Hydraulic Characteristics Near Streamside Structures Along the Kenai River, Alaska

By Joseph M. Dorava

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To obtain
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
foot per second (ft/s)	0.3048	meter per second
cubic foot per second (ft^3/s)	0.028317	cubic meter per second

Sea level:

In this report "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

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ABSTRACT

Hydraulic characteristics, water velocity, depth, and flow direction were measured near eight sites along the Kenai River in southcentral Alaska. Each of the eight sites contained a different type of structure: a road-type boat launch, a canal-type boat launch, a floating dock, a rock retaining wall, a pile-supported dock, a jetty, a concrete retaining wall, and a bank stabilization project near the city of Soldotna. Measurements of hydraulic characteristics were made to determine to what extent the structures affected natural or ambient stream hydraulic characteristics. The results will be used by the Alaska Department of Fish and Game to evaluate assumptions used in their Habitat Evaluation Procedure assessment of juvenile chinook salmon habitat along the river and to improve their understanding of stream hydraulics for use in permitting potential projects.

The study included structures along the Kenai River from about 12 to 42 miles upstream from the mouth. Hydraulic characteristics were measured during medium-, high-, and low-flow conditions, as measured at the Kenai River at Soldotna: (1) discharge ranged from 6,310 to 6,480 cubic feet per second during medium flow conditions that were near mean annual flow on June 9-10, 1994; (2) discharge ranged from 14,000 to 14,400 cubic feet per second during high flow conditions that were near peak annual flow conditions on August 2-3, 1994; and (3) discharge ranged from 3,470 to 3,660 cubic feet per second during open-water low-flow conditions on May 8-9, 1995.

Measurements made at the structures were compared with measurements made at nearby unaffected natural sites. The floating dock, pile-supported dock, road-type boat launch, and concrete retaining wall did not significantly alter the stream channel area. These structures contributed only hydraulic-roughness type changes. The structures occupied a much smaller area than that of the wetted perimeter of the channel and thus typically had little effect on velocity, depth, or flow direction. During this investigation, many of these subtle effects could not be separated from ambient hydraulic conditions. The jetty significantly altered stream channel area and therefore affected stream hydraulics more than the other structures that were investigated. Data indicated that velocity increased from 1.9 to 5.8 feet per second near the point of the jetty during measurements in May, June, and August.

Rock wall and jetty structures also divert flow away from near-shore areas in proportion to their projection lengths into the river. For the jetty, the effect on surface flow was observed downstream for a distance of about 10 times the length of the jetty's projection into the river and upstream for about 4 to 5 times the length of the projection. For the rock wall, the diversion of flow was evident for 10 to 15 feet downstream.

INTRODUCTION

Background

The Alaska Department of Fish and Game (ADF&G) has statutory authority, as defined by Alaska Statute 16.05.870, over stream activities that affect aquatic habitat in anadromous fish streams for all areas below the ordinary high water line. The department is also responsible for fish passage according to regulations defined in Alaska Statute 16.05.840. For example, the department reviews plans and specifications for proposed streamside construction projects and approves, disapproves, or places conditions on the project's completion as warranted under the ADF&G's Title 16 permitting program. Habitat values assigned to a location along the river are adjusted in the Habitat Evaluation Procedure (HEP) data base when permitted modifications are made. Habitat biologists with ADF&G approve construction projects when it can be shown that significant aquatic habitat characteristics—such as water velocity and depth, cover for fish, and stream substrate size necessary to sustain fish productivity—will be maintained and undisturbed. To further improve the permitting process, the ADF&G is interested in learning what effect commonly used streamside structures have on the life functions of salmon and in determining the value of a site with a structure as salmon habitat. This investigation by the U.S. Geological Survey (USGS) in cooperation with the ADF&G provides measurements of hydraulic characteristics near representative examples of several types of streamside structures along the Kenai River in southcentral Alaska. This information can be used to evaluate HEP analysis assumptions and to improve the Title 16 permitting process.

Although development in the Kenai River watershed is sparse, the popularity of the river has increased development along a narrow corridor. Many property owners in this corridor have constructed streamside structures to improve their access to the river or to protect their property from stream erosion. The ADF&G identified 1,869 sites where human modifications have been made to the streambank or where structures were installed along the Kenai River (Liepitz, 1994). They selected several types of structures, including docks, jetties, retaining walls, and boat launches, at which investigations by the USGS would help identify whether the structures may be affecting ambient hydraulic conditions. The ADF&G plans to evaluate these hydraulic data along with other associated effects of proposed structures on salmon behavior and habitat when permitting future structures and designs.

The ADF&G also requested USGS to collect hydraulic data near a unique bank stabilization project contracted by the city of Soldotna. The project is constructed near Soldotna Creek, a tributary to the Kenai River near the city of Soldotna and is referred to as the "Soldotna Creek Bioengineering Project." The ADF&G provided the city of Soldotna with recommendations in the design of the bank stabilization, which utilizes natural materials and biological engineering techniques to ensure that fish habitat near the site would be restored and maintained. The ADF&G will use data collected by the USGS during and following construction of this project to evaluate the short- and long-term effects of the project on fish habitat restoration.

In addition to assisting the ADF&G with mandated regulation and permitting of stream activities below the ordinary high water line, data collected during this investigation will be used to confirm or verify assumptions about water velocity used during HEP analyses of the Kenai River. Assumptions of the water velocity at streamside structures were used by the ADF&G to determine the value assigned to instream habitat near these structures during the HEP process. The ADF&G is using the HEP analysis to do an assessment of cumulative impacts of development and human uses on fish habitat in the Kenai River (Liepitz, 1994). If the measurements of water velocity at representative examples of streamside structures collected during this investigation are significantly different from those used in the HEP analysis, habitat values at the structures will be adjusted accordingly in future ADF&G studies.

Purpose and Scope

This report provides descriptions of six types of streamside structures and the Soldotna Creek Bio-engineering Project and their physical settings. It also provides hydraulic data and observations in the vicinity of the structures and assesses any detectable effects of the structure in the context of ambient hydraulic conditions. Water depth, velocity magnitude, and flow direction observations were made on three occasions to represent low-flow (May 8-9, 1995), medium-flow (June 9-10, 1994), and high-flow (August 2-3, 1994) conditions.

The report also discusses fish habitat requirements, Kenai River geomorphology and hydrology, and reasons for river velocity variability to provide context for the measurements and observations made at the study sites. Biological implications of the data are covered only in general terms.

Location

The Kenai River watershed drains about 2,200 mi^2 of the Kenai Peninsula in south-central Alaska (fig. 1). The watershed drains areas more than 80 mi inland; the headwater tributaries originate in the Snow River Valley east of Seward and flow to Kenai Lake. The Kenai River begins at the outlet of Kenai Lake, a narrow, 22-mi long glacially sculpted, moraine-impounded lake, at an elevation of about 420 ft. From the outlet, it flows for 17 mi before it passes through Skilak Lake, another large moraine-impounded lake approximately 13 mi long and about 225 ft lower in elevation (fig. 2). These two lakes attenuate high flows from the upper river; however, they also sustain river flow during periods of reduced runoff. The lakes also reduce the sediment movement into the lower river and provide overwintering habitat for fish. From Skilak Lake, the river flows another 50 mi before entering Cook Inlet near the city of Kenai (fig. 1).

Much of the Kenai River flows through the Kenai National Wildlife Refuge where development is restricted. The upstream boundary of the study area for this investigation is about 42 river miles upstream from the mouth, which is downstream from the refuge boundary (fig. 2). Because the action of tides in the lower reaches of the river could affect results of the investigation, a downstream boundary of the study area was established about 12 river miles upstream from the mouth where significant tidal influence commonly ends. Throughout this report, locations along the river are referred to by river miles above the mouth. For example, river mile 16 is upstream from the mouth a distance of 16 mi along the natural course of the river.

Fisheries and Fish Habitat

The Kenai River supports all 5 species of North American Pacific salmon and 22 other species of fish (Liepitz, 1994). It also provides a source of chinook [*Oncorhynchus tshawytscha* (Walbaum)], coho [*Oncorhynchus kisutch* (Walbaum)], and sockeye [*Oncorhynchus nerka* (Walbaum)] salmon for recreational, commercial, subsistence, and sport fisheries. The river is the most popular and most productive sport fishery in Alaska; as much as $38 million in direct economic benefit is generated annually (Mills, 1993). Much of this activity is in pursuit of the Kenai River strain of chinook salmon which is among the largest in the world (Estes and Kuntz, 1986; Liepitz, 1994). These large Kenai River chinook salmon typically spend between 1 and 3 years in freshwater, and as many as 5 years in saltwater (Bendock, 1994). The protection or maintenance of salmon habitat is necessary to sustain the economic input from this fishery.

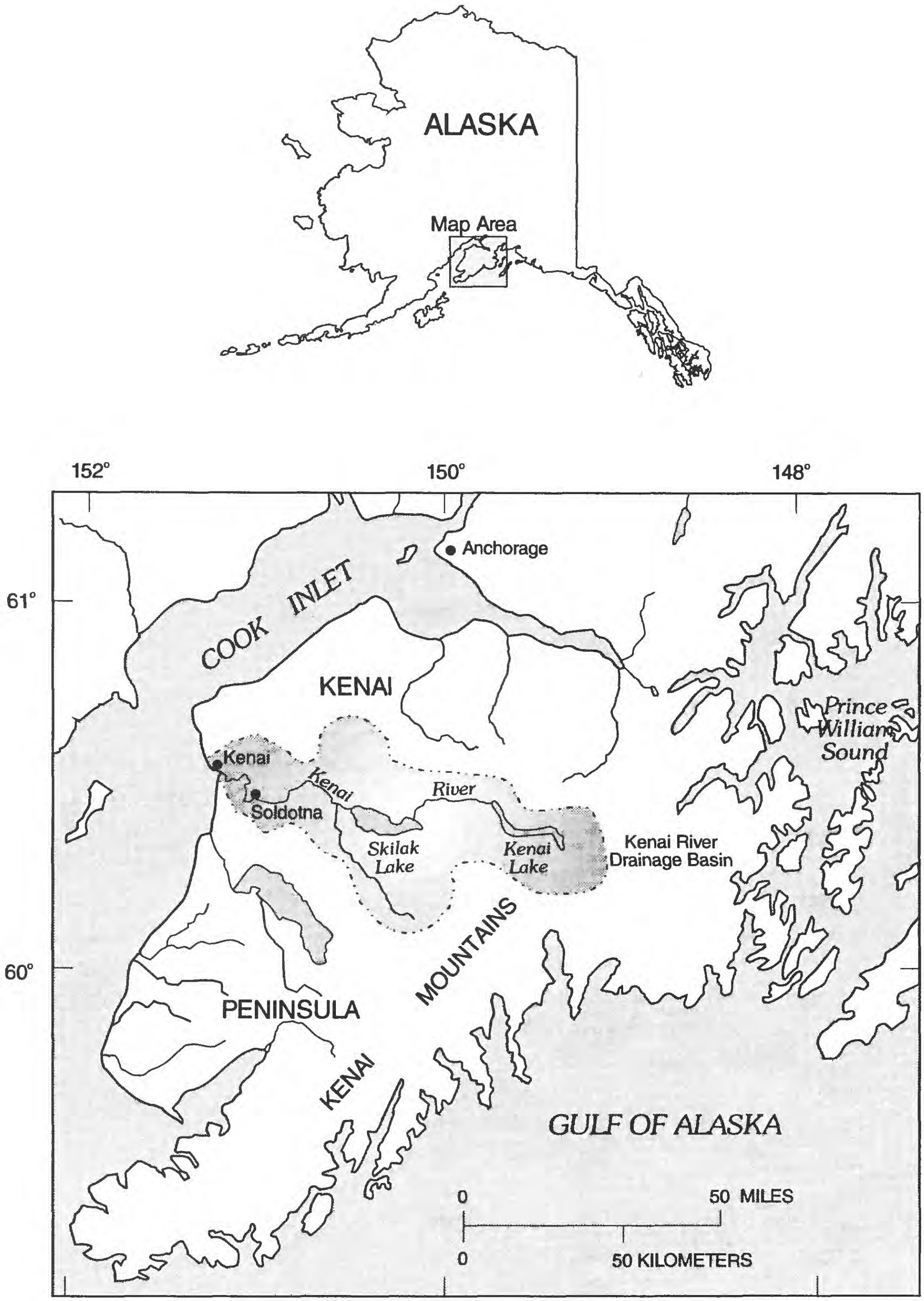


Figure 1. Location of Kenai River, Alaska.

