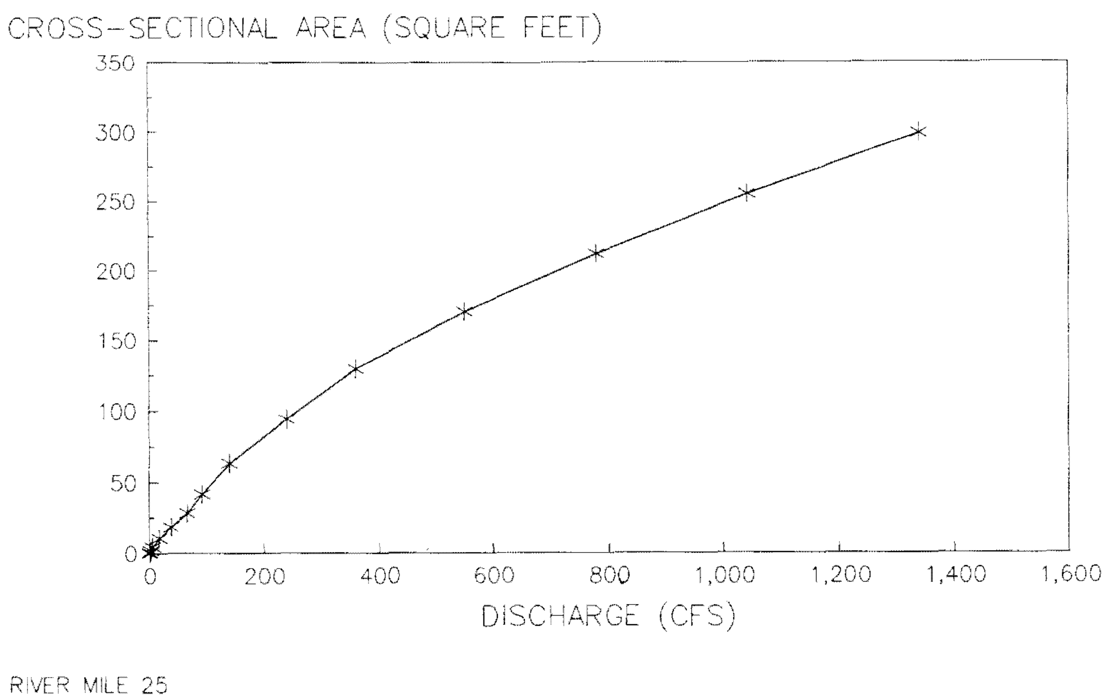

DISCHARGE VS. DEPTH
MAINSTEM OF THE GULKANA RIVER, ALASKA
DEPTH (FEET)
0
2
4
6
8
10
12
0
200
400
600
800
1,000
1,200
1,400
DISCHARGE (CFS)
RIVER MILE 33.5

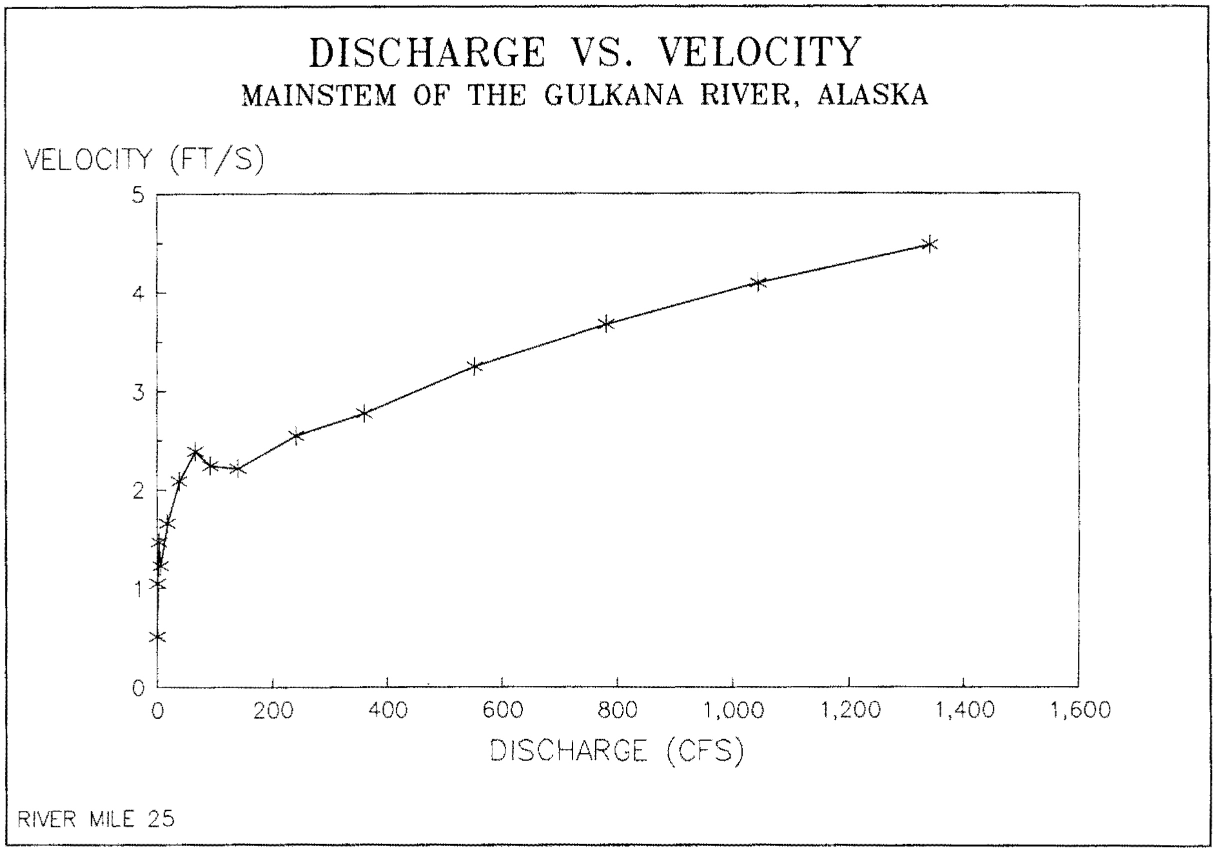

CROSS-SECTIONAL PROFILE
MAINSTEM OF THE GULKANA RIVER, ALASKA
ELEVATION ABOVE CHANNEL LOW POINT (FEET)
0
2
4
6
8
10
12
0
20
40
60
80
100
120
HORIZONTAL DISTANCE (FEET)
RIVER MILE 33.5

DISCHARGE VS. WETTED PERIMETER
MAINSTEM OF THE GULKANA RIVER, ALASKA

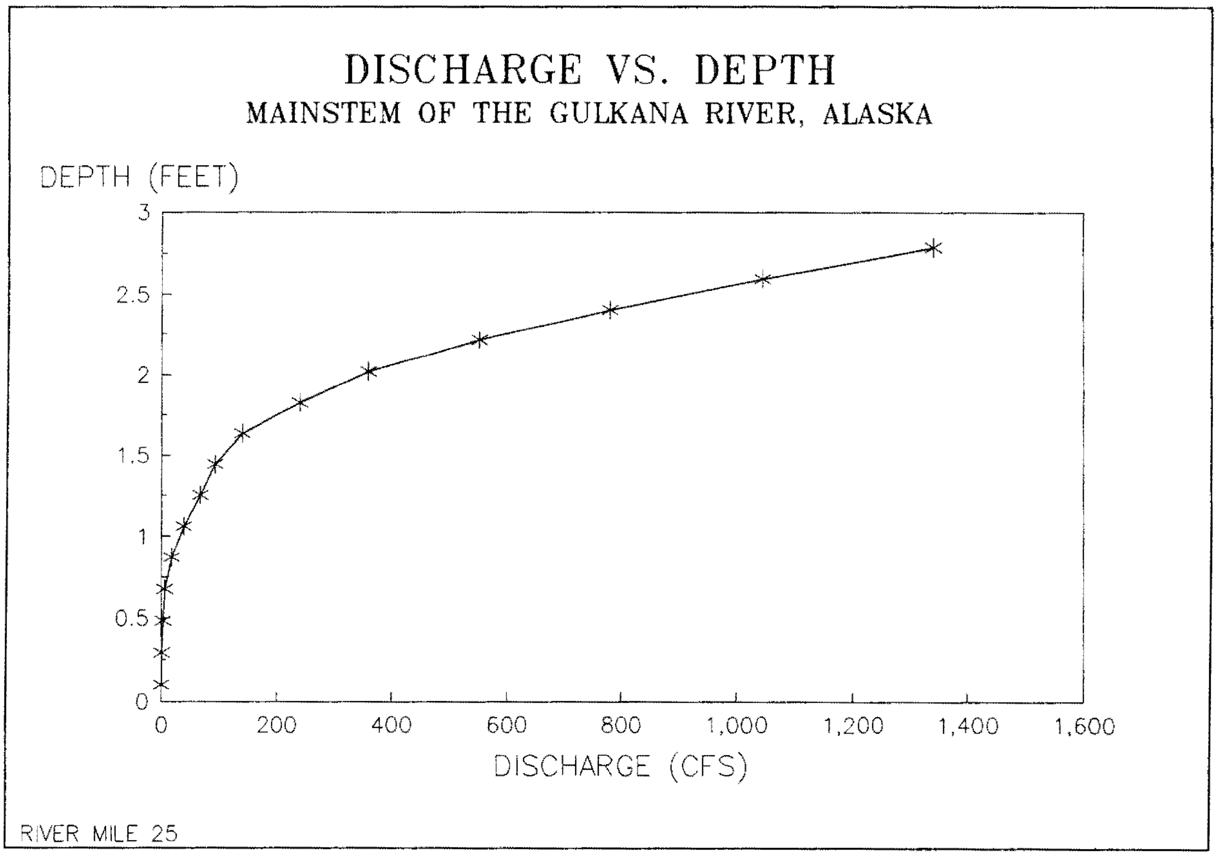


DISCHARGE VS. CROSS-SECTIONAL AREA
MAINSTEM OF THE GULKANA RIVER, ALASKA

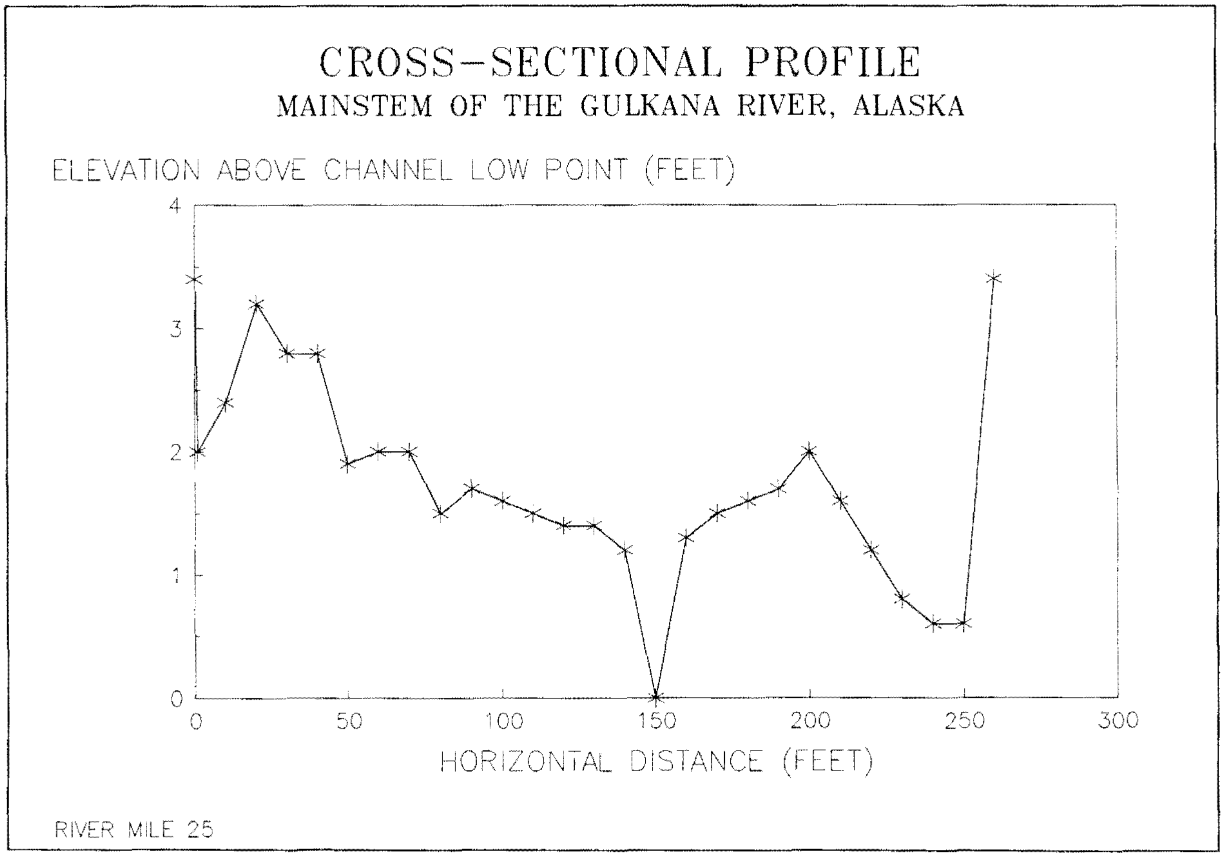


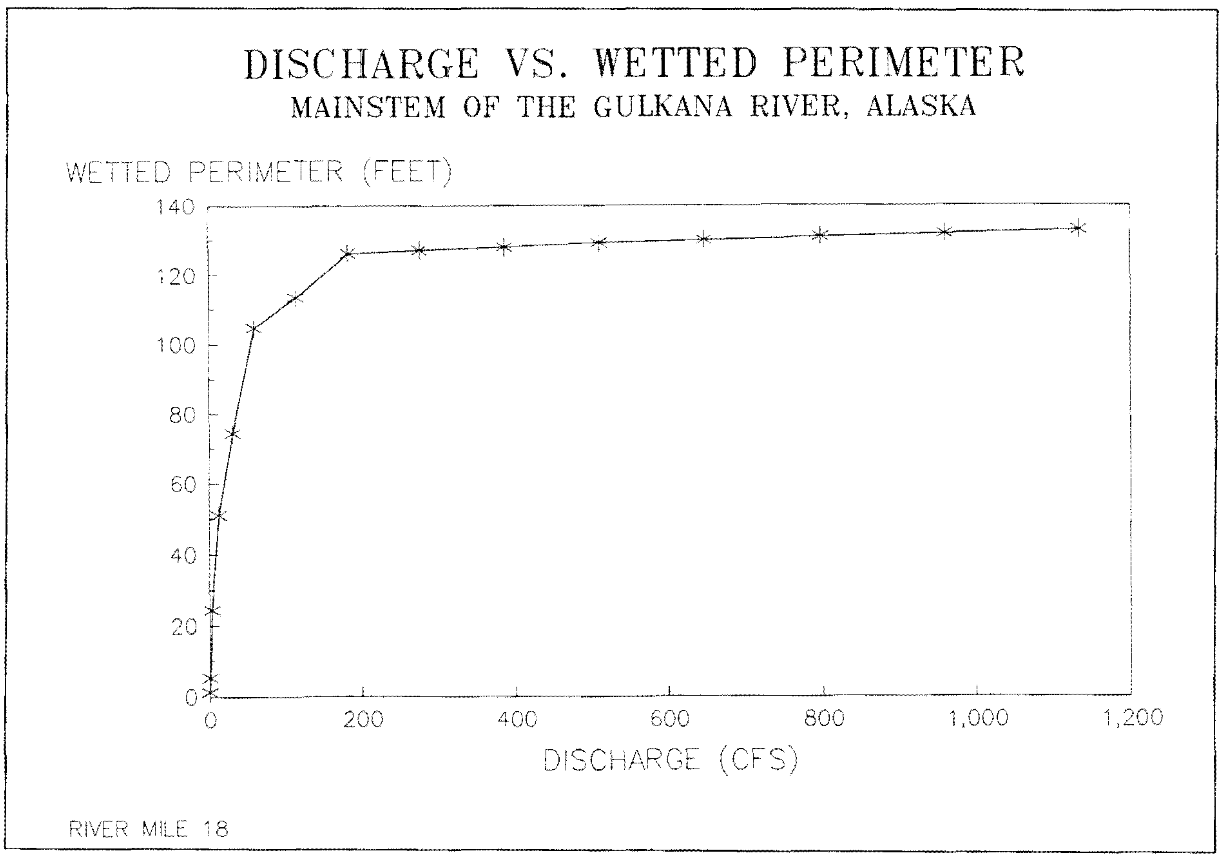


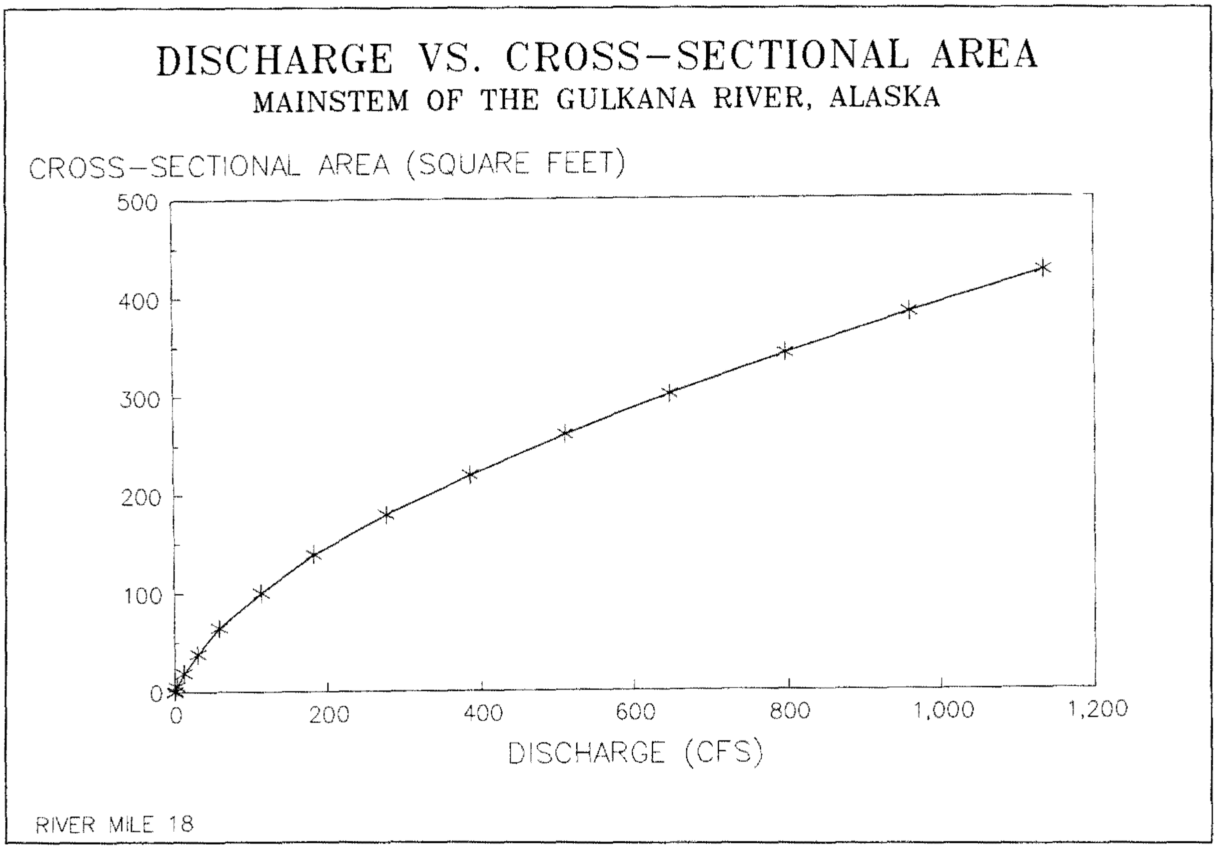
DISCHARGE VS. VELOCITY
MAINSTEM OF THE GULKANA RIVER, ALASKA
VELOCITY (FT/S)
0
1
2
3
4
5
0
200
400
600
800
1,000
1,200
1,400
1,600
DISCHARGE (CFS)
RIVER MILE 25

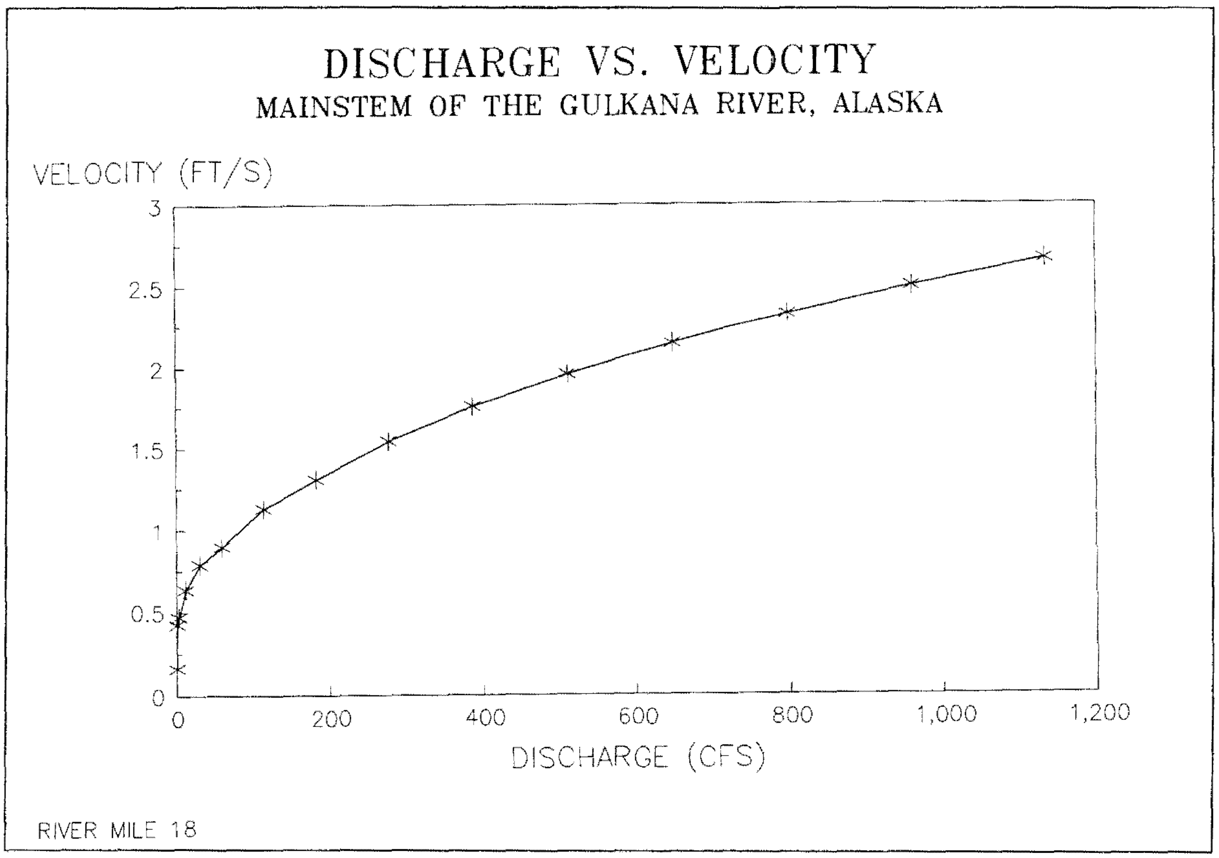


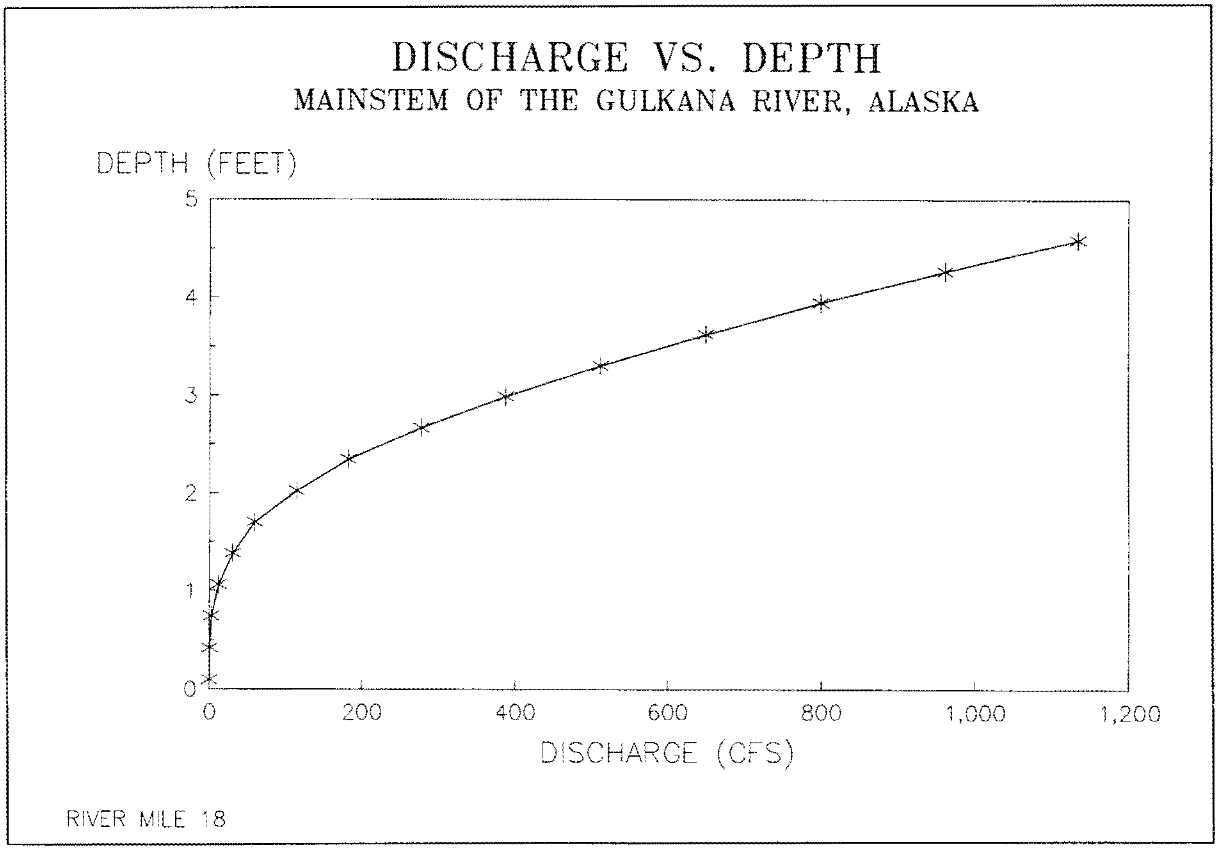
DISCHARGE VS. DEPTH
MAINSTEM OF THE GULKANA RIVER, ALASKA
DEPTH (FEET)
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1,000
1,200
1,400
1,600
DISCHARGE (CFS)
RIVER MILE 25