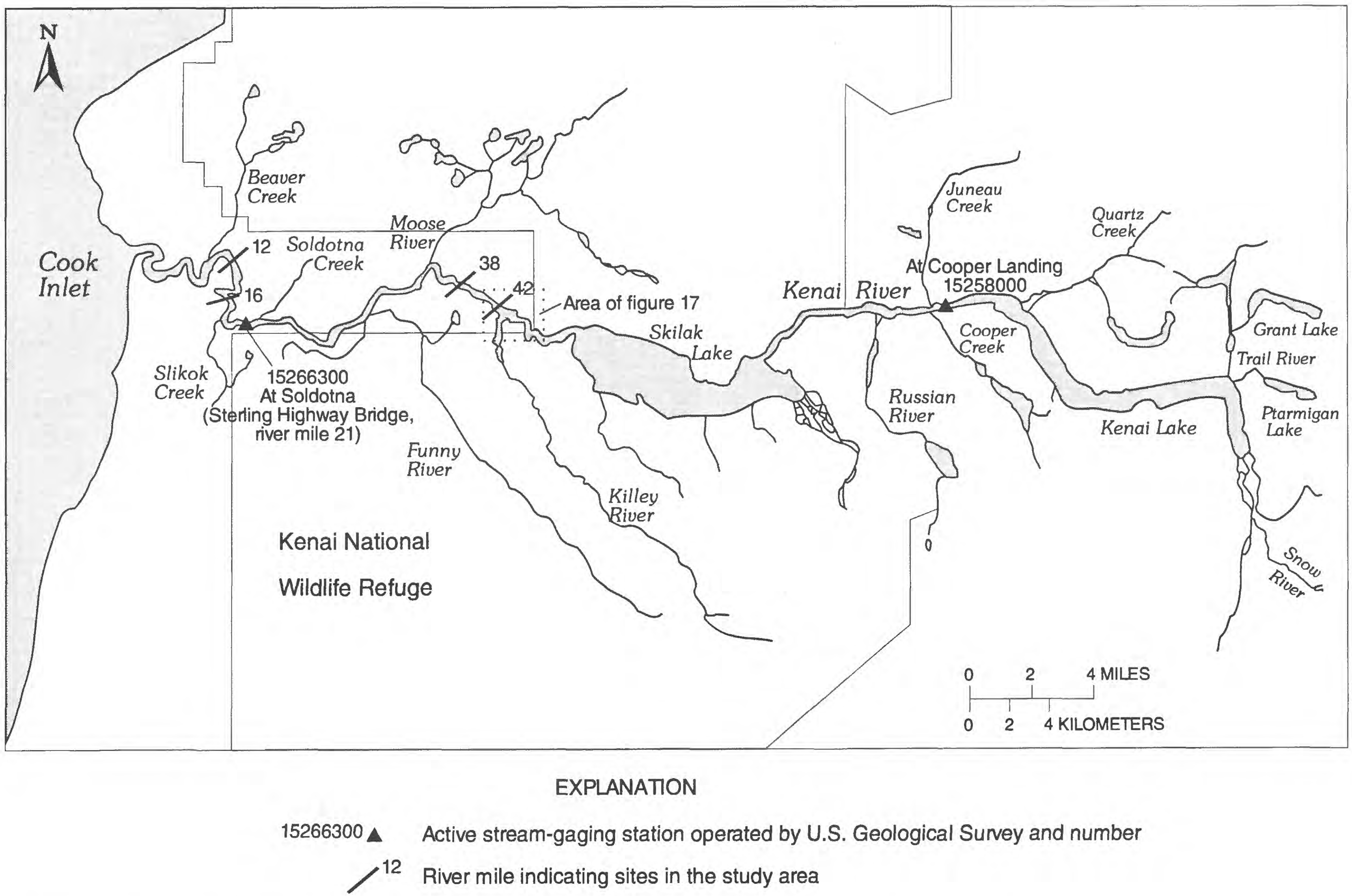


Figure 2. Kenai River,its major tributaries, and part of the Kenai National Wildlife Refuge on the Kenai Peninsula, Alaska. (Modified from the National Biological Service, unpublished report)

The freshwater requirements of juvenile chinook salmon have been described as one of the most restricted of the five salmon species found in the Kenai River (Bendock and Bingham, 1988; Burger and others, 1982; Estes and Kuntz, 1986; Liepitz, 1994; Litchfield, 1985, 1986). The term "juvenile" means the salmon life-stage during the one-or-more-year period spent in freshwater. During this period from emergence, when the salmon are only a fraction of an inch long, they grow into fingerlings which may be as long as 6 in. (Terry Bendock, fisheries biologist, Alaska Department of Fish and Game, oral commun., 1995). As fingerlings, the salmon out-migrate into saltwater where they mature before they return to freshwater where they spawn and die.

Before out-migrating to the sea, juvenile chinook salmon rear primarily in the main stem of the Kenai River instead of in the river's tributaries (Burger and others, 1982). Because of their lengthy exposure to the Kenai River and their more restrictive habitat requirements, juvenile chinook salmon have been selected by the ADF&G as the target species for HEP analysis and evaluation of the results from this study of hydraulic characteristics near streamside structures.

Juvenile chinook salmon primarily inhabit areas with water velocities between about 0.09 and 0.6 ft/s and rarely utilize areas with velocities greater than about 2.1 ft/s (Burger and others, 1982). These velocities are typically found near the streambank where riparian vegetation and bank irregularities slow the water and provide protective cover and food for the small salmon. During a 1980-81 study, 93 percent of juvenile chinook salmon captured were found within 6 ft of the riverbank (Carl Burger, National Biological Service, written commun, 1995). This streamside area is also heavily used by land owners for stream access. A recent inventory of streamside conditions indicates that about 7 percent of the Kenai River's length has been altered by man-made structures (Liepitz, 1994).

Results from some previous investigations of the hydraulic effects of instream or streamside structures indicate that instream or streamside development for improved access, bank stabilization, or habitat enhancement can alter the ambient stream hydraulics that occur naturally (Burger and others, 1982; House and Boehne, 1985, 1986; Knudsen and Dilley, 1987; Stern and Stern, 1980; Swales and O'Hara, 1980; Tauriainen, 1986). Even a small change in water velocity or depth may affect the habitat value for juvenile salmon (Alaska Department of Natural Resources, 1986; Burger and others, 1982; Liepitz, 1994; Stalnaker and Arnette, 1976; Taylor, 1988). Additionally, streamside alterations resulting in the diversion of water flow towards the bank may accelerate or initiate erosion and cause the loss of productive habitat (Scott, 1982). The diversion of river flow towards the middle of the river may also force juvenile salmon away from the near-shore area into water that is moving too fast for their swimming abilities. This process may impede their upstream movement or prematurely wash them downstream. Additionally, alterations to stream velocity may prevent juvenile salmon from finding adequate food supplies or make them more vulnerable to predators.

During a study on the Kenai River in the summer of 1981, water velocities of 5.0 and 5.6 ft/s were measured at the point of a non-permeable or solid jetty (Burger and others, 1982). These velocities were reported to be beyond the usable range of juvenile chinook salmon, implying potential passage impediment by the structure. Bell (1986) identified the sustained swimming ability of juvenile salmon (4.75 in. long) as between 1.4 and 2.1 ft/s. Velocities greater than 2.1 ft/s, if present for a long distance along the migratory corridor, may interfere with passage of juvenile salmon. Rundquist and Baldrige (1990) report that the velocity range providing optimal rearing habitat for salmon is between 0 and 1.5 ft/s. Changes in velocity also affect the behavior of juvenile salmon, causing them to shift position in the water column or to move to a new station (Taylor, 1988).

KENAI RIVER GEOMORPHOLOGY AND HYDROLOGY

Geomorphology

The Kenai River is one of the most productive salmon rivers in the world. Although poorly understood, many factors likely contribute to its productivity. The river characteristics that potentially contribute to this productivity include (1) sparse development in the river's drainage basin; (2) sustained high flows during extended periods when salmon are present; (3) two large lakes along the river that regulate flow variations, reduce sediment movement, and provide salmon with overwintering habitat; and (4) for much of its course, an entrenched channel with steep high banks and a narrow flood plain, which provides a stable environment for salmon rearing and spawning.

This entrenched channel was developed when the river conveyed much larger discharges when glaciers were more prominent in the basin (Scott, 1982). Now that the glaciers have been reduced in size and areal extent, the river conveys less water than in the past and the existing channel is larger than it would be without this history. As a result, the river is less susceptible to lateral movement, and its streambed is less mobile compared with streambeds of other rivers that do not have this glacial history.

Along the 80-mile course between Cook Inlet and Kenai Lake, the Kenai River crosses the poorly drained lake-dotted Kenai Lowland. Downstream from Skilak Lake, the Kenai River meanders through this 50-mile course in a single channel except for two reaches where the river branches into multiple distinct channels (anabranches) (Scott, 1982). An upper anabranched reach is between river miles 42.7 and 39.6, and a lower anabranched reach is between river miles 15.8 and 11.4. The islands within these anabranched reaches are covered with mature vegetation indicating that they are only rarely inundated. These islands affect stream hydraulics—especially water velocity, depth, and flow direction—because water slows as it flows nearby and as it is diverted around the islands. Some natural features—such as glacier moraines, landslides, rock falls, or large boulder fans—may accelerate water velocity by acting as impermeable projections into the river. However, the Kenai River passes through lengthy lowland areas, so these features are rare. A notable exception is the glacier moraine forming Naptowne Rapids near river mile 39.3, where a steep walled, narrow section of the river has numerous natural projections into the flow.

Major tributaries to the Kenai River downstream from Skilak Lake include the Killey River which enters from the southwest at about river mile 44; the Moose River which enters from the north at about river mile 36.2; the Funny River which enters from the southeast at about river mile 30.4; Soldotna Creek which enters from the northwest at about river mile 22; Slikok Creek which enters from the south at about river mile 18.9; and Beaver Creek which enters from the north at about river mile 10.1 (fig. 2). These tributaries, with the exception of the Killey River, have no permanent snow and ice in their basins. Because of this, they contribute runoff (predominantly snowmelt and rainfall runoff) and have annual peaks generally in April or May. These tributaries periodically affect stream hydraulics by increasing flow in the Kenai River and by depositing sediment near their mouths. These factors can decrease water depth and divert Kenai River flow towards the middle of the main channel. Little data are available for these tributaries.

Within the watershed, climatological data are concentrated in populated areas, which are generally at lower elevations. Thus, these data provide information that may not be representative of the entire watershed. Jones and Fahl (1994) summarized precipitation records for the State of Alaska and identify mean annual rainfall in the Kenai watershed at about 20 in. near Kenai and Soldotna, 160 in. for areas along the southern watershed boundary near the Harding Icefield, and 240 in. along the eastern watershed boundary near the Sargent Icefield.