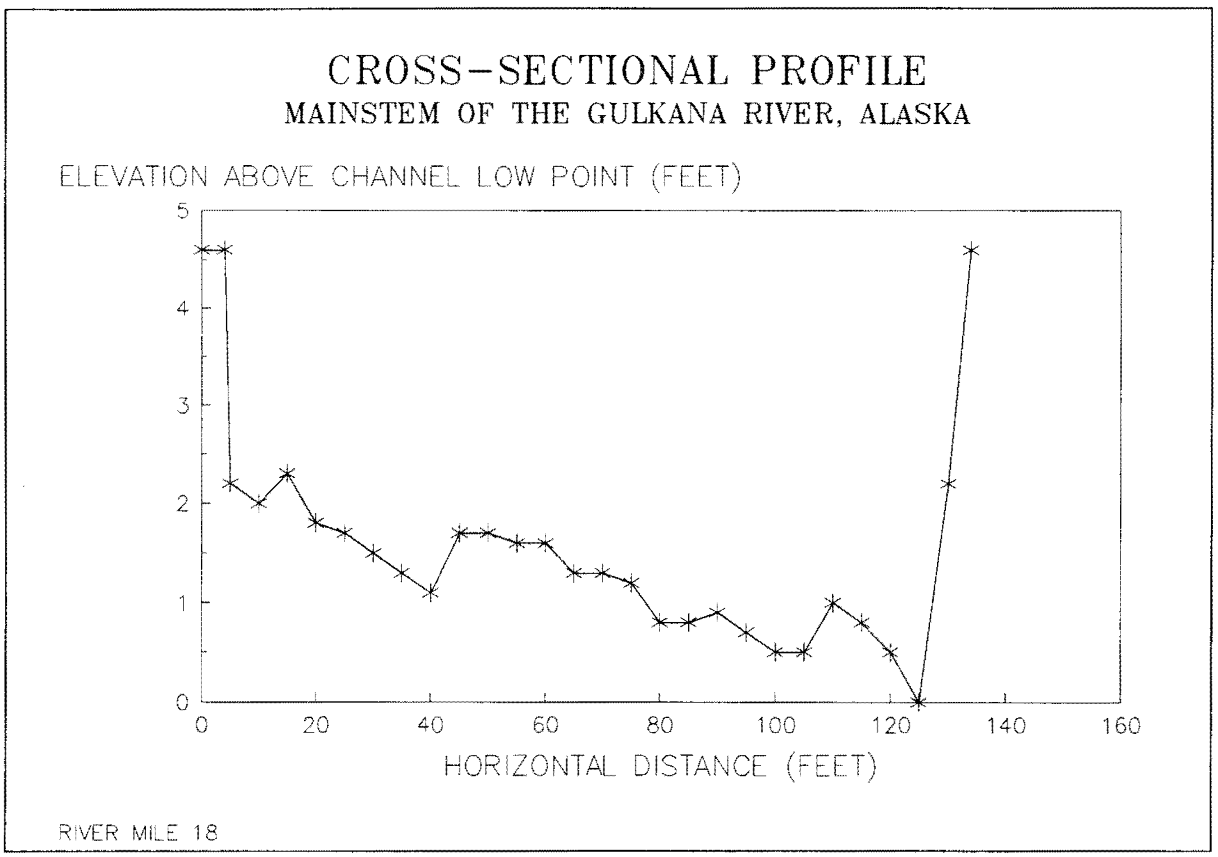

CROSS-SECTIONAL PROFILE
MAINSTEM OF THE GULKANA RIVER, ALASKA
ELEVATION ABOVE CHANNEL LOW POINT (FEET)
4
3
2
1
0
0
50
100
150
200
250
300
HORIZONTAL DISTANCE (FEET)
RIVER MILE 25

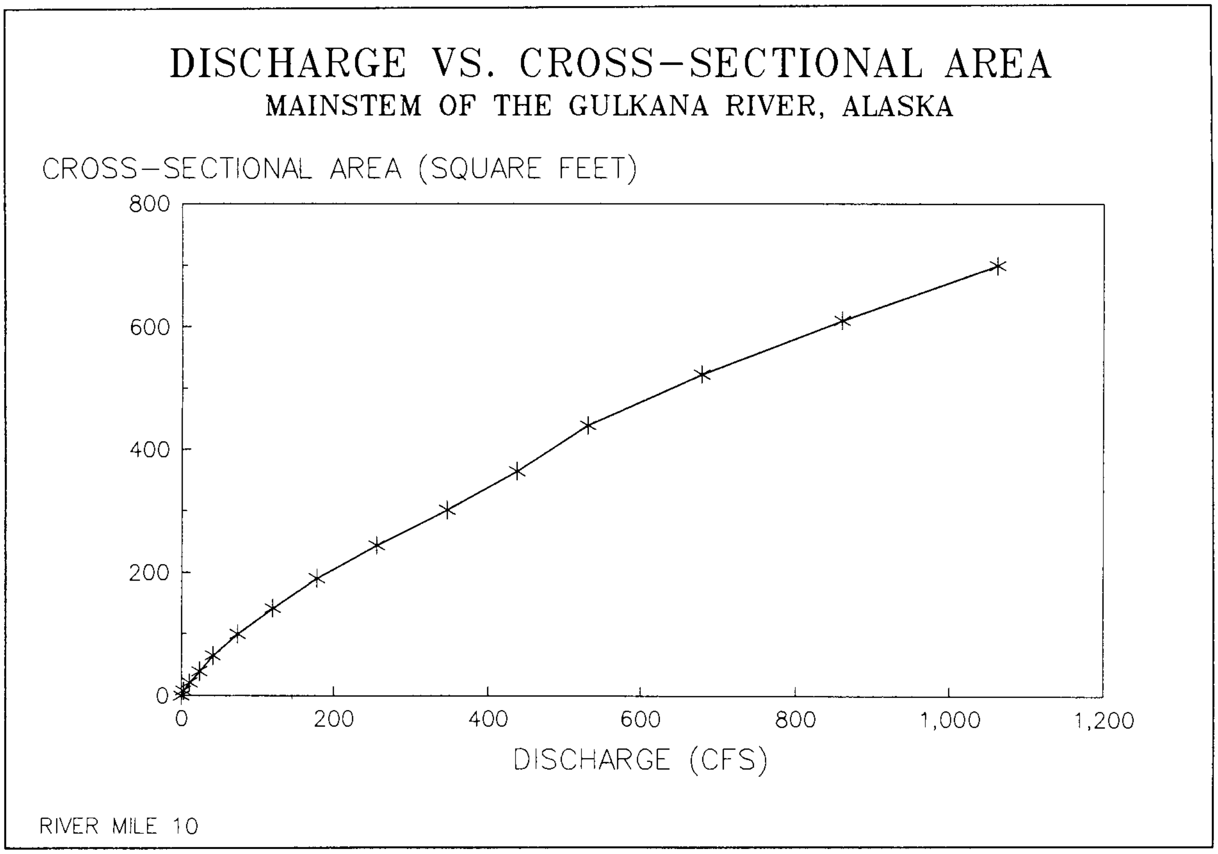

DISCHARGE VS. WETTED PERIMETER
MAINSTEM OF THE GULKANA RIVER, ALASKA
WETTED PERIMETER (FEET)
140
120
100
80
60
40
20
0
0
200
400
600
800
1,000
1,200
DISCHARGE (CFS)
RIVER MILE 18

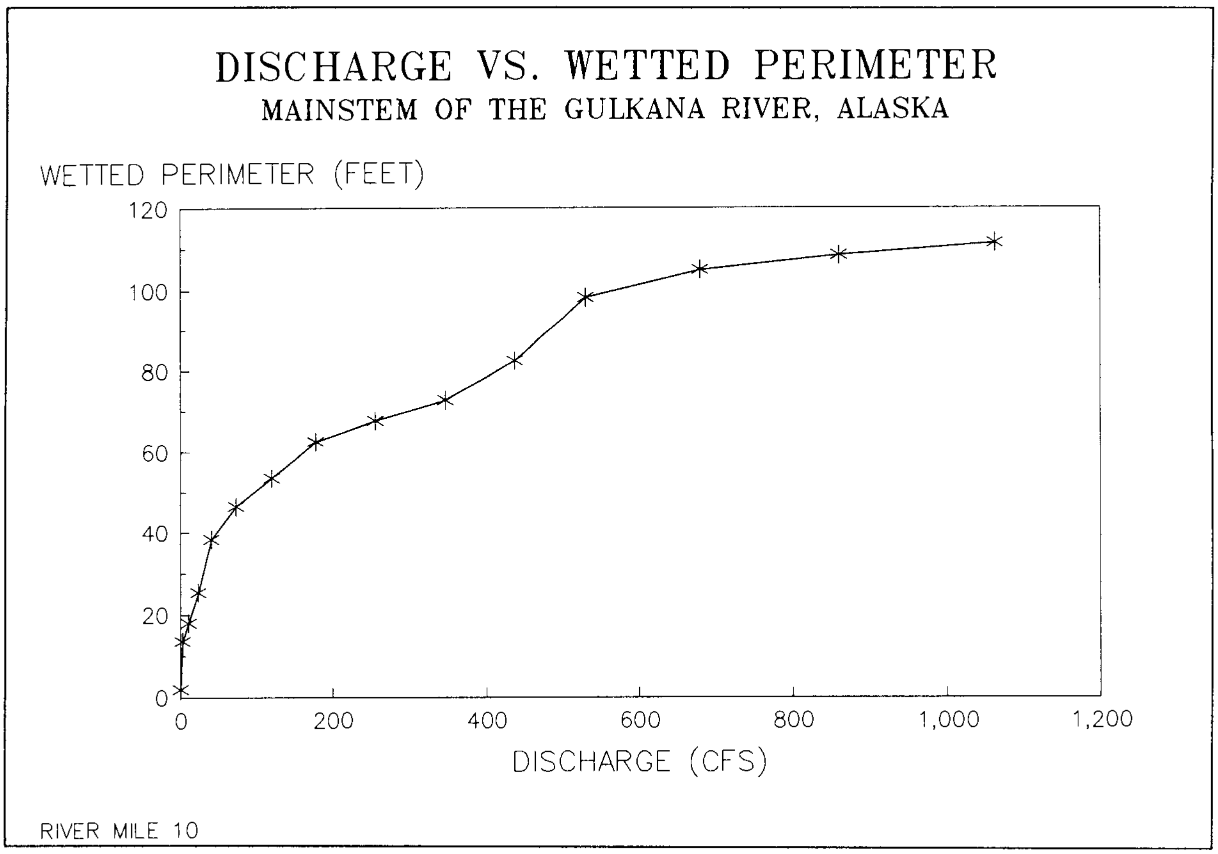

DISCHARGE VS. CROSS-SECTIONAL AREA
MAINSTEM OF THE GULKANA RIVER, ALASKA
CROSS-SECTIONAL AREA (SQUARE FEET)
500
400
300
200
100
0
0
200
400
600
800
1,000
1,200
DISCHARGE (CFS)
RIVER MILE 18

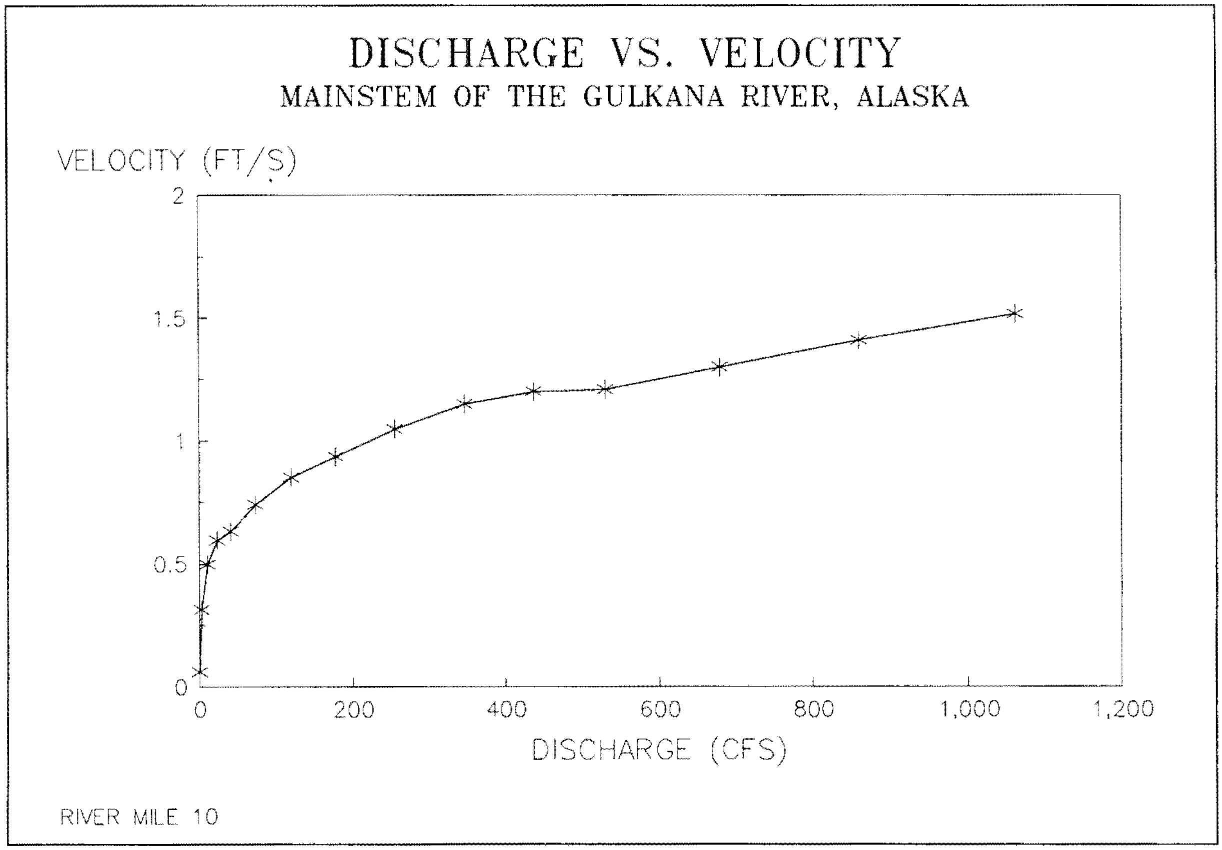

DISCHARGE VS. VELOCITY
MAINSTEM OF THE GULKANA RIVER, ALASKA
VELOCITY (FT/S)
3
2.5
2
1.5
1
0.5
0
0
200
400
600
800
1,000
1,200
DISCHARGE (CFS)
RIVER MILE 18