Hydrology

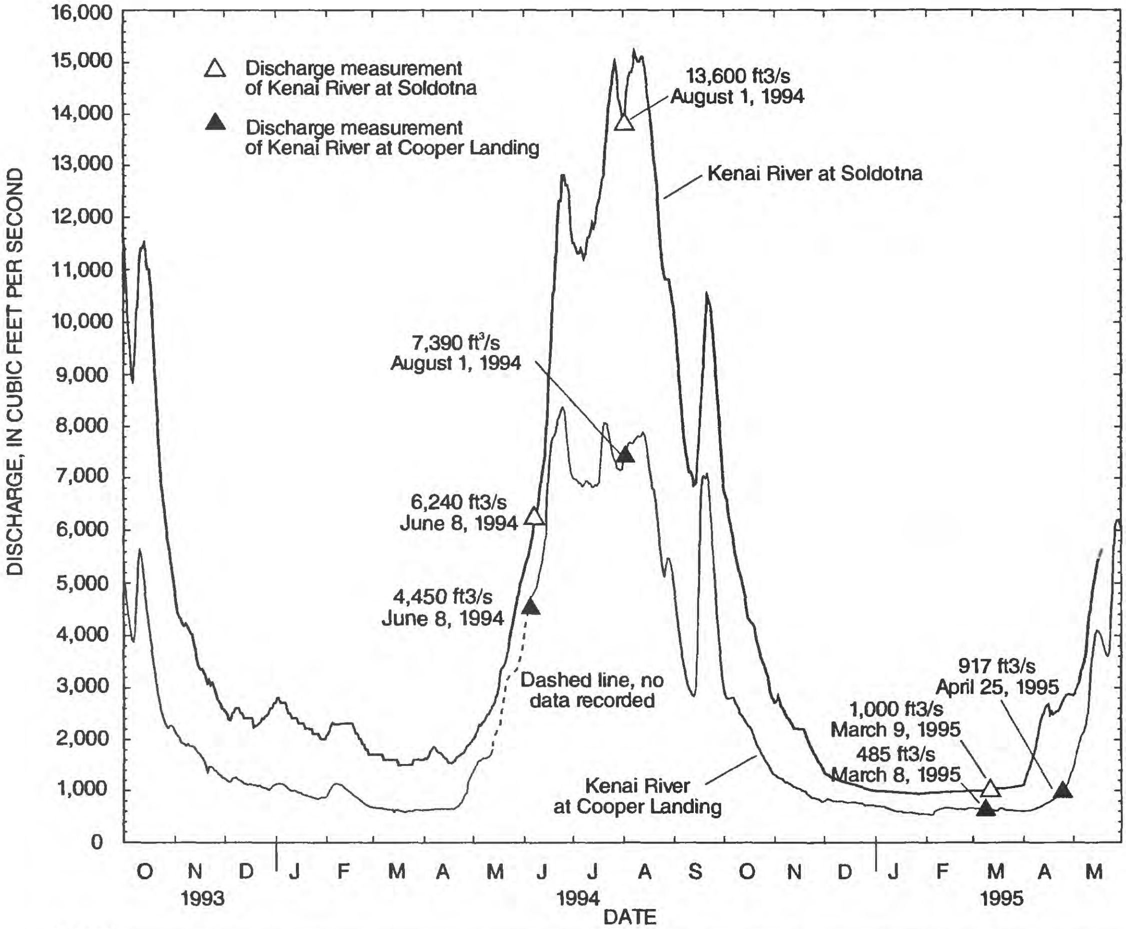
Because several of the headwater tributaries drain areas having elevations of more than 5,000 ft, about 10 percent of the watershed is covered by permanent snow and ice. This greatly influences the natural flow of the river. High sustained flows during the summer are the result of an increase in snow and glacier melt, which combines with rainfall runoff. Flows decrease during the fall and winter when glacier melting and runoff are reduced. Although hydrologic data have not been collected on the tributaries and climatological data may be inadequate to describe flows everywhere in the watershed, a significant amount of hydrologic data for the Kenai River has been collected. The USGS has collected stage and discharge data since 1947 at a stream-gaging station near river mile 80 at the outlet of Kenai Lake known as the Kenai River at Cooper Landing gaging station (No. 15258000; fig. 2). Discharge records for this site through September 1994 indicate a mean annual flow of about 2,910 ft^3/s (Bigelow and others, 1995). Discharge at the site reflects the glacial influence on the 634-square-mile basin, with sustained high flows during the summer and decreasing flows as temperatures fall and winter progresses into spring (fig. 3). Typically, the warmer months of June through September have similar mean monthly flows, and the river discharge declines to a minimum in March (table 1).

Table 1. Mean monthly discharges at two gaging stations on the Kenai River
[All values in cubic feet per second]

Station name and period of record	Oct.	Nov.	Dec.	Jan.	Feb.	Mar	Apr.	May	June	July	Aug.	Sept.
Cooper Landing (1947-94)	3,344	1,871	1,166	810	655	512	533	1,873	5,337	6,942	6,436	5,214
Soldotna (1965-94)	7,245	3,521	2,304	1,914	1,694	1,375	1,523	3,090	8,365	13,230	14,670	11,700

Historical discharge records for the site also indicate that glacier freeze and melt cycles can result in extreme flow conditions. For example, the lowest mean 7-consecutive-day minimum flow of 190 ft^3/s, occurred in March 1951, after an extensive period of reduced glacier melt (Bigelow and others, 1995). The record instantaneous peak flow of 23,100 ft^3/s, which occurred on September 21, 1974, resulted from local rainfall combined with the release of stored water from a glacier-dammed lake at the head of an unnamed glacier in the Snow River Basin, a headwater tributary to Kenai Lake (Bigelow and others, 1995). Outburst floods have been recorded in the Kenai River system at a 2 or 3-year interval since records began in 1947 (Post and Mayo, 1971).

Discharge records have also been kept by the USGS since 1965 for the stream-gaging station known as the Kenai River at Soldotna gaging station (No.15266300; fig. 2). This gaging station at the Sterling Highway Bridge in Soldotna is at about river mile 21. The discharge records for the 2,010-square-mile basin contributing flow to this site also reflect the effects of glaciers on the streamflow (fig. 3). The mean annual streamflow is about 5,975 ft^3/s, and the highest mean monthly streamflow occurs in August (table 1; fig. 3), when summer temperatures are typically the highest and glacier melt the greatest (Bigelow and others, 1995). The lowest mean monthly streamflows occur in March (table 1; fig. 3), when the duration of time with temperatures below freezing has been the longest.



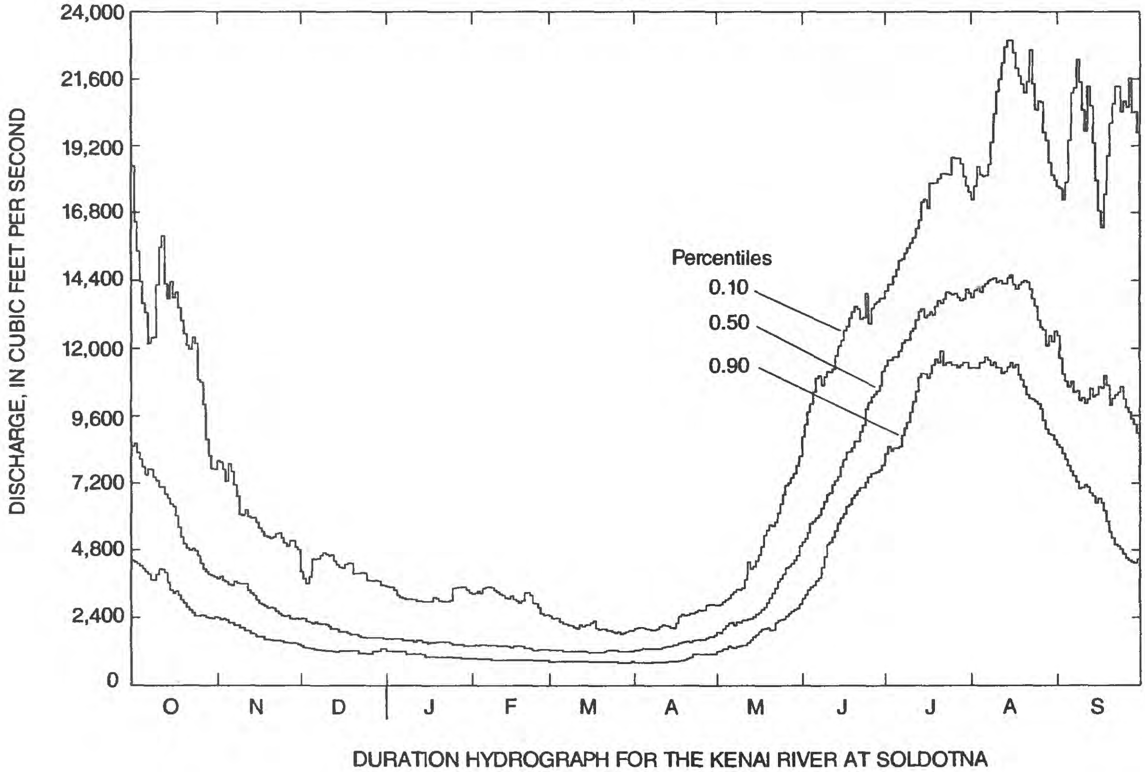


Figure 3. Discharge of Kenai River at Soldotna and at Cooper Landing, October 1993 to May 1995 and duration hydrograph for the Kenai River at Soldotna for the period of record 1965-94.

METHODS

Velocity is one of the most important hydraulic properties contributing to the habitat value of a site along a river. Water velocity is also one of the most widely variable stream properties. It is controlled by many variables such as channel size, shape, slope, and course. Other influencing variables include the type of streambank and streambed material, the volume of water flowing in the channel, and the presence of islands, meander bends, or other flow restrictions. When water velocity is excessively fast at a site, fish may avoid using the site and it would then contribute little value as habitat.

From a hydraulic perspective, streamside structures can influence the ambient velocity either by altering the channel cross-section area, the channel roughness, or a combination of both. Structures that modify the channel cross-section area (jetties, protruding rock retaining walls and excavated boat launches) have the greater potential to affect local velocity conditions than do structures that only change channel roughness. The extent to which a given structure can influence local flow patterns depends both on its relative size in the cross section and orientation in the current, and on ambient hydrologic and hydraulic conditions in the river. A given structure may noticeably constrict or divert the river during high flow, but have little or no effect during lower flow. A jetty or wall protruding from the streambank in a deep, slow-moving reach of the river would have less effect on velocity than the same structure built into a shallower, faster moving reach.

Description of Velocity Variation

The mean water velocity at any cross section along a river decreases as the area of the channel increases for a given discharge. If the discharge increases at a cross section along the river where the channel size is constant, velocity will also increase. Velocity along the river will also vary across the channel from bank to bank (Chow, 1959, p. 24-25) and within the water column from the stream bottom to the water surface (Rantz and others, 1982, p. 132-133) (fig. 4). Typically, the greatest velocities will be found near the middle of the channel and near the surface of the stream where there are little vegetation or rocks to generate hydraulic roughness or friction which slows the water. Near the middle of the channel and the surface of the stream, hydraulic roughness and friction, forces are smaller than those near the stream bottom or banks.

The mean velocity at a cross section in the river during a specific discharge does not provide information on the maximum or minimum values of velocity. It also does not reveal the variability of velocity with depth or channel width at the site. For example, during a measurement at the gaging station in Soldotna on August 1, 1994, the discharge was 13,600 ft^3/s (fig. 3) and the mean velocity was 5.4 ft/s. However, the velocity (reported as means in the vertical water column across the river) ranged from 2.0 to 6.8 ft/s. Individual point measurements of velocity were as much as 8.4 ft/s near the surface in the middle of the river.

Velocity Measurements

Point velocity measurements were made to characterize hydraulic conditions at and in the vicinity of a streamside structure. For this study, the water velocity in the narrow, 6-foot wide streamside corridor occupied by juvenile salmon is the primary concern. The velocity in this area is influenced by the same channel hydraulic characteristics described earlier, but can be influenced considerably by streambank geometry and roughness. Velocity in this corridor is generally slower

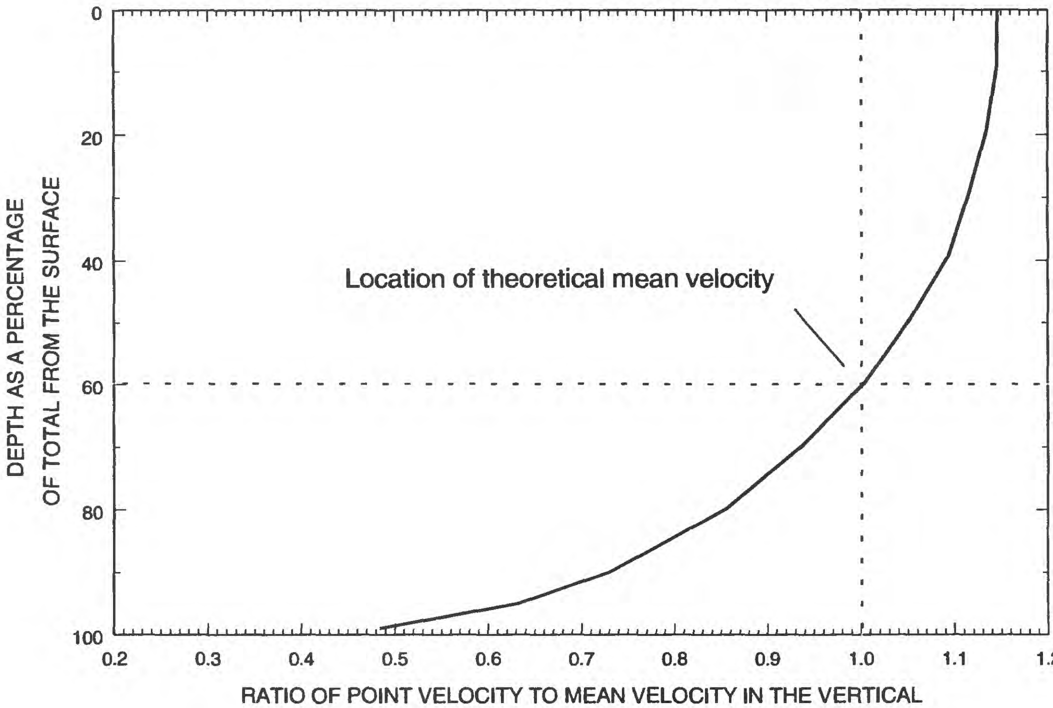


Figure 4. Theoretical velocity distribution (Modified from Rantz, 1982).

close to the bank and faster as distance from the bank increases. Measurements were typically made where velocity was expected to be the maximum in the corridor, or at a point 6 ft from the bank or structure. Because the water depths in this streamside corridor were relatively shallow, point velocity measurements were made 0.6 times the depth down from the surface to obtain a mean velocity in the vertical (Rantz, 1982). When a structure appeared to result in a deviation from the normal vertical velocity profile (fig. 4), additional point measurements were made to better define the influence of the structure.

To characterize velocity conditions under different flow conditions, measurements were made at most of the structures under low-, medium-, and high-flow conditions in the Kenai River (table 2).

Table 2. Variations in discharge and velocity with flow conditions in the Kenai River at Soldotna

[ft^3/s, cubic foot per second; ft/s, foot per second]

Date	Flow condition	Mean discharge (ft^3/s)	Mean velocity (ft/s)
June 9-10, 1994	Medium	6,310-6,480	4.3-4.4
August 2-3, 1994	High	14,000-14,400	5.3-5.4
May 8-9, 1995	Low	3,470-3,660	2.0-2.2

Velocity at each site was measured with a calibrated Price-AA meter. This type of meter is made of stainless steel and is formed into a circle of six cups that are mounted on a vertical axis and rotate in a horizontal plane (fig. 5). This is the standard velocity meter used by the USGS. The meter was mounted on a hand-held rod because all depths were wadable. The meter was lowered into the water and the number of rotations during a fixed interval of time were recorded. The rotation rate for the Price-AA meter is proportional to the water velocity.

Figure 5. Price-AA velocity meter attached to a top-setting wading rod.

Flow Direction Determinations

The direction of water flow along the river channel is a direct indication of the hydraulic influences on the flow. For example, expansions or contractions of the streambank will divert flow and cause eddies of swirling water that can travel in all directions along the stream. Although small circular flow eddies are commonly generated by bank irregularities, the near-shore streamflow generally occurs with a surface pattern parallel to the streambank. Disruptions of this flow pattern caused by structural anomalies of the bank—such as rock projections or bank indentations—were usually evident in the surface flow pattern near these features. The disturbance of surface-water flow near each structure was described in a two-step process: (1) examining closely the patterns of surface flow approaching the structure, and (2) comparing that undisturbed flow pattern to the flow pattern at the structure and downstream from it. All significant disturbances to the naturally occurring surface flow near the structures were noted with flow vectors in field sketches and on illustrations in this report. The angle of flow as it approached the structures was also noted each time a velocity measurement was made and this was also depicted on sketches.

IDENTIFICATION OF STRUCTURES AND COLLECTION OF HYDRAULIC DATA

The ADF&G has identified 1,869 streamside structures along the Kenai River. These structures vary widely in size, shape, and purpose, and thus in their effects on stream hydraulics. For the purpose of this study, they were categorized into six commonly used access improvements or bank protection techniques: (1) boat launches, (2) floating docks, (3) stone or rock retaining walls, (4) pile/pier supported docks, (5) jetties, and (6) concrete retaining walls. In practice, one or more bank protection measures are commonly used in conjunction with access improvement modifications. For example, retaining walls have been installed along the streambank upstream and downstream from many docks to minimize local bank erosion. Small jetties have been built on the upstream sides of many boat launches to protect the launch entrance and create a safe, low-velocity condition for boat operations.

Two boat launch sites and one example each of the other five structure categories were identified for investigation by a habitat biologist from AFD&G after an extensive inventory of streamside structures (Liepitz, 1994). The Soldotna Creek Bio-engineering project was also included for the investigation. At each of the study sites, observations of water depth and flow velocity and direction were made under low-, medium-, and high-flow conditions as described previously.

Of the eight structures or sites investigated, the boat launch, boat harbor, floating dock, rock retaining wall, and the pile-supported dock are downstream from the Sterling Highway Bridge at Soldotna (fig. 2), whereas the Soldotna Creek Bio-engineering Project, the jetty, and the concrete wall are upstream. In providing details of hydraulic measurement at each site, the type of structure was also described along with a general overview of the hydraulic setting and the probable effects of the structure on stream hydraulics. Each structure's location was referenced by river mile upstream from the mouth and by latitude and longitude. Descriptions of the site investigations proceed in an upstream direction starting from the farthest downstream site. The exception is the Soldotna Creek Bio-engineering Project site, which is described last in this report, but is about 0.9 mi upstream from the Sterling Highway Bridge and downstream from two other sites.

Boat Launches and Harbors

Many different styles of boat launches and harbors have been constructed along the Kenai River. Some are simply roads extending into the water at a constant slope. Others are similar to a harbor and contain canal systems that allow a boat to be floated on and off the river in a protected area. Generally, boat launches are located in an area of naturally deep slow water, or the launch is formed to create these conditions to facilitate easier launching. Typically, a gently sloping road or a dredged canal forms an expansion of the streambank which increases the streamflow area and consequently reduces flow velocity.

The ADF&G has identified 106 boat launches along the Kenai River (Liepitz, 1994). The hydraulic effects of the two different styles of boat launches described above were investigated at two sites along the lower river. The first site is the farthest downstream structure investigated and is just upstream from normal tidal influences which end at about river mile 12. This site was at a place called "The Pillars" near river mile 12.3, at approximate lat 60°32'06"N., long 151°05'53"W. In this lower section of the river, the channel forms anabranches around several islands. The main channel has a width of about 600 ft and the flood plain has a width of about 1 mi. The river is generally straight for approximately 0.5 mi on both sides of The Pillars. Two long narrow islands downstream from The Pillars slow the water, but likely have little effect on flow direction at the boat launch.This launch was not fully developed for use at the time of these measurements, but consisted of a sloping roadway about 20 ft wide. The road extended into the river and had a raised section of rock about 2 ft above the stream bottom that extended about 5 ft into the river at the upstream edge of the launch (fig. 6).

Velocity measurements were made at this site about 10 ft upstream from the launch (V#1); at the point of the raised rock projection (V#2); about 10 ft downstream from the launch (V#3); and about 200 ft farther downstream where an eddy was ending (V#4). Measurements were made only during high-flow conditions on August 2, 1994 (table 3). At a location about 200 ft downstream from the launch, an eddy created by the rock projection upstream from the launch, was ending and water was flowing towards the bank (fig. 6). The upstream direction of water flow upstream from this location is indicated in table 3 by a minus (-) sign in front of a velocity value and on figure 6 by an arrow pointing upstream.

Table 3. Velocity and depth data collected at the road type boat launch near river mile 12.3 along the Kenai River

	Measurement location and data (velocity in feet per second; depth in feet)							
Date	Velocity	Depth	Velocity	Depth	Velocity	Depth	Velocity	Depth
	Upstream (V#1) 6 feet from bank		At the structure (V#2) 6 feet from launch		Downstream (V#3) 6 feet from bank		Downstream (V#4) 6 feet from bank	
8-2-94	1.0	1.3	3.1	2.2	-1.2	2.2	0.2	1.4

This site was not visited during the June measurements because it had not been identified as a potential launch site. It was not visited for subsequent measurements because the rock pile upstream from the launch was controlling hydraulics at the site. The rocks were acting like a submerged jetty or channel constriction and water velocity was increasing at the upstream edge of the launch where the channel area was reduced. The slower water present downstream from the rocks will provide a protected boat launch site and juvenile salmon will have acceptable velocities in the area approaching the launch from downstream. However, the faster velocity at the rocks may interfere with free upstream passage of juvenile salmon and the flow directed towards the bank downstream from the launch site may initiate or accelerate bank erosion. An earlier investigation at Bing's Landing, a similar road-type boat launch near river mile 40, also found that an upstream jetty affected velocity measurements near the launch entrance (Tauriainen, 1986)

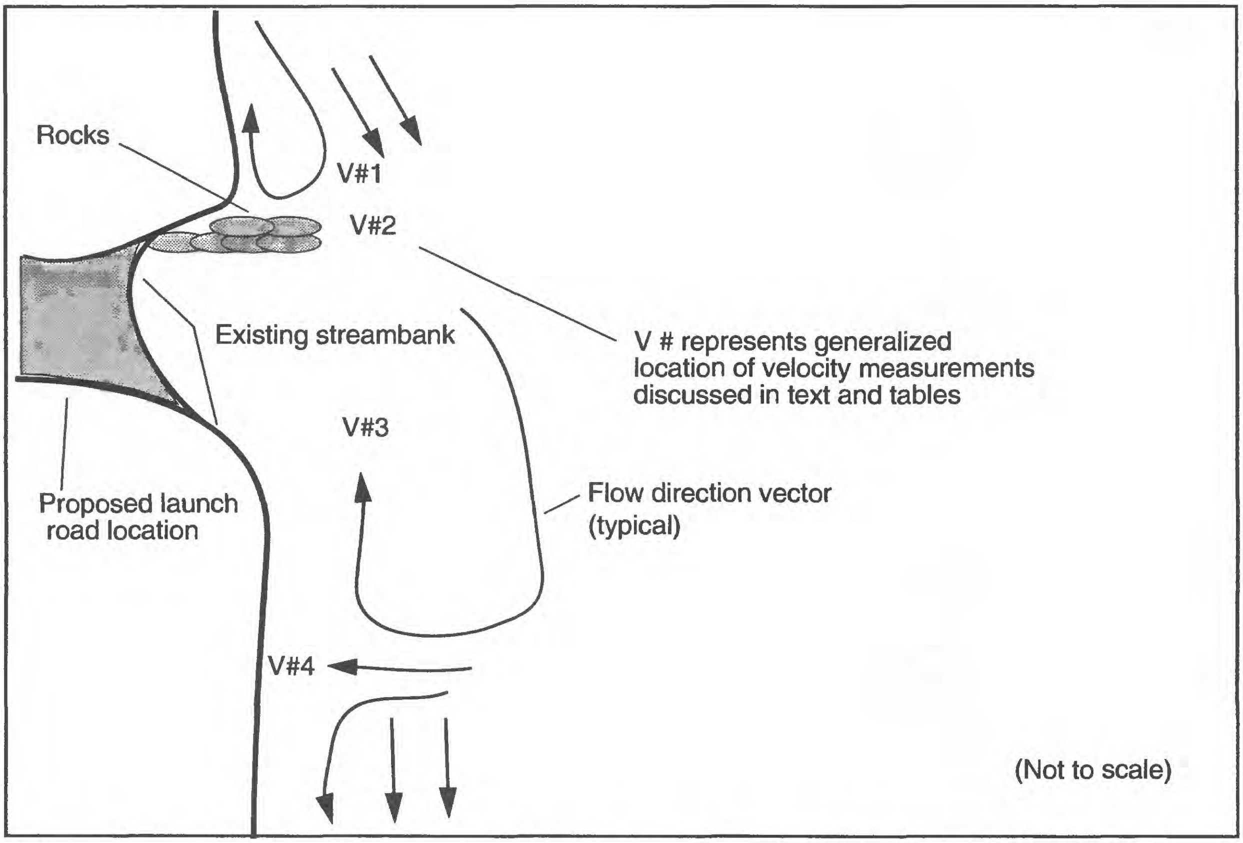


Figure 6. Schematic of road type boat launch near river mile 12.3 along the Kenai River.

The second launch style investigated was a harbor style with a canal entrance at the Kenai River Family Campground Boat Harbor at lat 60°30'32"N, long 151°07'55"W near river mile 16.0 (A, on fig. 7). The canal inlet, which was about 40 ft wide, allowed boats to be stored in calm water away from the river, while providing access to the river (fig. 8). The canal is on the inside of a large meander bend where water is naturally shallow and slow. The excavated inlet to the canal abruptly expanded the streambank and increased the water depth, likely slowing the water further.

Measuring points associated with this site (fig. 8) were about 10 ft upstream from the launch, where the bank was grass covered (V#1) and at the canal inlet where the channel expanded into the harbor (V#2). Measurements were made only during high-flow conditions on August 2, 1994. Although the water depth increased by 1.4 ft between sites upstream from and at the entrance of the canal, the velocity at these sites was nearly identical (table 4).