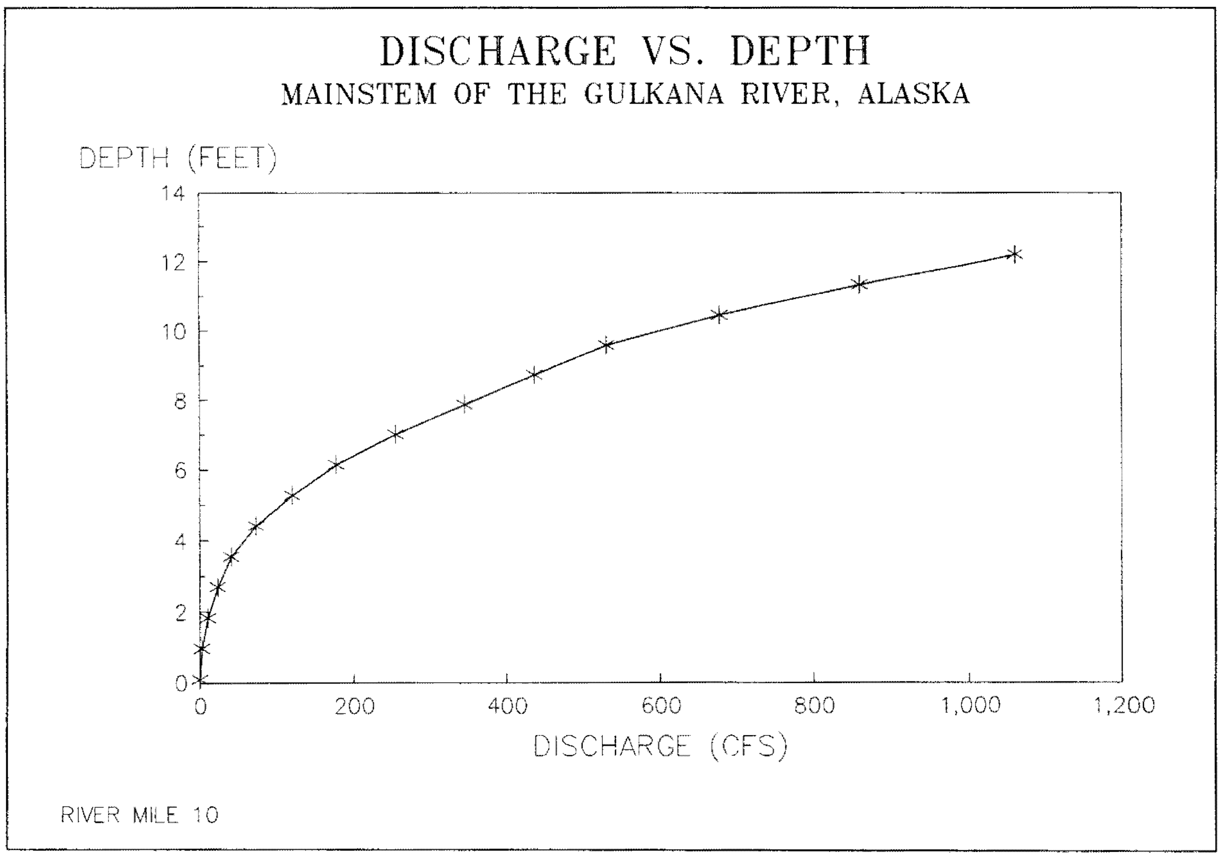

DISCHARGE VS. DEPTH
MAINSTEM OF THE GULKANA RIVER, ALASKA
DEPTH (FEET)
5
4
3
2
1
0
0
200
400
600
800
1,000
1,200
DISCHARGE (CFS)
RIVER MILE 18

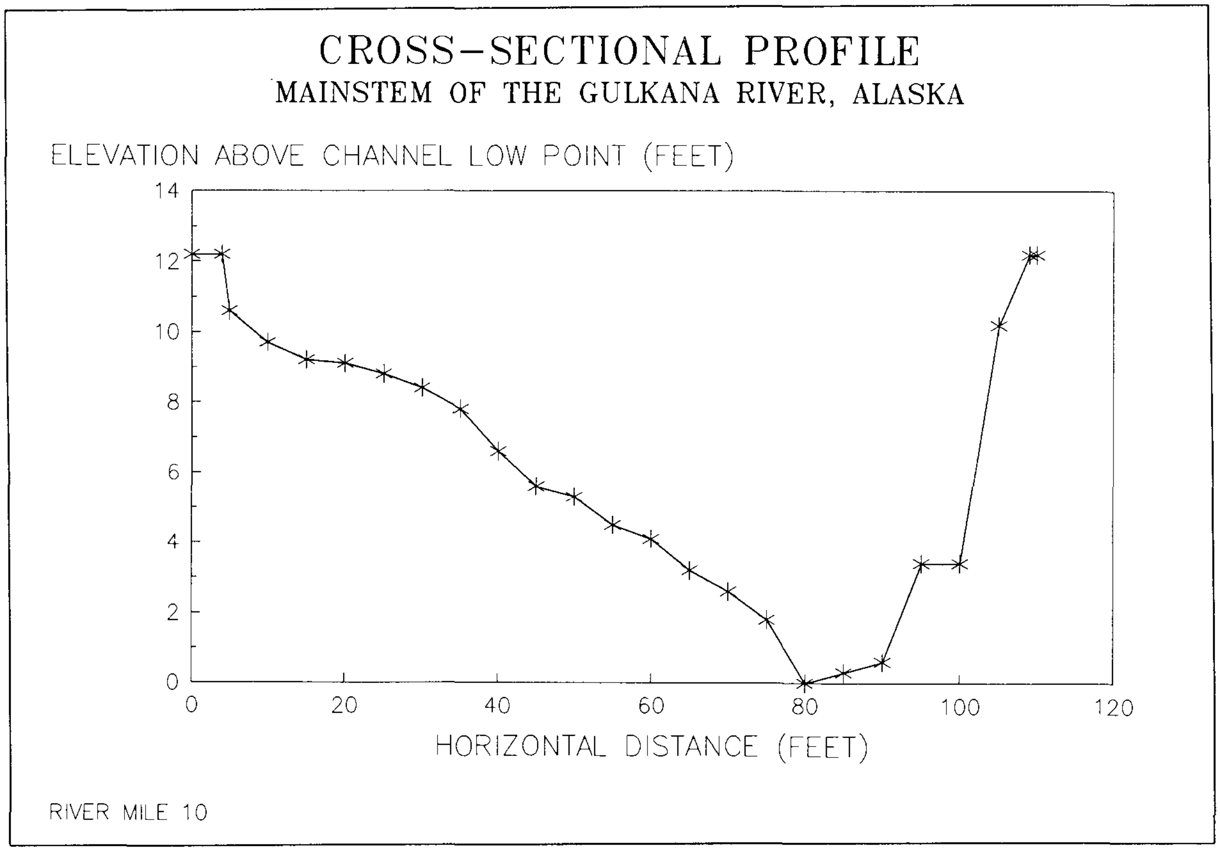

CROSS-SECTIONAL PROFILE
MAINSTEM OF THE GULKANA RIVER, ALASKA
ELEVATION ABOVE CHANNEL LOW POINT (FEET)
5
4
3
2
1
0
0
20
40
60
80
100
120
140
160
HORIZONTAL DISTANCE (FEET)
RIVER MILE 18

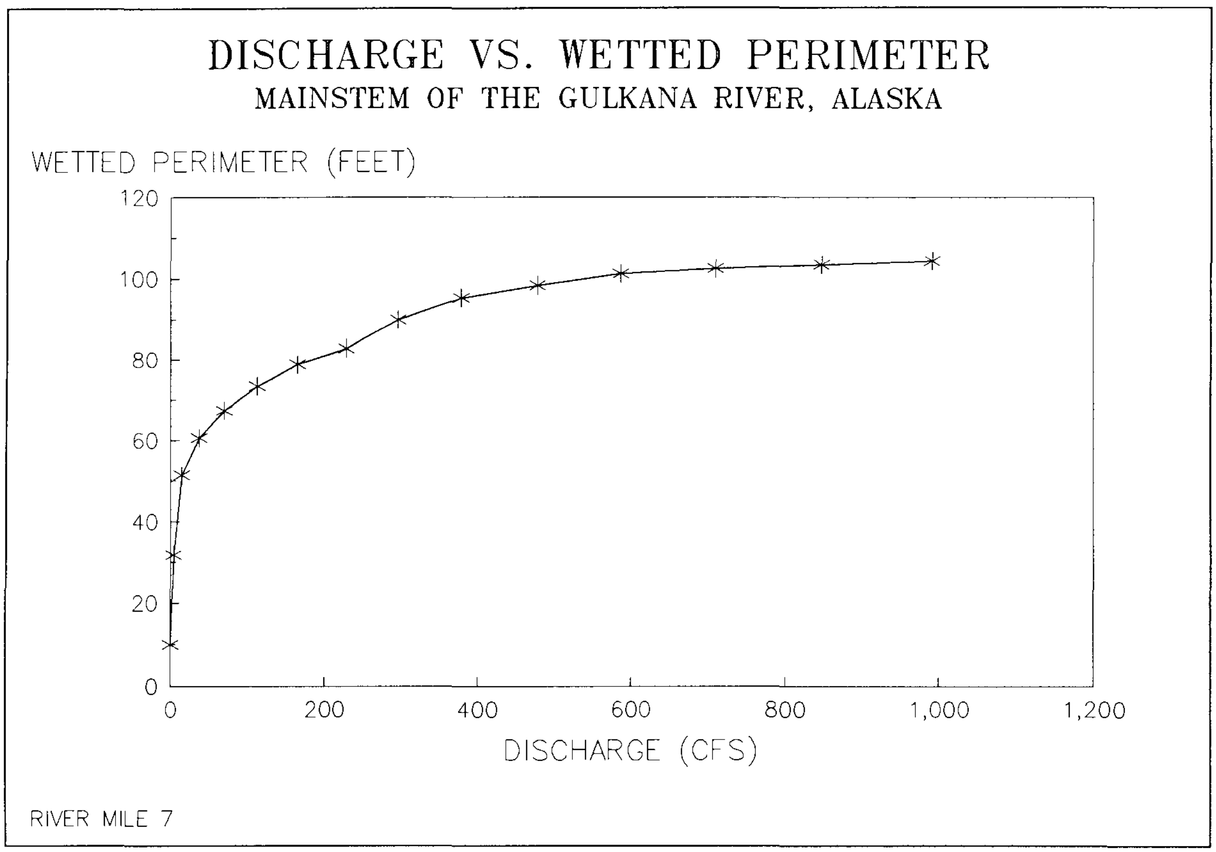

DISCHARGE VS. CROSS-SECTIONAL AREA
MAINSTEM OF THE GULKANA RIVER, ALASKA
CROSS-SECTIONAL AREA (SQUARE FEET)
800
600
400
200
0
0
200
400
600
800
1,000
1,200
DISCHARGE (CFS)
RIVER MILE 10

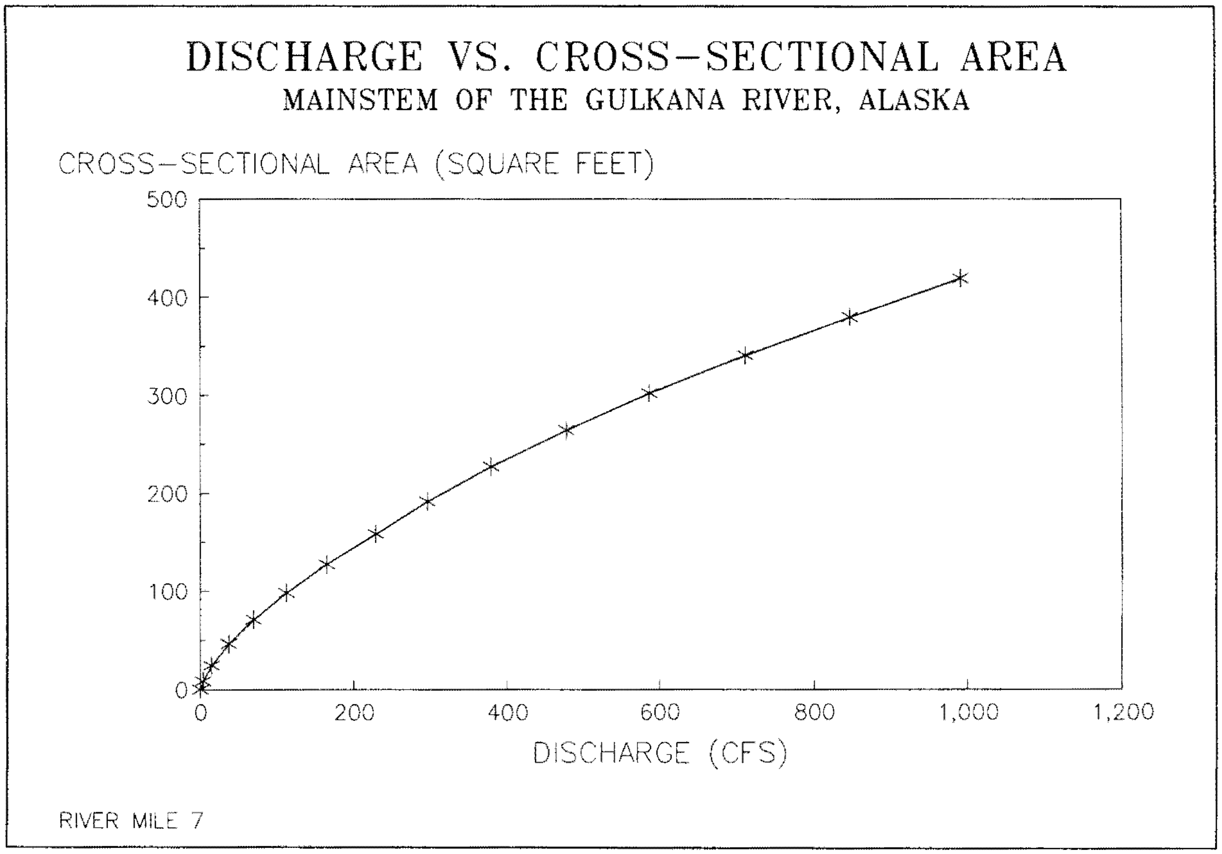

DISCHARGE VS. WETTED PERIMETER
MAINSTEM OF THE GULKANA RIVER, ALASKA
WETTED PERIMETER (FEET)
120
100
80
60
40
20
0
0
200
400
600
800
1,000
1,200
DISCHARGE (CFS)
RIVER MILE 10