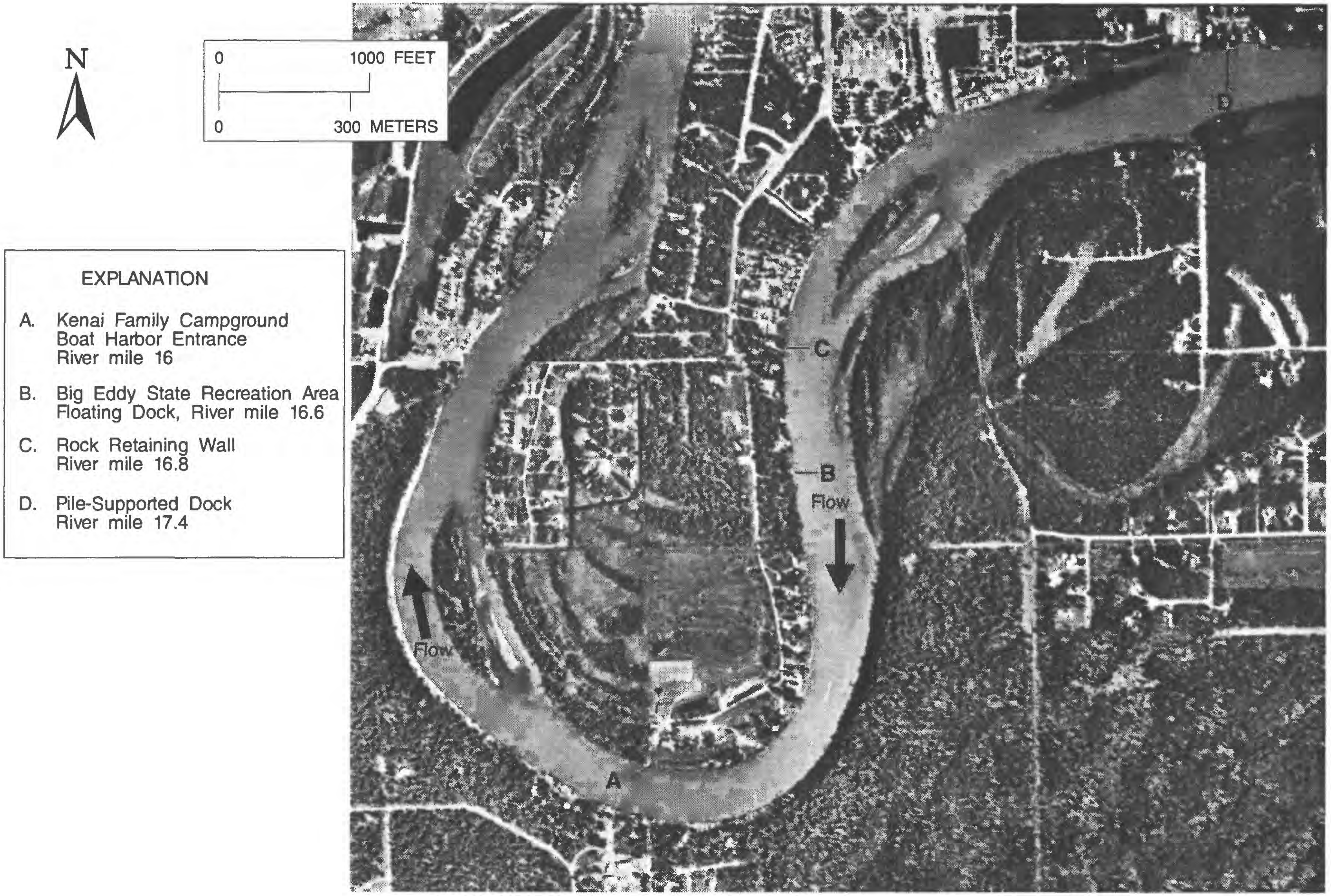


Figure 7. Location of selected streamside structures along the Kenai River. Modified from aerial photograph, dated July 2, 1992, provided by the Alaska Department of Fish and Game.

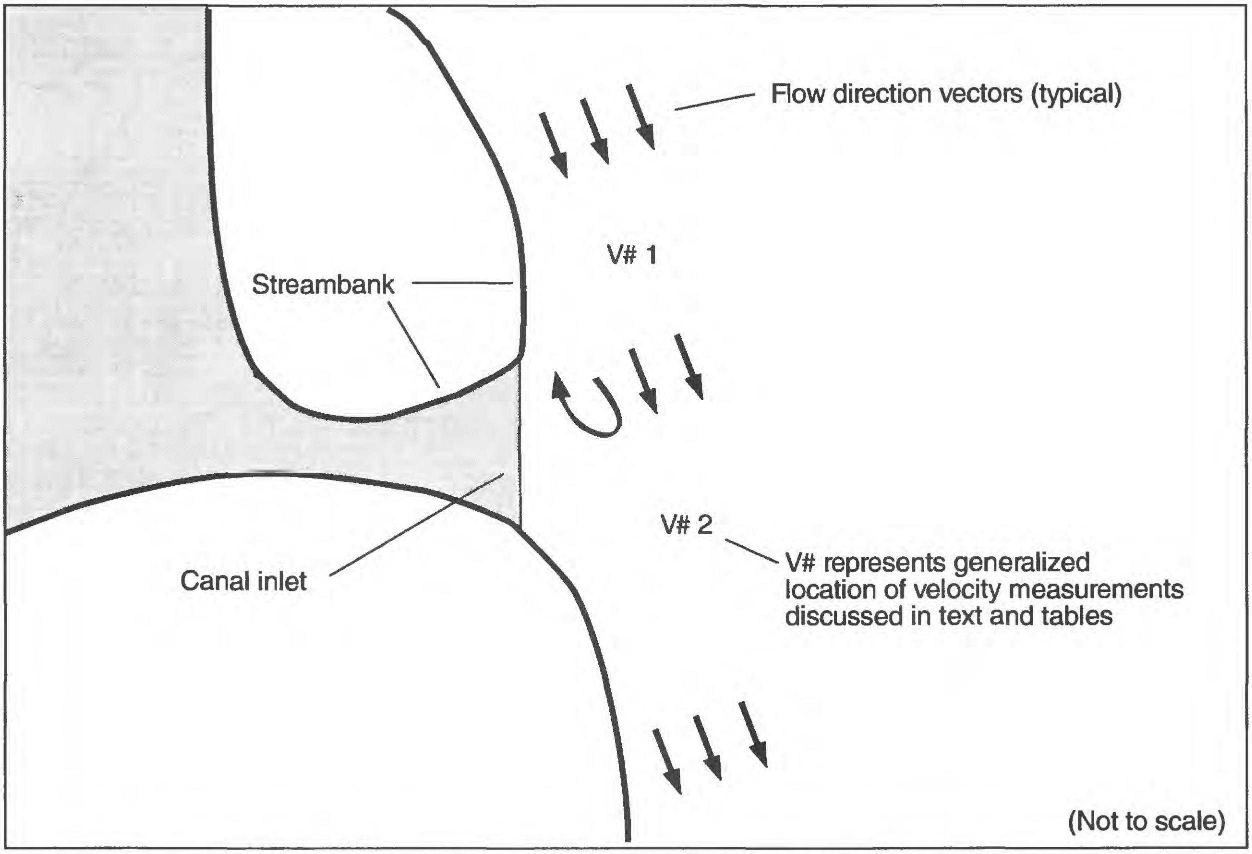


Figure 8. Schematic of canal type boat launch near river mile 16.0 along the Kenai River.

Table 4. Velocity and depth data collected at the canal type boat launch near river mile 16.0 along the Kenai River

Date	Measurement location and data (velocity in feet per second; depth in feet)			
	Velocity	Depth	Velocity	Depth
	Upstream (V#1) 6 feet from bank		At the structure (V#2) 6 feet from launch	
8-2-94	2.0	1.8	1.8	3.2

The flow appeared to be parallel to the streambank across the entrance except for a small area of swirling water just inside the mouth of the canal (fig. 8). The eddy in the inlet of this canal type boat launch is typical of that reported by Burger and others (1982) at other canal type launches on the Kenai River. Some bank erosion was evident above the water surface at the canal inlet. Although the hydraulic data do not identify the cause, this erosion is probably the result of a combination of factors. These include the eddy at the canal inlet, boats traveling into the canal or being parked at the canal inlet, and foot traffic of campground residents.This site was visited in March and in May, but no water had yet entered the canal inlet. Streamflow during these times was parallel to the bank at a distance of at least 100 ft from the dry canal.

The measured water velocities at the canal entrance during high-flow conditions in the river are slow enough to provide easy access for boats and acceptable habitat for juvenile chinook salmon. The site also likely provides adequate habitat velocities during decreased flow conditions until the canal goes dry. As it goes dry, fish must move towards the opposite bank with the decreasing channel width, which may be several hundred feet narrower in March than in August.

Floating Docks

Ninety-two floating docks have been identified along the Kenai River (Liepitz, 1994). These structures were anticipated to have little effect on the velocity or direction of the water. This is because their effect on the water surface typically extends only a small distance into the water column, even though they project into the flow from the streambank. This assumption was verified during investigations at a floating dock at the Big Eddy State Recreation Area, about 16.6 mi upstream from the mouth near lat 60°30'22"N., long 151°07'05"W. (B, on fig. 7).

The dock investigated is operated seasonally during open-water periods. It is a rectangular shaped, aluminum structure about 8 ft wide and 6 ft long. It is attached to a permanent aluminium stairway and walkway on the bank with a hinged joint so that it will easily travel up or down with changes in river height (figs. 9 and 10). The dock is supported by hollow floats that sink into the water column about 3 in. with the weight of three people standing on it. Because this site is a State operated recreational area and has a significant number of visitors, the banks along the river have been protected. For about 10 ft upstream from the dock, the shore is lined with rock riprap about 1 ft in diameter. For about 20 ft upstream from the riprap, the shoreline was reinforced with small-diameter spruce trees cabled together. These bank reinforcement measures increase bank hydraulic roughness near the dock and likely decrease ambient velocity. The dock is in place along a short relatively straight reach of the river between one meander bend upstream and a larger meander loop downstream (fig. 7). Because of this location, the channel thalweg is on the near side (right bank) of the channel upstream from the dock and is on the opposite (left bank) downstream from it. This thalweg movement reduces the flow volume along the bank adjacent to the dock and naturally reduces velocity at this site.

Measuring locations associated with this site (fig. 9) were about 20 ft upstream from the dock (V#1); at the dock (V#2); and about 10 ft downstream from the dock (V#3). During the measurements taken on June 9, 1994, the dock was not in the water. Measurements were made at the V#2 site where the dock would be installed, at points 3, 6 and 9 ft from the dock's attachment point. Velocity was nearly equal at all three points in June (table 5) and flow was essentially parallel to the streambank (fig. 9).

During high-flow conditions on August 2, 1994 measurements were made with the dock in place (table 5). The depth increased from 2.2 ft at V#1 to 3.8 ft at the dock's upstream edge (V#2). This increase likely results because the channel is deeper at the dock than upstream from it. Also, because the deeper channel provides a larger area of flow, the mean velocity is slower (table 5). The water velocity at the surface was also measured near the dock floats. Surface velocities were 0.5 ft/s along the upstream edge of the dock and 0.6 ft/s along the downstream edge. These surface velocities are similar and both are much less than the 2 ft/s mean velocity measured upstream. This significant difference in velocity indicated that the influence of the dock on water velocity may be greatest near the floats. However, most of the slowing of flow at this site likely results from changes in channel area, because the channel was 1.6 ft deeper at the dock than upstream from it.