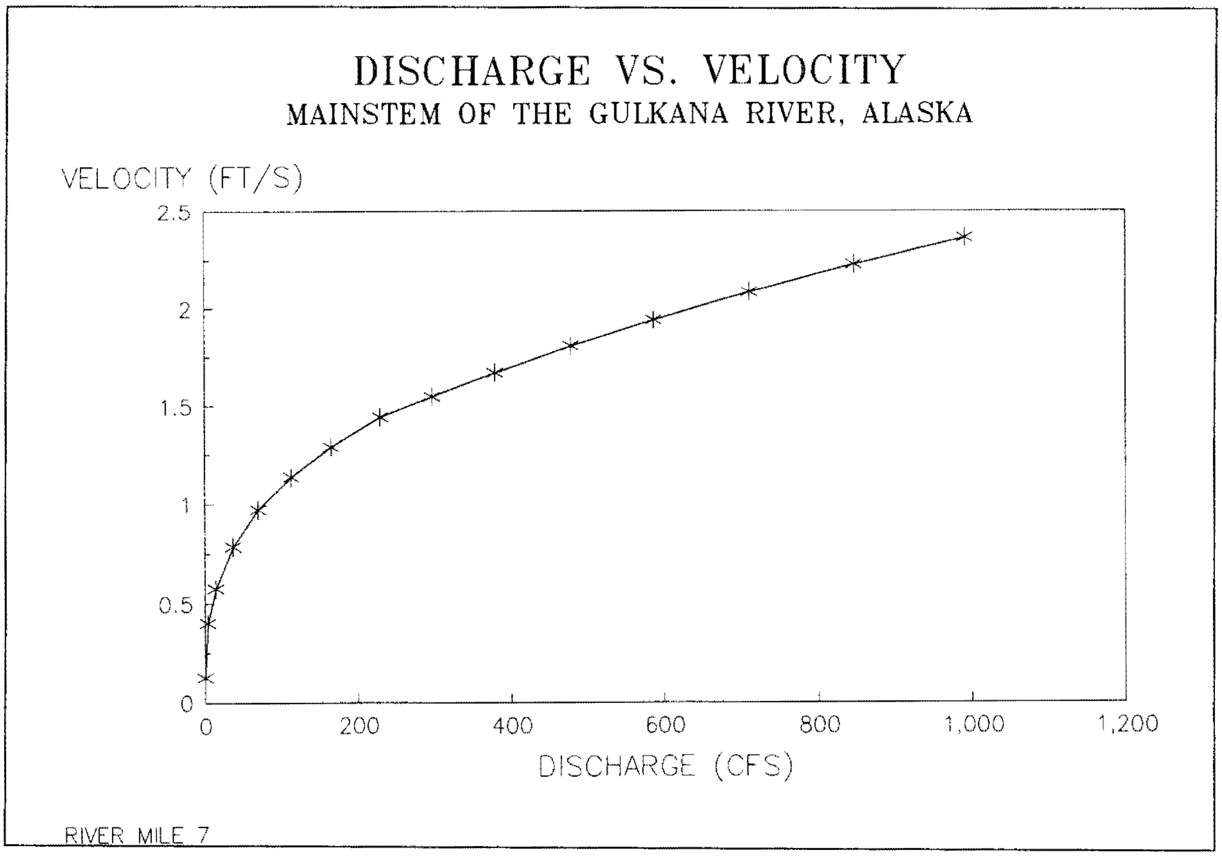

DISCHARGE VS. VELOCITY
MAINSTEM OF THE GULKANA RIVER, ALASKA
VELOCITY (FT/S)
2
1.5
1
0.5
0
0
200
400
600
800
1,000
1,200
DISCHARGE (CFS)
RIVER MILE 10

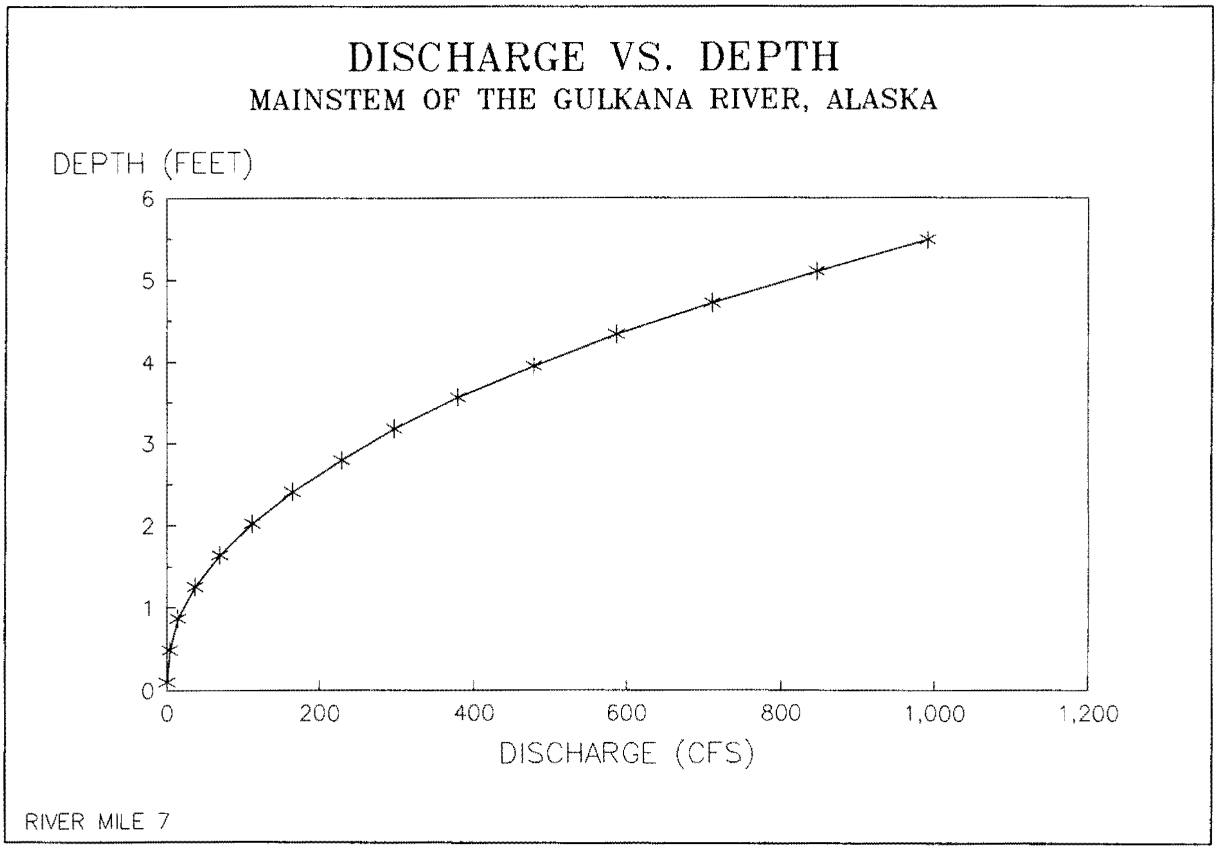

DISCHARGE VS. DEPTH
MAINSTEM OF THE GULKANA RIVER, ALASKA
DEPTH (FEET)
14
12
10
8
6
4
2
0
0
200
400
600
800
1,000
1,200
DISCHARGE (CFS)
RIVER MILE 10


CROSS-SECTIONAL PROFILE
MAINSTEM OF THE GULKANA RIVER, ALASKA
ELEVATION ABOVE CHANNEL LOW POINT (FEET)
14
12
10
8
6
4
2
0
0
20
40
60
80
100
120
HORIZONTAL DISTANCE (FEET)
RIVER MILE 10

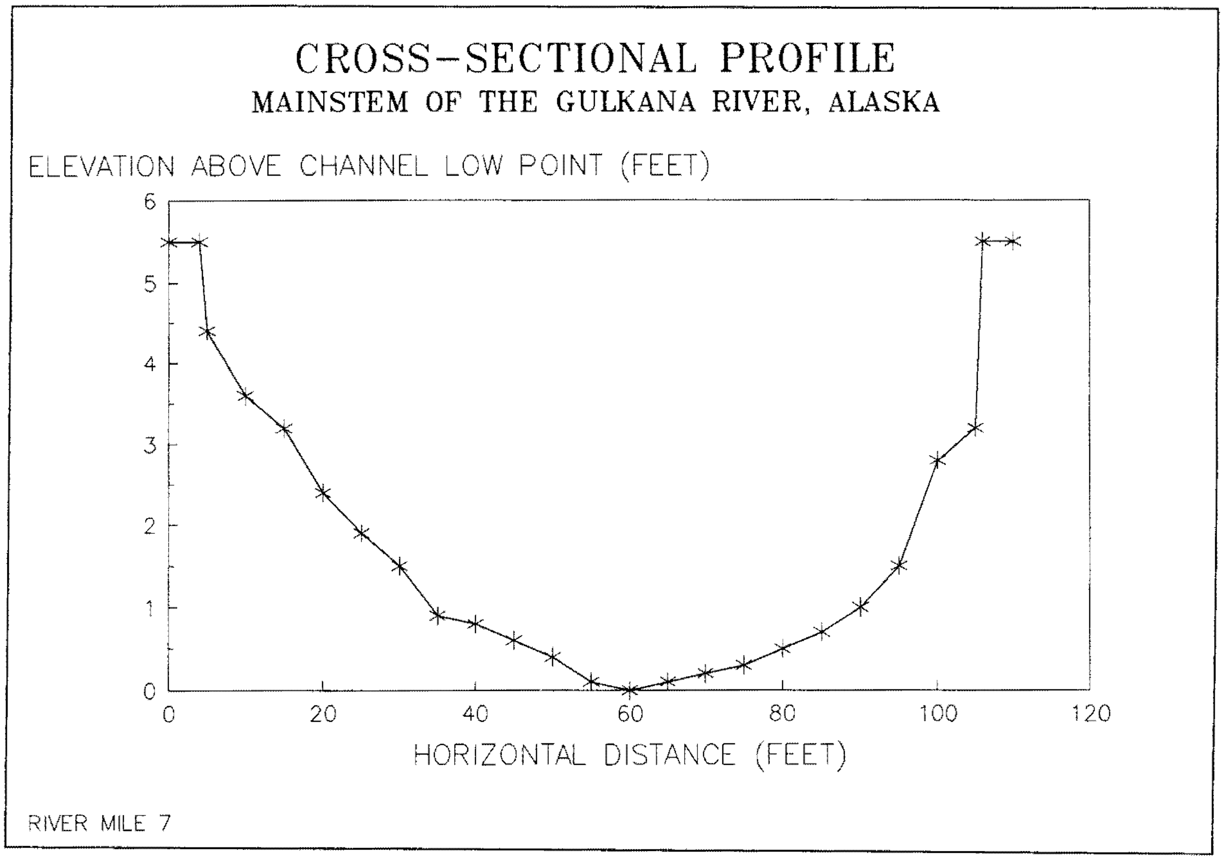

DISCHARGE VS. WETTED PERIMETER
MAINSTEM OF THE GULKANA RIVER, ALASKA
WETTED PERIMETER (FEET)
120
100
80
60
40
20
0
0
200
400
600
800
1,000
1,200
DISCHARGE (CFS)
RIVER MILE 7


DISCHARGE VS. CROSS-SECTIONAL AREA
MAINSTEM OF THE GULKANA RIVER, ALASKA
CROSS-SECTIONAL AREA (SQUARE FEET)
500
400
300
200
100
0
0
200
400
600
800
1,000
1,200
DISCHARGE (CFS)
RIVER MILE 7

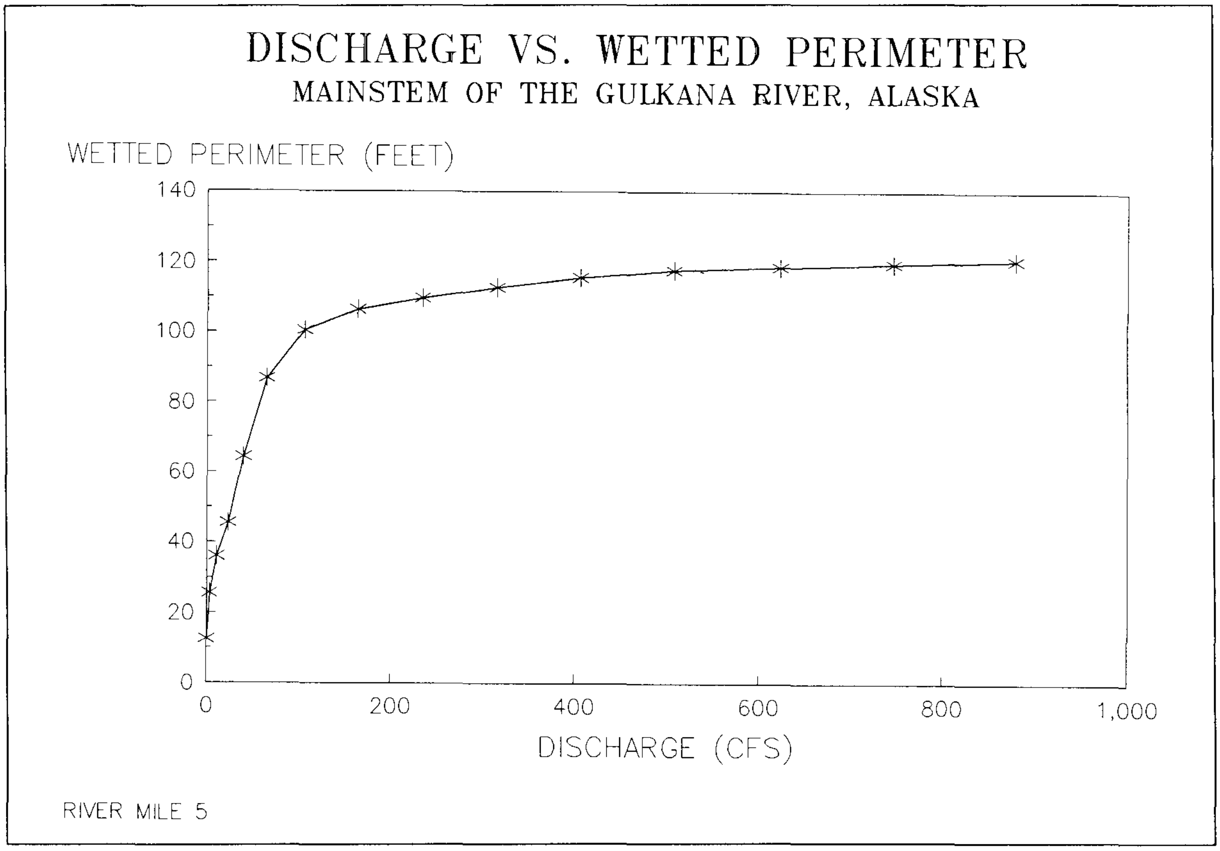

DISCHARGE VS. VELOCITY
MAINSTEM OF THE GULKANA RIVER, ALASKA
VELOCITY (FT/S)
2.5
2
1.5
1
0.5
0
0
200
400
600
800
1,000
1,200
DISCHARGE (CFS)
RIVER MILE 7