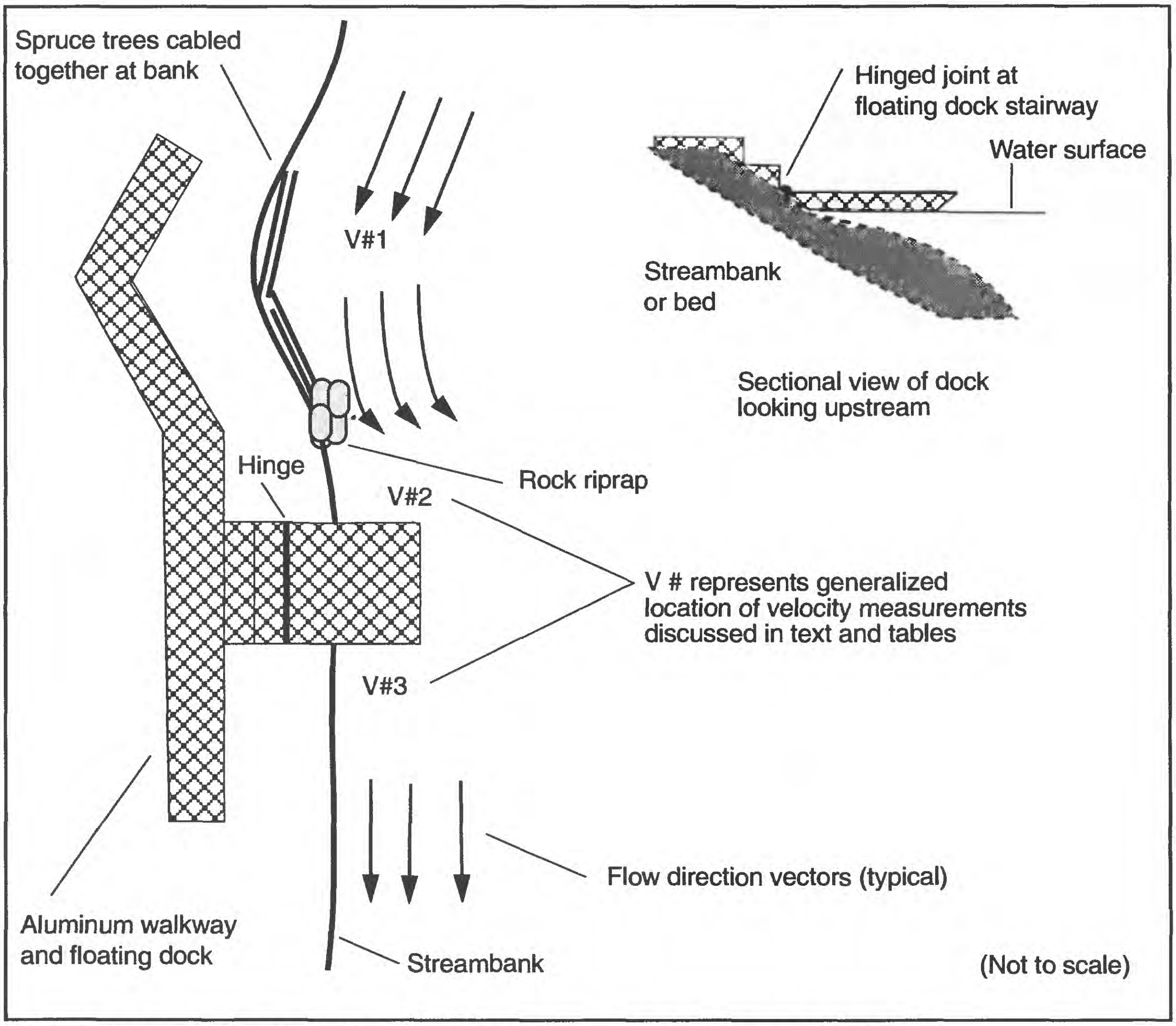


Figure 9. Schematic of floating dock at river mile 16.6 along the Kenai River.

With the exception of a narrow area around the dock floats, which were diverting surface flow around them, flow direction at the dock site was again generally parallel to the streambank. Any diversion of flow around the dock floats extended only a few inches into the main channel and returned to its natural parallel pattern within a few feet downstream.

Measurements on May 9, 1995 at this site were made with the dock out of the water (table 5). Flow velocity and depth were nearly equal at points upstream from, at, and downstream from the dock's attachment point during these measurements.

Because the dock requires a specific height of water to float it at its attachment point, it can not be deployed until the high-water period that usually occurs in mid- to late June. The dock must be removed again when the water height declines in the fall. Although it was only in the water during high flow, measurements at the floating dock indicate no velocities that were unacceptable to juvenile salmon. The velocities measured were within the range commonly utilized by rearing salmon and the direction of streamflow was not altered in a manner that would likely increase bank erosion.

Figure 10. Floating dock area near river mile 16.6 along Kenai River. Riprap placed near dock attachment is in the small boulder size range (10-40 inches). View is looking downstream from right bank on May 9, 1995.

Table 5. Velocity and depth data collected at the floating dock near river mile 16.6 along the Kenai River, Alaska

Date	Measurement location and data (velocity in feet per second; depth in feet)					
	Velocity	Depth	Velocity	Depth	Velocity	Depth
	At the structure (V#2) 3 feet from dock		At the structure (V#2) 6 feet from dock		At the structure (V#2) 9 feet from dock	
6-9-94 (dock out of water)	0.3	0.8	0.2	1.3	0.4	1.7
	Upstream (V#1) 6 feet from bank		At the structure (V#2) 6 feet from dock		Downstream (V#3) 6 feet from bank	
8-2-94	2.0	2.2	1.3	3.8	0.7	3.6
5-9-95 (dock out of water)	0.4	1.0	0.4	1.0	0.5	1.2

Rock Retaining Walls

Rock structures are the most numerous type of streamside structure along the river: 147 examples have been identified by the ADF&G (Liepitz, 1994). The effects on stream hydraulics from rock structures will vary in their construction and design. Among the most important variables are the size of rock used, the extent of any projection into the river, and whether the wall or riprap is vertical or sloped away from the river. Rock was also involved in the construction of many of the streamside structures that are generally classified as another type, and the effects are described in association with these structures. For example, at the road type boat launch, rocks were used to reinforce the upstream side of the road entrance to the river; rock riprap was also used to stabilize the shoreline areas upstream from the floating dock we investigated.

For this investigation, a near-vertical, irregularly protruding rock wall built of 2-to 3-foot diameter boulders was selected for evaluation (fig. 11). It is located on the right bank near river mile 16.8 (C, on fig. 7) at lat 60°30'26"N and long 151°06'49"W.The wall was built to protect the streambank near a boat launch from erosion. The wall is about 40 ft long and has sections that project from 3 to 6 ft into the channel The wall is near the downstream end and on the outside of a meander bend (fig. 7), an area of this reach that experiences naturally higher velocity.

Figure 11. Rock retaining wall near river mile 16.8 along the Kenai River. Large boulders are 2 to 3 feet in diameter. The natural bed material at base of wall is in the cobble size range

Measuring locations associated with this site (fig. 12) were about 30 ft upstream from the wall, where the streambank was covered by grass and trees (V#1); along the wall about 20 ft upstream from the boat launch road (V#2); and about10 ft downstream from the wall (V#3). Point V#2 was located downstream from one of the irregular projections of the wall.

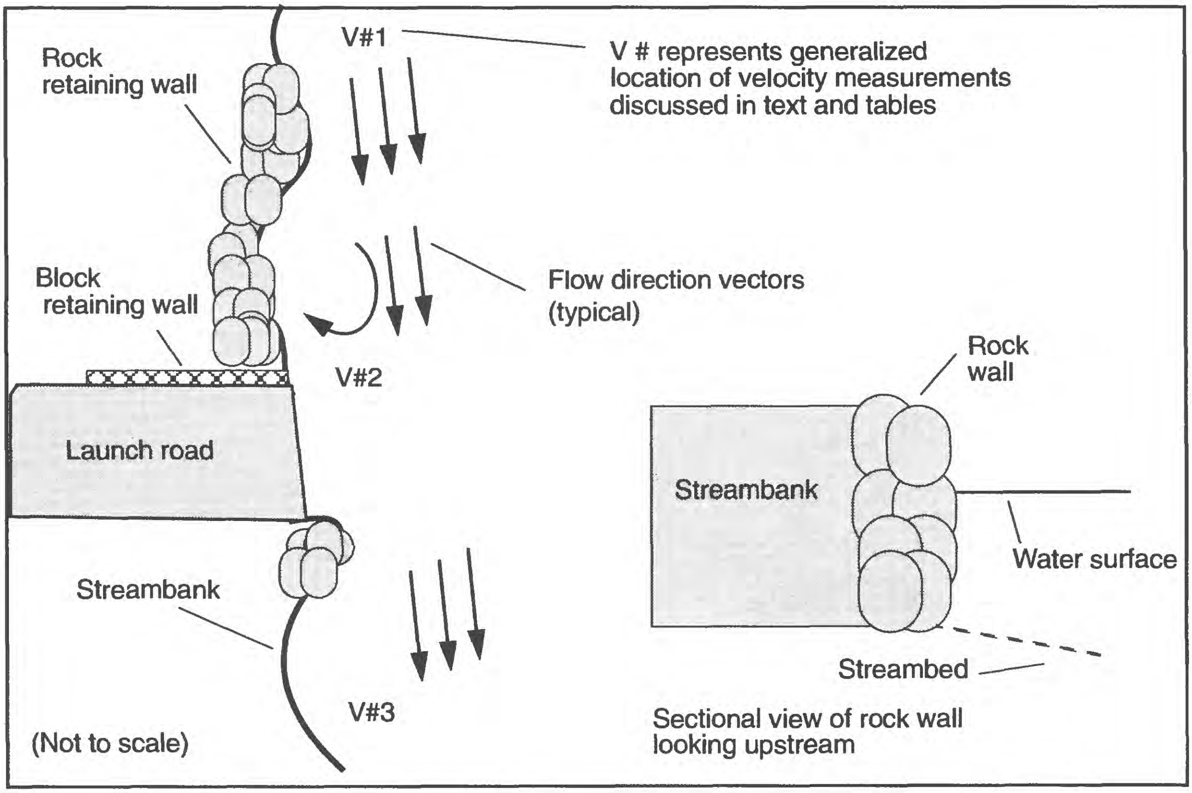


Figure 12. Schematic of rock retaining wall near river mile 16.8 along the Kenai River.

Measurements made during medium-flow conditions on June 9, 1994 were made at locations V#1 and V#2, at points 3, 6, and 9 ft from the bank (table 6). While the velocity at V#1 varied little with distance from the bank, the velocity at V#2 was much slower at a point 3 ft from the bank than at one 9 ft from it. Flow atV#2 was also much slower than that at V#1. The projecting rocks just upstream from V#2 diverted flow away from the wall and created a local decrease of velocity at V#2.

During high-flow conditions on August 2, 1994, measurements were made again at V#1 and V#2, but only at points 6 ft from the bank. The observation depths were about 2 ft deeper than those measured in June, and velocity readings were more than doubled. The rock projection upstream from V#2 was still slowing the velocity at V#2 to almost half of that measured at V#1.

During the low-flow period on May 9, 1995, the river stage had dropped sufficiently so that the rock wall was out of water, about 6 ft from the water's edge. A large gravel bar 200 ft upstream from the wall was diverting flow to the opposite shore, creating a slack flow zone near V#2.

Table 6. Velocity and depth data collected at the rock retaining wall near river mile 16.8 along the Kenai River

Date	Measurement location and data (velocity in feet per second; depth in feet; ND, no data)					
	Velocity	Depth	Velocity	Depth	Velocity	Depth
	Upstream (V#1) 3 feet from bank		Upstream (V#1) 6 feet from bank		Upstream (V#1) 9 feet from bank	
6-9-94	0.8	0.5	1.1	1.0	1.0	1.2
	At the structure (V#2) 3 feet from wall		At the structure (V#2) 6 feet from wall		At the structure (V#2) 9 feet from wall	
6-9-94	0.2	0.5	0.6	0.8	1.1	1.2
	Upstream (V#1) 6 feet from bank		At the structure (V#2) 6 feet from wall		Downstream (V#3) 6 feet from bank	
8-2-94	2.7	2.6	1.5	2.8	ND	ND
5-9-95	ND	ND	0.0	0.7	0.5	0.8

Because the rock wall somewhat constricted the natural channel, it could be expected to have increased, rather than decreased the flow velocity in its vicinity. The irregular protrusions of this rock wall created small channel expansion zones just downstream and measuring point V#2 was in one of them. With the exception of the V#1 measurement during high-flow conditions, velocity measurements at this site were within acceptable limits for juvenile salmon.

Pile-Supported Docks

There are 63 pile-supported docks along the Kenai River (Liepitz, 1994). These structures vary greatly in their construction and should vary predictably in their influence on streamflow. Unless the dock is overtopped by water, the size, shape, and length of the supporting piles will be the primary influence of the structure on stream hydraulics. Many of the hydraulic effects of piles will act according to well-documented models of drag on immersed bodies (Streeter and Wylie, 1985). Most pile-supported docks along the Kenai River are small in size and the piles supporting them are also small. The small pile size relative to the wetted perimeter of the stream channel will not produce significant effects on stream hydraulics. Typically, the effects will be restricted to a small area in any direction around the pile, depending on its shape, length, and orientation in the flow (Streeter and Wylie, 1985).

For this study, a pile-supported dock supported by 3-inch-wide angle-iron legs was investigated. This dock was located in the lower river downstream from the Sterling Highway Bridge near river mile 17.4 (D, on fig. 7). This site is near Poacher's Cove at lat 60°29'53"N., long 151°06'16"W. It is on the right bank of the river along a 1-mile-long straight reach centered between two meander bends. This river reach is upstream from the lower anabranched reach of the river; however, a small island is about 250 ft downstream from the dock (fig. 7). Upstream from the dock is a bank inset and a large vertical wood retaining wall (fig. 13). The dock is nearly surrounded by rock riprap (fig. 13). The hydraulic influence of the dock was investigated by measuring velocity, depth, and flow direction at several points: about 10 ft upstream from the pile supports(V#1); close to the piles both upstream (V#2) and downstream and (V#3); and finally downstream about 10 ft beyond the piles (V#4) (fig. 13).