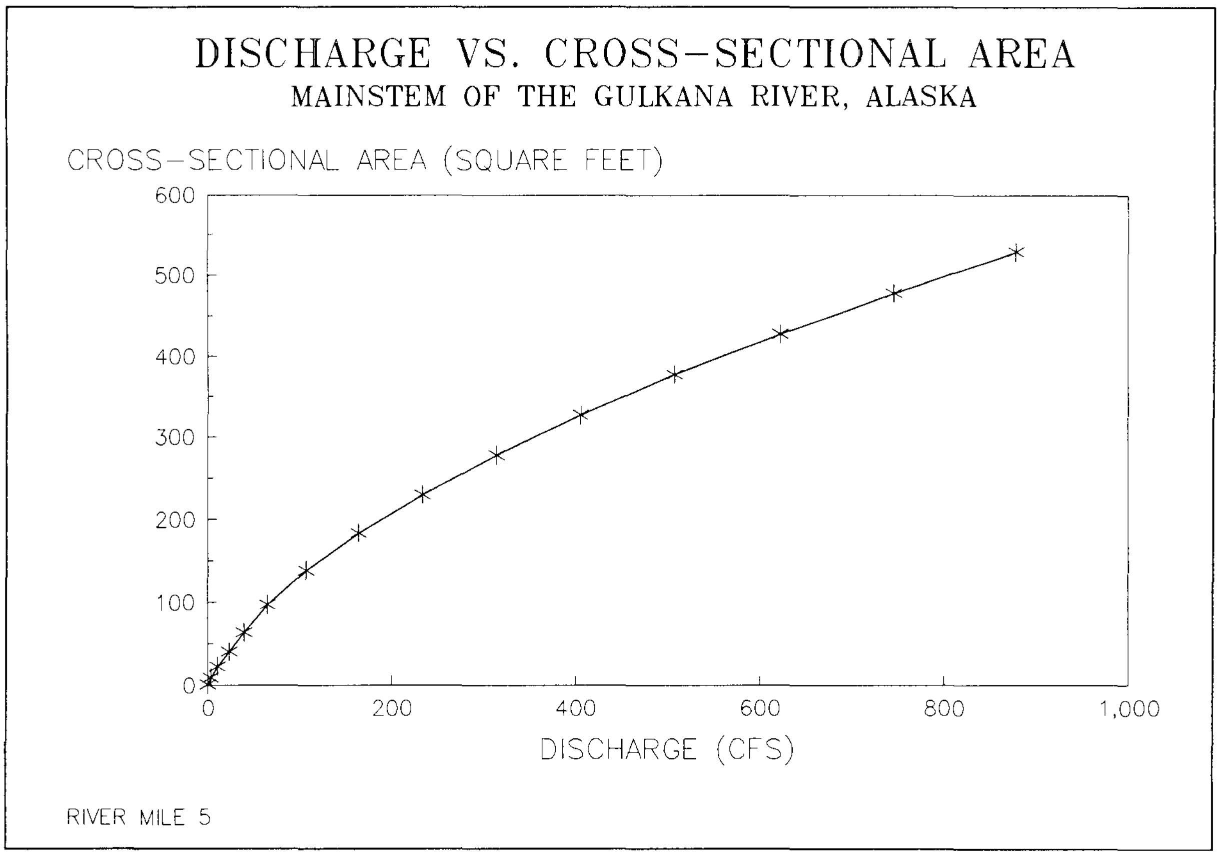


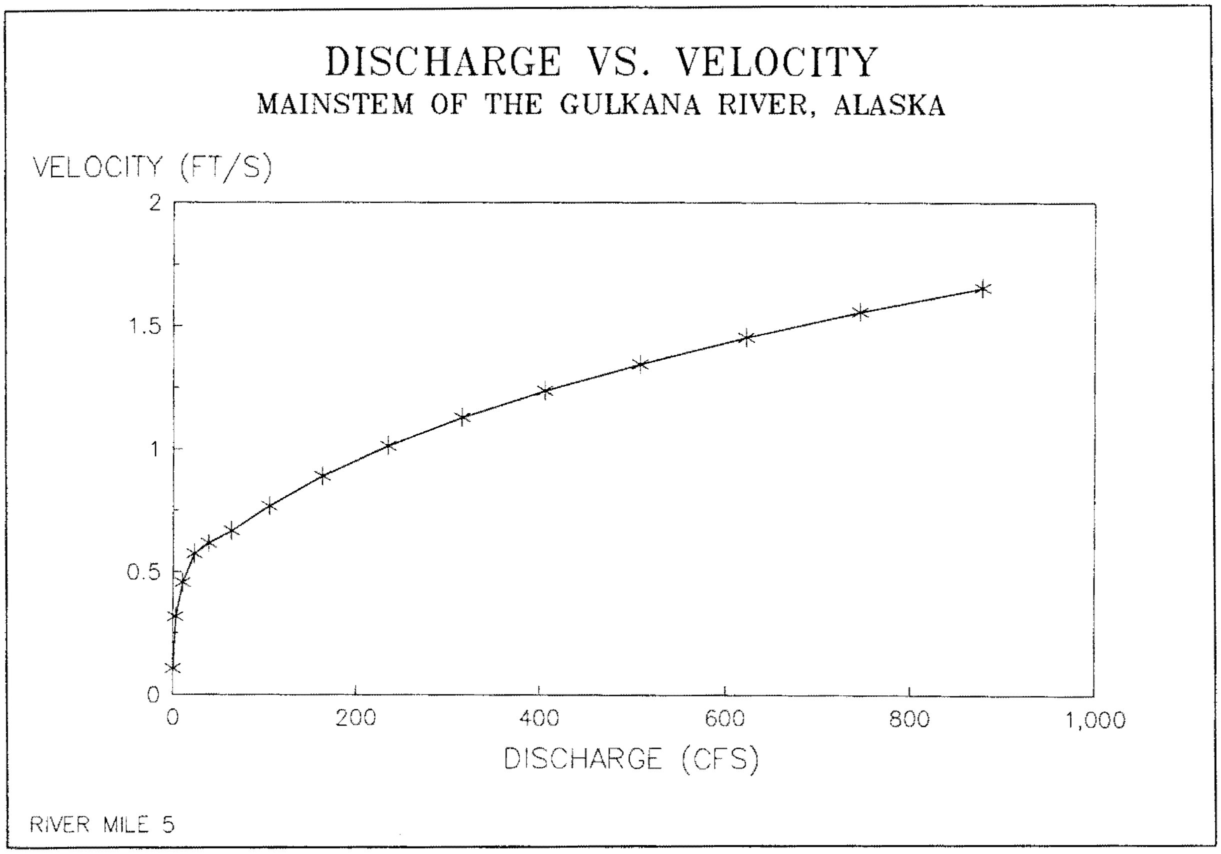
DISCHARGE VS. DEPTH
MAINSTEM OF THE GULKANA RIVER, ALASKA
DEPTH (FEET)
6
5
4
3
2
1
0
0
200
400
600
800
1,000
1,200
DISCHARGE (CFS)
RIVER MILE 7

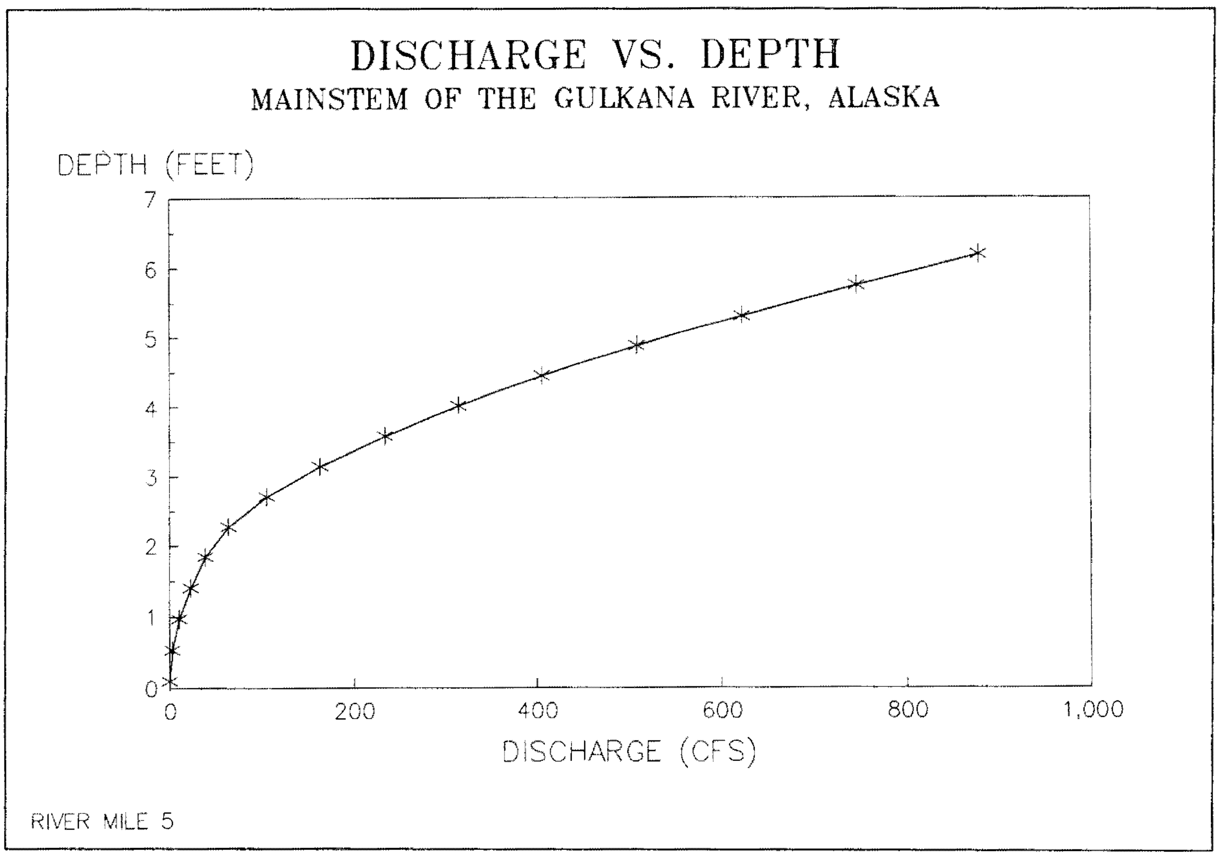


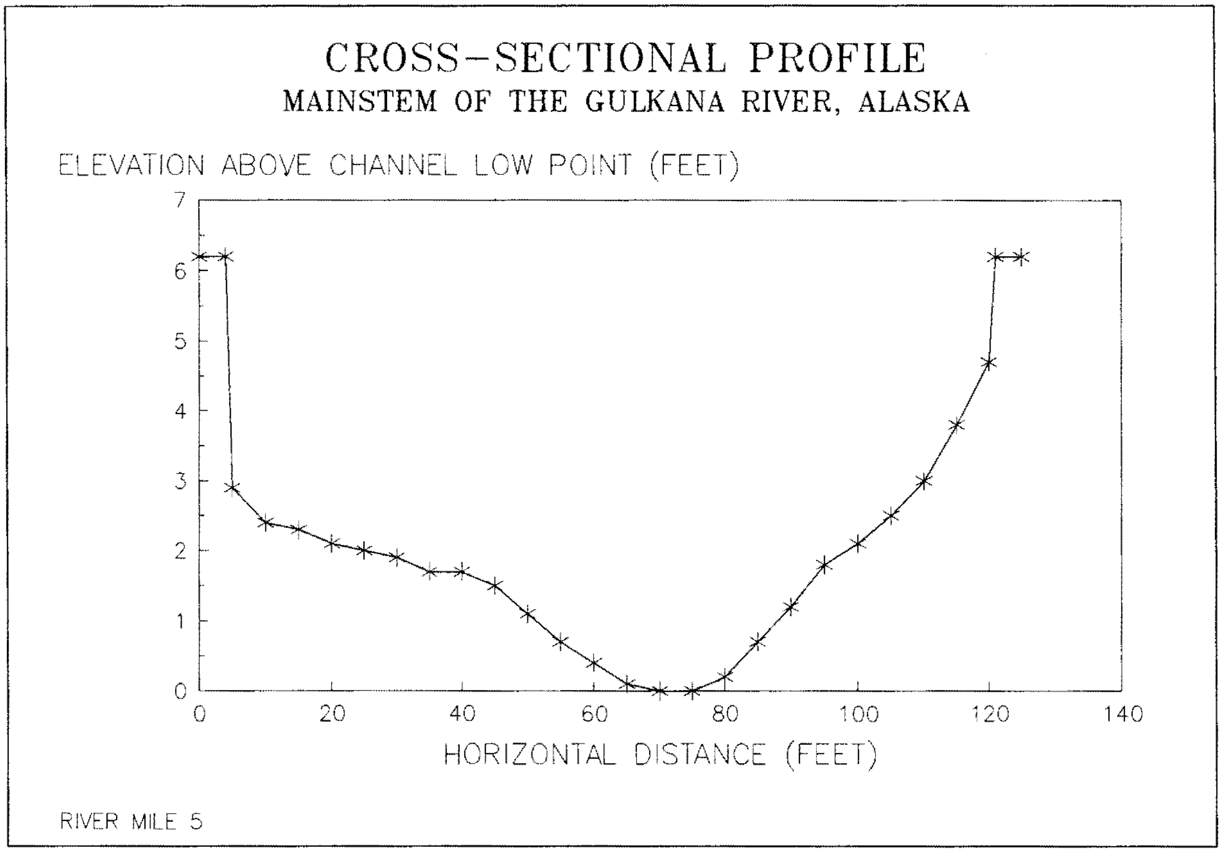
CROSS-SECTIONAL PROFILE
MAINSTEM OF THE GULKANA RIVER, ALASKA
ELEVATION ABOVE CHANNEL LOW POINT (FEET)
6
5
4
3
2
1
0
0
20
40
60
80
100
120
HORIZONTAL DISTANCE (FEET)
RIVER MILE 7

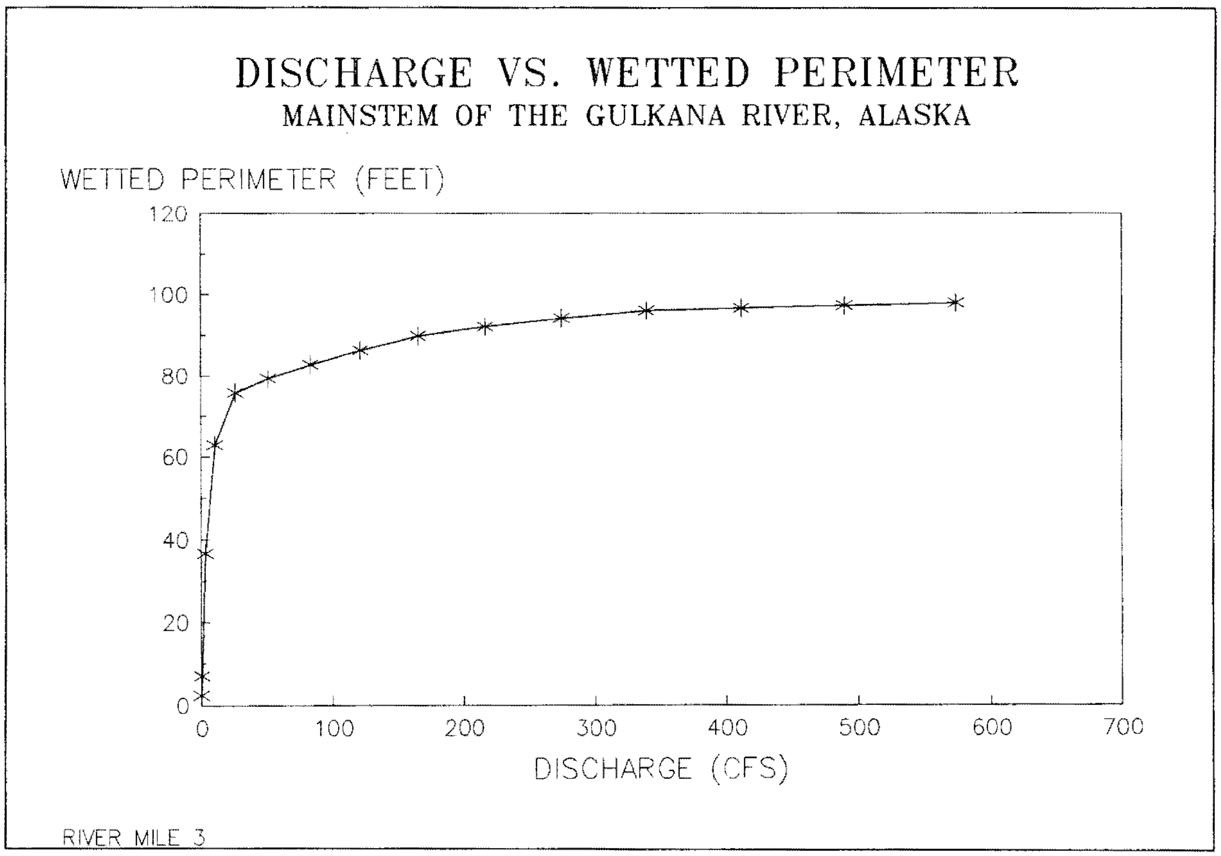

DISCHARGE VS. WETTED PERIMETER
MAINSTEM OF THE GULKANA RIVER, ALASKA
WETTED PERIMETER (FEET)
140
120
100
80
60
40
20
0
0
200
400
600
800
1,000
DISCHARGE (CFS)
RIVER MILE 5

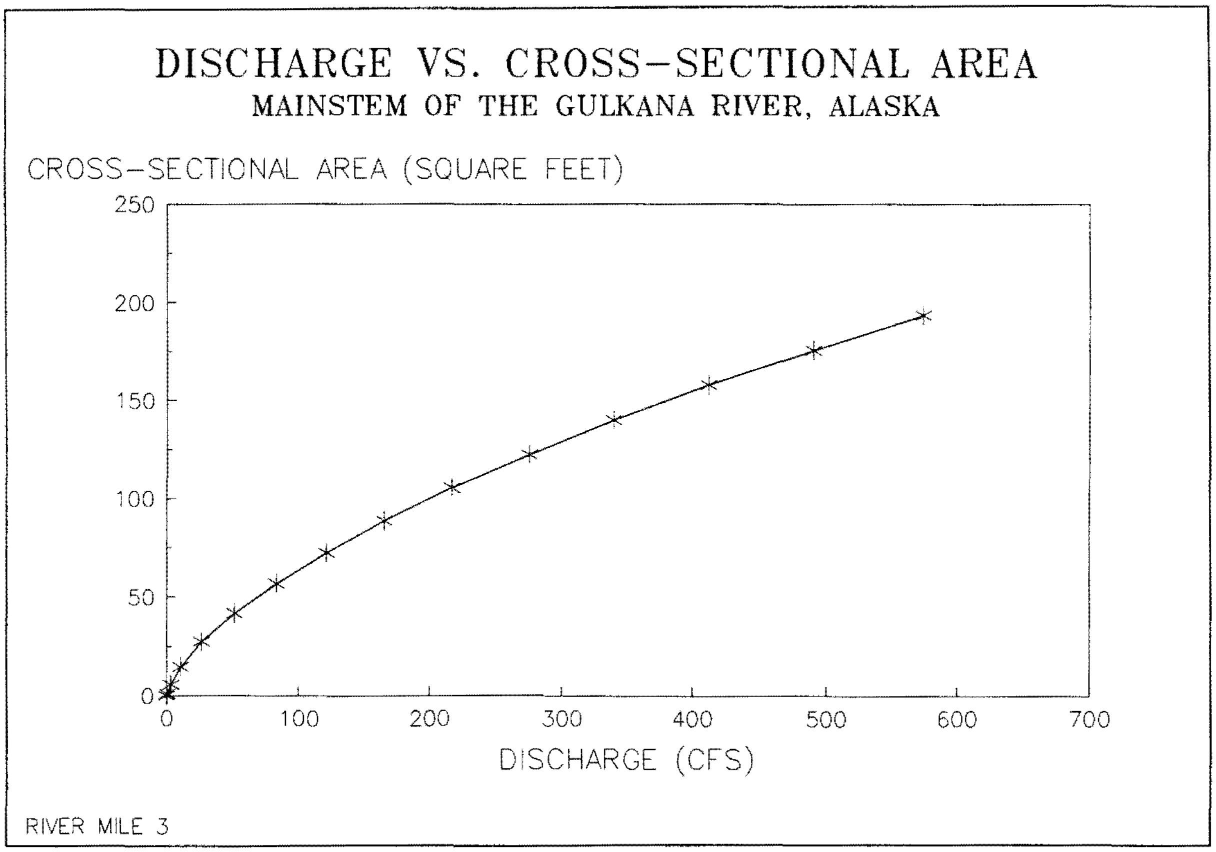

DISCHARGE VS. CROSS-SECTIONAL AREA
MAINSTEM OF THE GULKANA RIVER, ALASKA
CROSS-SECTIONAL AREA (SQUARE FEET)
600
500
400
300
200
100
0
0
200
400
600
800
1,000
DISCHARGE (CFS)
RIVER MILE 5

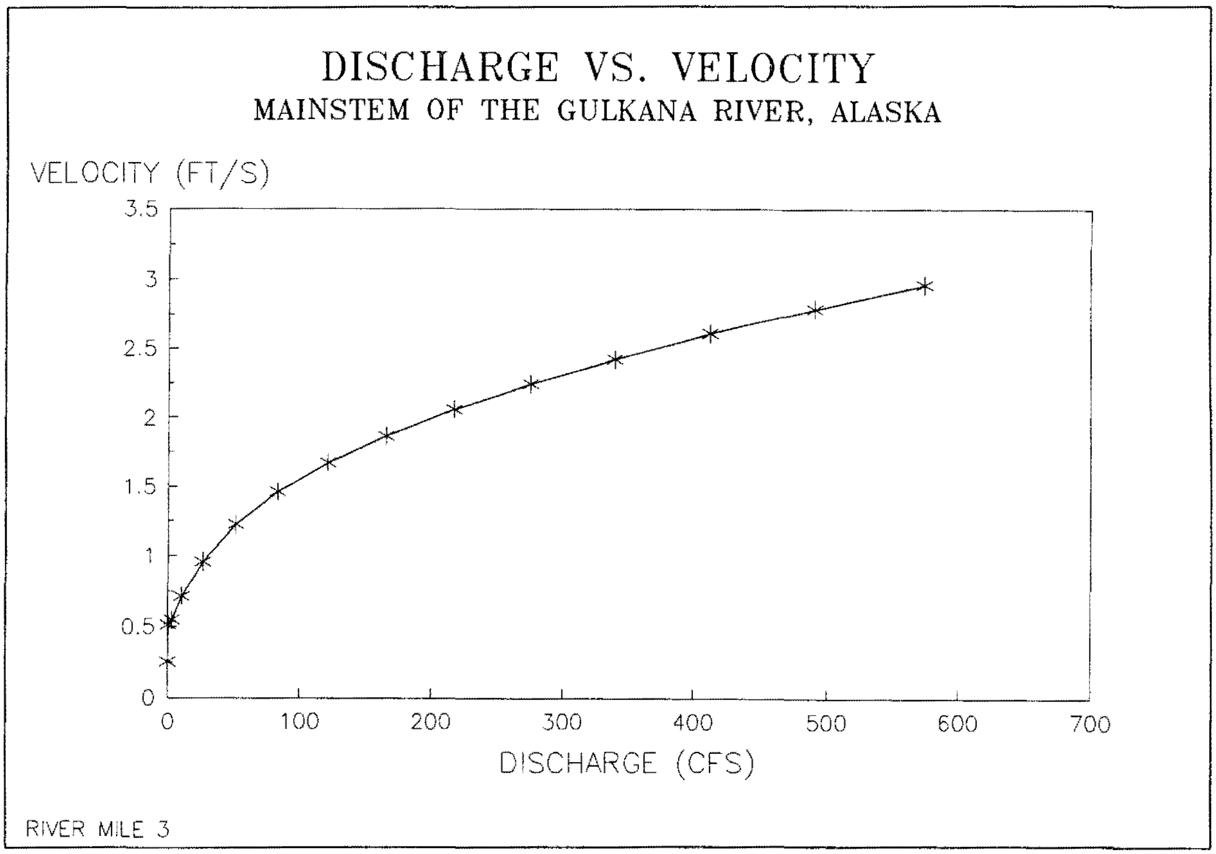

DISCHARGE VS. VELOCITY
MAINSTEM OF THE GULKANA RIVER, ALASKA
VELOCITY (FT/S)
2
1.5
1
0.5
0
0
200
400
600
800
1,000
DISCHARGE (CFS)
RIVER MILE 5

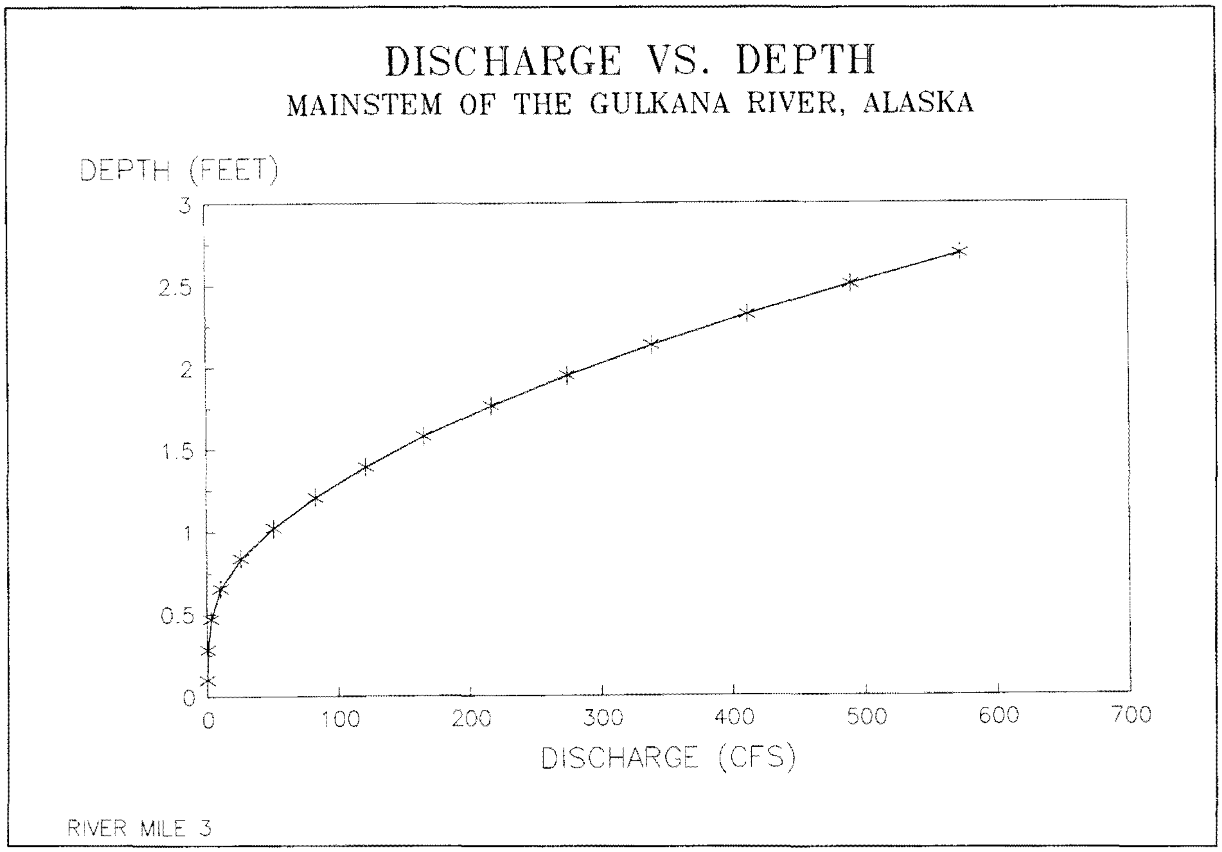

DISCHARGE VS. DEPTH
MAINSTEM OF THE GULKANA RIVER, ALASKA
DEPTH (FEET)
7
6
5
4
3
2
1
0
0
200
400
600
800
1,000
DISCHARGE (CFS)
RIVER MILE 5