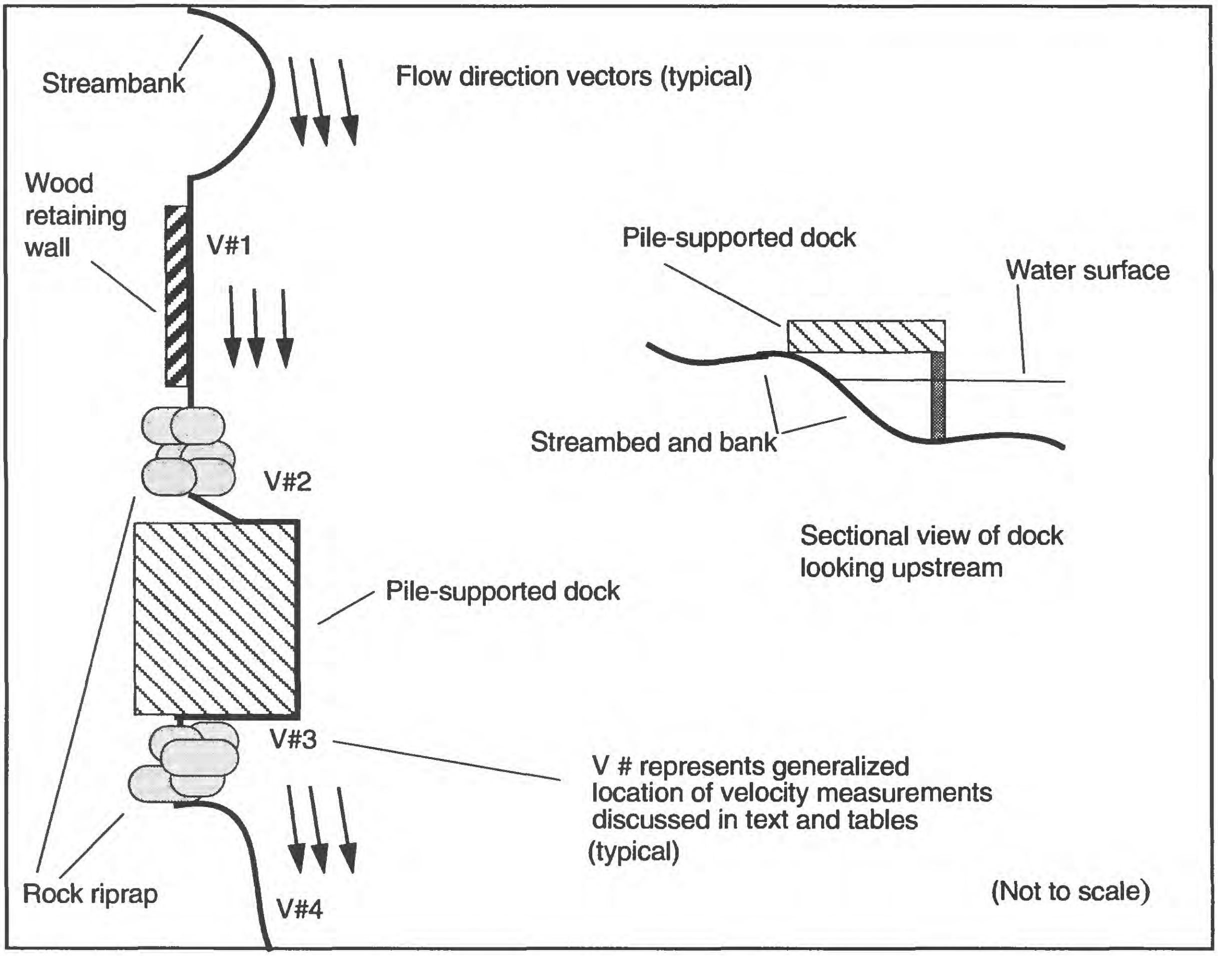


Figure 13. Schematic of pile-supported dock near river mile 17.4 along the Kenai River.

At this small angle-iron supported dock, the velocity measured on August 3, 1994, was 0.4 ft/s upstream and it reduced to 0.1 ft/s near the piles (table 7). This velocity difference is not significant and probably reflects the influence of coarse riprap protecting the dock rather than the small angle-iron supports. Although the velocity measured upstream approaching the piles was somewhat faster than that measured at the piles, no difference in mean velocity was detected by measurements made as close as physically possible to the upstream and downstream edges of the dock piles, where velocities were 0.1 ft/s. Faster velocities measured downstream from the dock (table 7) may be attributable to distance from the effects of the riprap or the bank indentation, and not to the dock piles.

Table 7. Velocity and depth data collected at the pile-supported dock near river mile 17.4 along the Kenai River

Date	Measurement location and data (velocity in feet per second; depth in feet)							
	Velocity	Depth	Velocity	Depth	Velocity	Depth	Velocity	Depth
	Upstream (V#1) 6 feet from bank		At the structure (V#2) 6 feet from dock		Downstream (V#3) 6 feet from bank		Downstream (V#4) 6 feet from bank	
8-3-94	0.4	2.0	0.1	1.8	1.7	1.2	2.3	2.2

The slower velocity measured upstream from this site may also be influenced by the inset or dug-out bank that has been reinforced with a wood wall (fig. 13). This inset bank provided a place for the river to expand and the water to slow down prior to reaching the dock. The bank expansion at the inset upstream from the dock and the bank constriction at the rocks downstream from the dock contributed to the increase in velocity in a downstream direction. The bank inset also created eddies evident in the water surface, which indicated an angle to the flow that was not clearly attributable to the dock piles.

The site may have been unfavorably suited for an investigation of a pile-supported dock because of the numerous other influences on ambient hydraulics. It was selected for its easy roadside access and its location in a developed section along the river between river mile 17 and 40, where most of the pile-supported docks are found. Observations in August indicated that the pile-supported dock site was complex hydraulically and separation of the effects of the piles themselves was difficult. The pile-supported dock had no detectable effect on velocity and no significant diversion of flow near the piles during high-flow conditions in August. Although the site was not revisited—because the pile supports will be in less water—this structure likely also has no significant effect during lower discharges. With the exception of the velocity downstream from the dock where a rock projection was accelerating flow, all measured velocities at the pile-supported dock are less than the sustained swimming ability of juvenile salmon.

Jetties

A jetty can be defined as a solid, impermeable, landmass that projects from the streambank into the water to deflect the current. Such structures typically have been constructed along the ocean for the prevention of coastline beach erosion. In the Kenai River, jetties were constructed into the river to divert flow away from an eroding bank and to provide calm water to launch or store boats. These structures also provide an artificial fishing area for red salmon, which often rest in the slower water resulting downstream (Lance Trasky, habitat biologist, ADF&G, oral commun., 1995). The size, shape, and construction of the jetties are highly variable. Although some use concrete, they are generally made of natural material, such as large rocks dredged from the river or hauled to the site in combination with sand and gravel. Many jetties are left as piles of natural material, whereas others have been developed into grassed areas or permanent recreational sites.

These structures are commonly substantial enough to withstand high flows in the river. Their effects on stream hydraulics vary with the length and orientation of their projection into the river and the size and type of material used in their construction. As with any natural or man-made constriction of the river channel, water velocity is accelerated near the point of constriction and flow is diverted away from the constriction. For the jetties along the Kenai River, this means that the fastest velocities are near the point of the jetty where the jetty intersects the water, and water flow is diverted towards the opposite bank. Of all the structures investigated, the jetty demonstrated the greatest influence on flow velocity and direction.

Eighty jetties were identified by ADF&G along the Kenai River (Liepitz, 1994). Thirteen of these, ranging in length from 15 to 75 ft, are along the inside edge of a large meander bend between river miles 37 and 38 (Scott, 1982) (fig. 14). These jetties are about 2 mi downstream from the upper anabranched reach of the river where numerous islands are slowing and diverting water around them. However, between these islands and the jetties is Naptowne Rapids, where the Kenai River is perhaps its fastest and steepest. Below these rapids, the river enters a series of long meanders where the river thalweg likely shifts between banks following the outside of the meanders. Near river mile 37.9, along the inside of the second meander about 1.5 mi downstream from Naptowne Rapids, a rock jetty (fig. 14) about 50 ft long was investigated for its influence on stream hydraulics. This jetty, at approximate lat 60°31'10"N., long 150°44'01"W., was selected because it is one of the larger jetties on the river. It also had easy roadside access and the downstream residents were experiencing some streambank loss, which they attributed to the jetty.

The base or toe of this jetty is made of large 1-to-3-foot-diameter rocks (fig. 15). It is further reinforced with a poured concrete foundation in the center, which supports a large, approximately 20-foot-diameter screened gazebo and an extensive wooden deck (fig. 16). This wooden gazebo/deck combination rests on the rock jetty. Its floor was about 7 ft above the water surface on June 9, 1994. This jetty has been in place since sometime prior to 1972 (Scott, 1982). However, no indication of the date when the gazebo was constructed or when concrete reinforcement of the jetty was completed is available. In addition to supporting the gazebo, the jetty provides protection for a boat launch which enters the river at the jetty's downstream edge (fig. 16). Upstream from the jetty, the streambank is reinforced by a wood retaining wall approximately 30 ft long and more than 8 ft high. Having experienced some bank loss, the downstream landowner has also reinforced the bank utilizing natural vegetation along the upper bank and cabled spruce trees below the ordinary high water line (fig. 16).

Measuring points associated with this site (fig. 16) were about 20 ft upstream from the jetty along the wood retaining wall (V#1); near the point of the jetty (V#2); and downstream from the jetty about 20 ft along the cabled trees on the streambank of the downstream landowner (V#3).

Measurements during medium-flow conditions on June 9, 1994 were made at locations 3, 6, and 9 ft from the point of the jetty (table 8). Flow velocity was increasing from the measuring point 3 ft from the jetty to a point 6 ft from the jetty point and decreased at a point 9 ft from the jetty point. Surface flow was diverted around the jetty and, although velocity measurements were not taken, eddy currents flowing upstream were observed both downstream and upstream from the jetty.

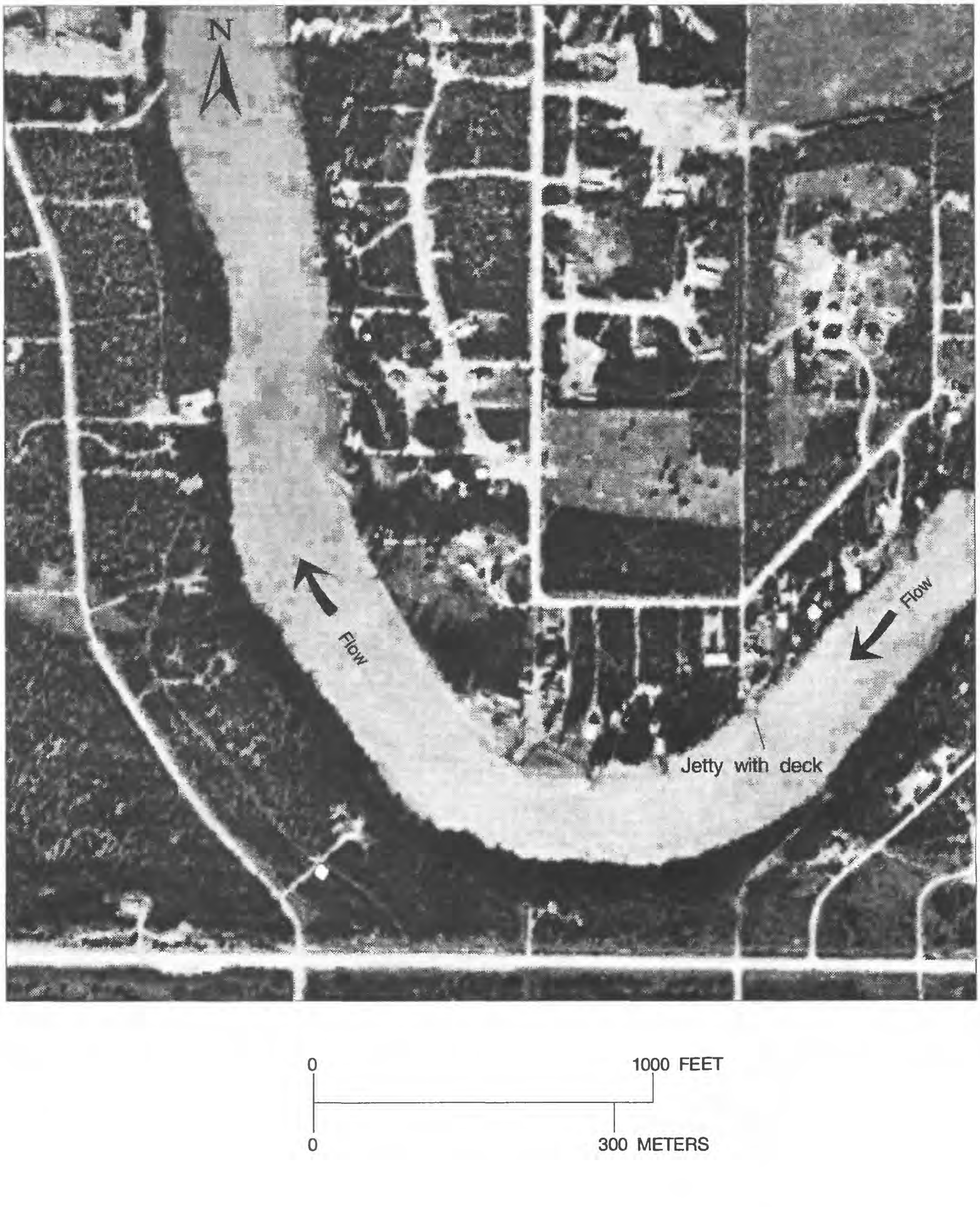


Figure 14. Location of jetty with deck near river mile 37.9 along the Kenai River. Area shown extends from approximately river mile 38.2 downstream to 37.0. Modified from aerial photograph, dated July 2, 1992, provided by Alaska Department of Fish and Game.