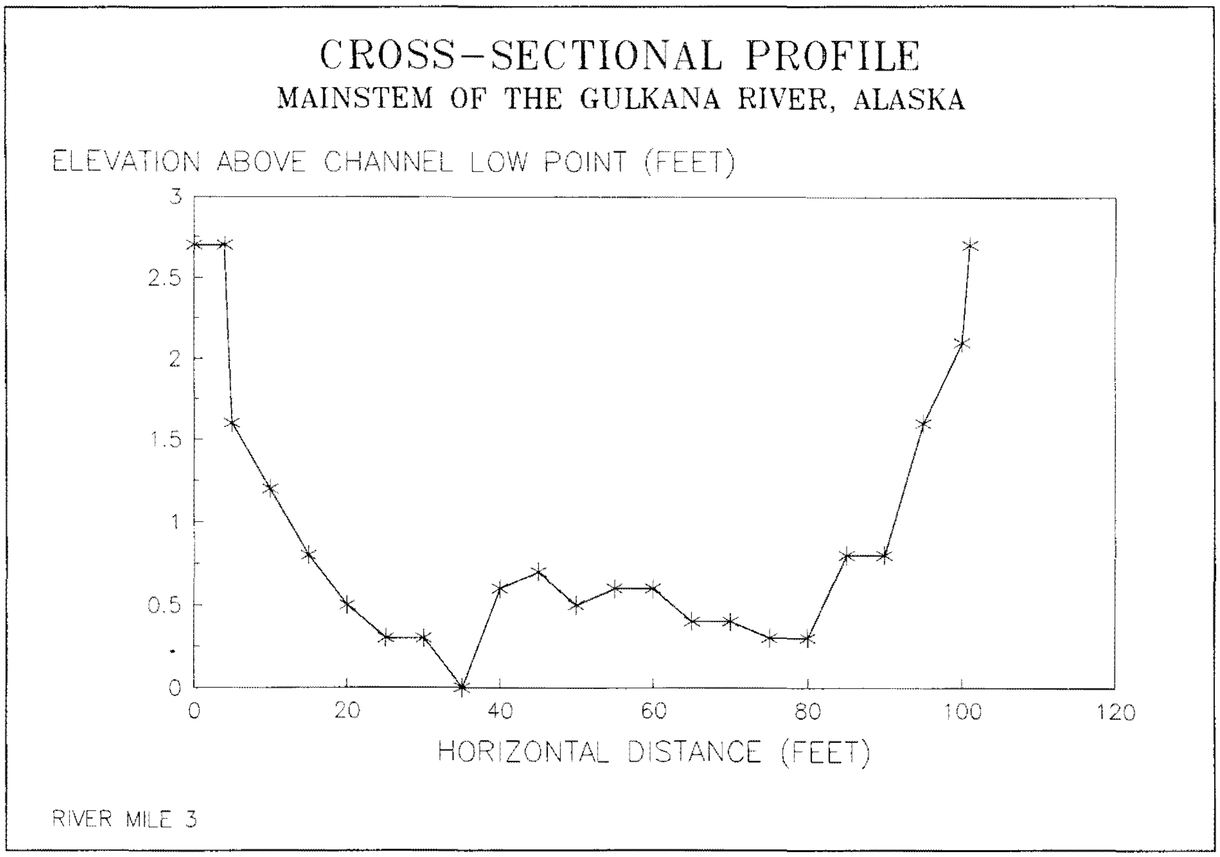

CROSS-SECTIONAL PROFILE
MAINSTEM OF THE GULKANA RIVER, ALASKA
ELEVATION ABOVE CHANNEL LOW POINT (FEET)
HORIZONTAL DISTANCE (FEET)
RIVER MILE 5

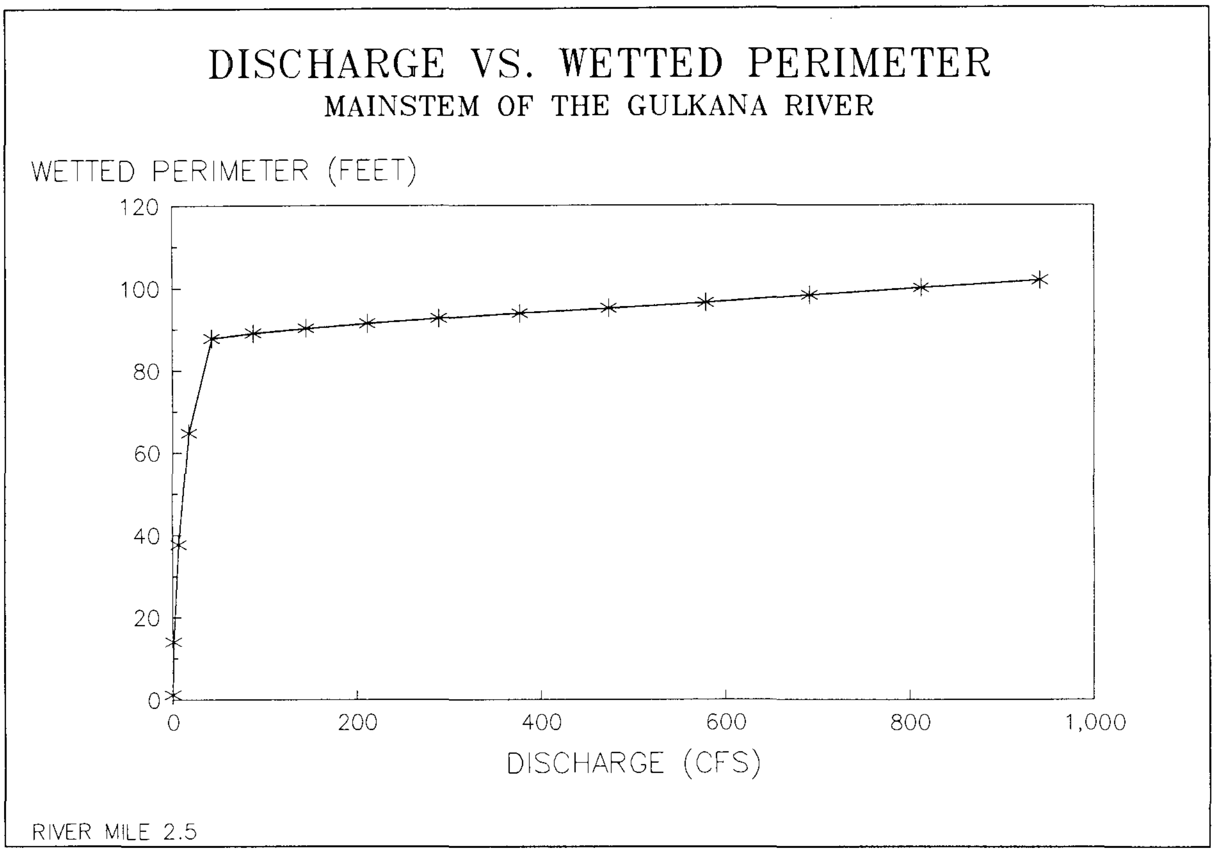

DISCHARGE VS. WETTED PERIMETER
MAINSTEM OF THE GULKANA RIVER, ALASKA
WETTED PERIMETER (FEET)
DISCHARGE (CFS)
RIVER MILE 3

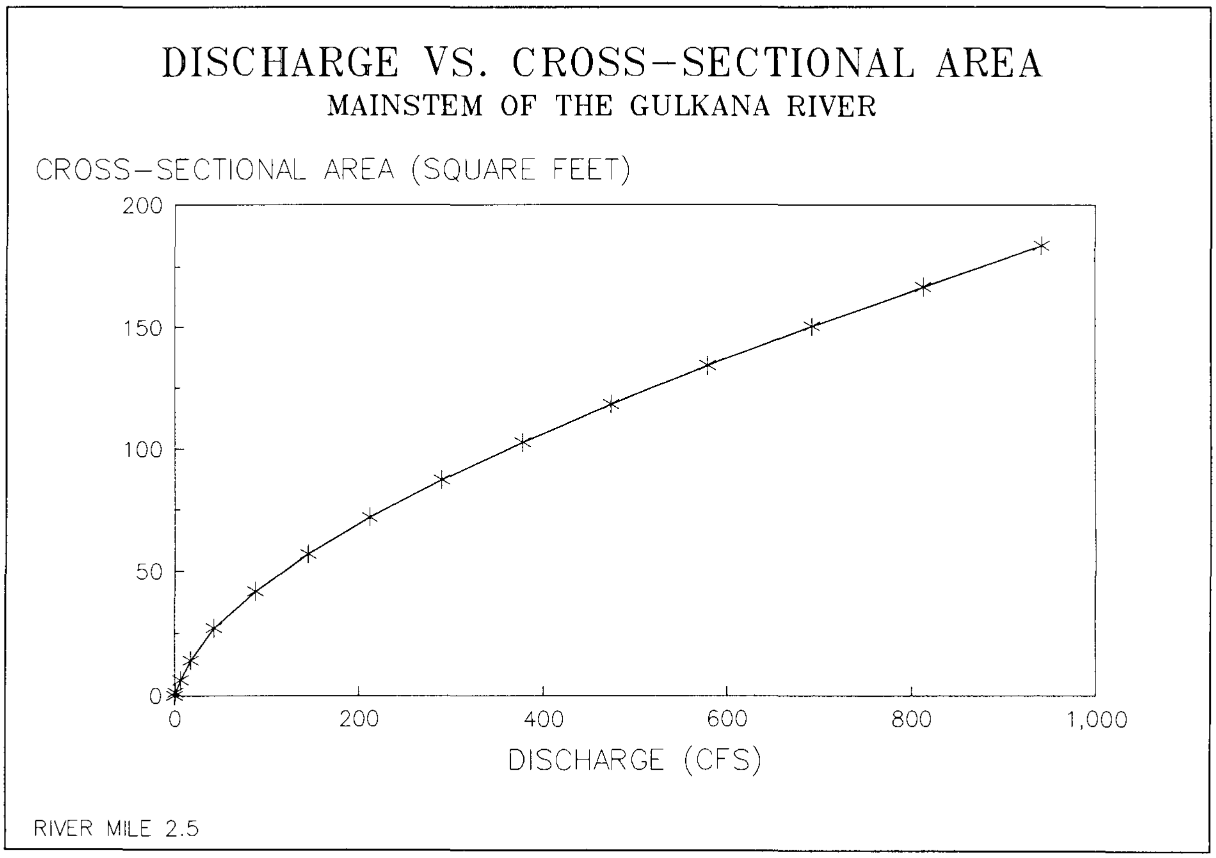

DISCHARGE VS. CROSS-SECTIONAL AREA
MAINSTEM OF THE GULKANA RIVER, ALASKA
CROSS-SECTIONAL AREA (SQUARE FEET)
250
200
150
100
50
0
0
100
200
300
400
500
600
700
DISCHARGE (CFS)
RIVER MILE 3


DISCHARGE VS. VELOCITY
MAINSTEM OF THE GULKANA RIVER, ALASKA
VELOCITY (FT/S)
3.5
3
2.5
2
1.5
1
0.5
0
0
100
200
300
400
500
600
700
DISCHARGE (CFS)
RIVER MILE 3


DISCHARGE VS. DEPTH
MAINSTEM OF THE GULKANA RIVER, ALASKA
DEPTH (FEET)
0
0.5
1
1.5
2
2.5
3
0
100
200
300
400
500
600
700
DISCHARGE (CFS)
RIVER MILE 3


CROSS-SECTIONAL PROFILE
MAINSTEM OF THE GULKANA RIVER, ALASKA
ELEVATION ABOVE CHANNEL LOW POINT (FEET)
0
0.5
1
1.5
2
2.5
3
0
20
40
60
80
100
120
HORIZONTAL DISTANCE (FEET)
RIVER MILE 3


DISCHARGE VS. WETTED PERIMETER
MAINSTEM OF THE GULKANA RIVER
WETTED PERIMETER (FEET)
120
100
80
60
40
20
0
0
200
400
600
800
1,000
DISCHARGE (CFS)
RIVER MILE 2.5


DISCHARGE VS. CROSS-SECTIONAL AREA
MAINSTEM OF THE GULKANA RIVER
CROSS-SECTIONAL AREA (SQUARE FEET)
200
150
100
50
0
0
200
400
600
800
1,000
DISCHARGE (CFS)
RIVER MILE 2.5