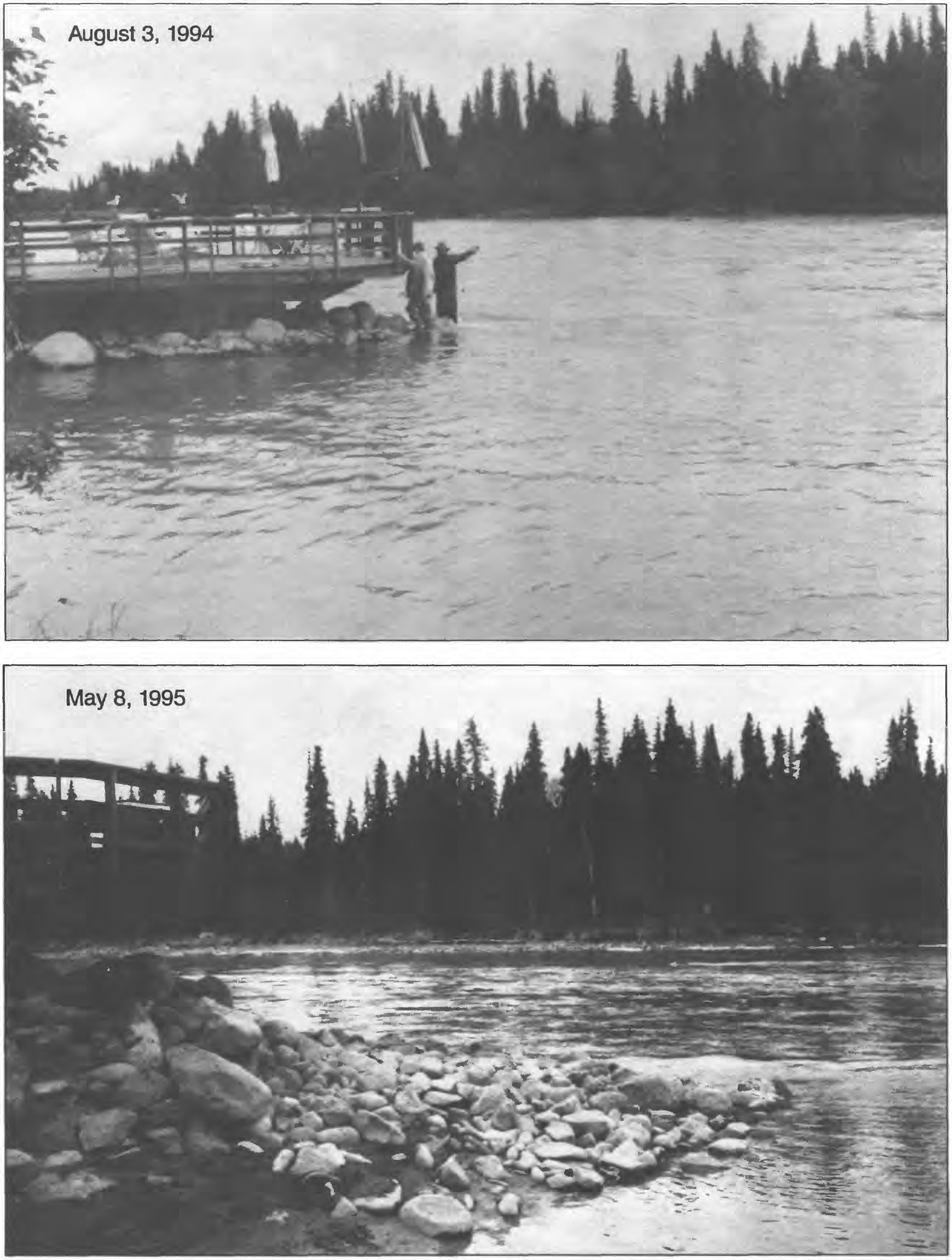


Figure 15. Jetty with deck near river mile 37.9 along the Kenai River. View is looking upstream from right bank.

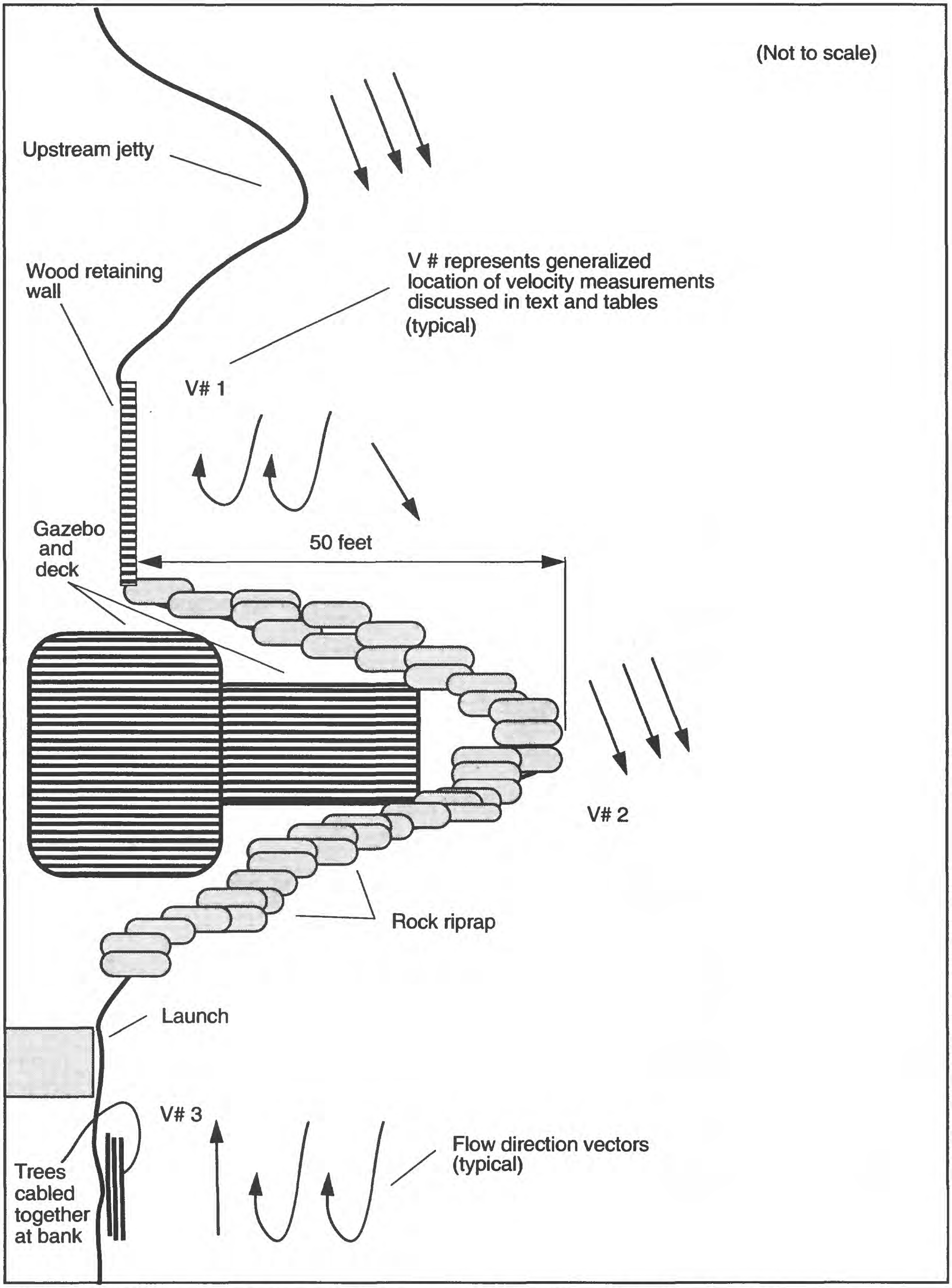


Figure 16. Schematic of jetty with deck near river mile 37.9 along the Kenai River.

Table 8. Velocity and depth data collected at the jetty with the deck near river mile 37.9 along the Kenai River, Alaska

Date	Measurement location and data (velocity in feet per second; depth in feet; ND, no data; minus sign (-) indicates upstream flow velocity)					
	Velocity	Depth	Velocity	Depth	Velocity	Depth
	At the structure (V#2) 3 feet from jetty		At the structure (V#2) 6 feet from jetty		At the structure (V#2) 9 feet from jetty	
6-9-94	1.5	1.2	3.6	1.6	2.9	2.3
	Upstream (V#1) 6 feet from bank		At the structure (V#2) 6 feet from jetty		Downstream (V#3) 6 feet from bank	
8-2-94	-1.1	5.0	4.7	1.9	-0.5	3.6
5-8-95	0.1	1.6	2.0	2.3	0.1	1.0

On August 2, 1994, hydraulic characteristics at this structure were measured again (fig. 16; table 8). During these high-flow conditions the water upstream from the jetty at V#1 was flowing in an upstream direction and the velocity was designated as a negative value. The velocity was accelerated around the jetty point and was flowing in an upstream direction downstream from the jetty (fig. 16; table 8). Water was much higher on the jetty during high flows: the water depth at V#2, a point 6 ft from where the jetty intersects the water, was 0.3 ft deeper than it was when measured in June. The projection of the jetty into the water during these high-flow conditions resulted in large eddies both downstream and upstream from the jetty. The eddies circulated downstream for a distance up to 10 times farther than the projection of the jetty into the river and upstream for a distance of 4 or 5 times the projection length of the jetty. Although not measured, the diversion of water into the channel from the point of the jetty was observed for a distance of at least one jetty projection length past the point.

During low-flow conditions on May 8, 1995, velocities upstream at V#1 and downstream from the jetty at V#3 were nearly zero. At the point of the jetty at V#2, the velocity was accelerated. The eddies observed during medium and high flow were not clearly visible during low-flow conditions. In addition, velocity measured during low-flow conditions did not have any negative values (table 8).

The recurring phenomenon of changing flow direction and large eddy generation at this site results in water velocities directed towards the bank at two inflection points, downstream and upstream from the jetty. Additional investigations would be required to quantify the effects on velocity and flow direction across the channel from this or other jetties.The difference in jetty exposure during varying flow conditions (fig. 15) indicates the significant difference this structure can have on riverine hydraulics. For example, the point where the jetty intersects the water surface moves toward the right bank as flow increases. This allows the depth at V#2—which was measured 6 ft into the flow from this jetty point—to increase with decreasing flow from August to May. The increase in depth occurs primarily because the measuring point was significantly farther into the main channel of the Kenai River during low-flow conditions. Velocities measured on June 9 and August 2 at the point of the jetty were greater than the sustained swimming ability of juvenile salmon, whereas velocities measured elsewhere in the vicinity of the jetty are more favorable.

Concrete Retaining Walls

Concrete retaining walls are the least common structure along the Kenai River for many reasons: they are difficult and expensive to build, they may be considered unsightly, they may be difficult to fit into natural settings, and they may not be effective. Only 20 have been identified along the river by the ADF&G (Liepitz, 1994). These structures, if constructed for bank stabilization, generally do not project into the river. If they do not project into the river, they will likely not have significant effects on the flow direction. Because they are made of concrete and provide a smoother-than-natural flow roughness at the streambank, this type of structure is anticipated to increase velocity.

The concrete retaining wall that was selected for investigation was in the upper river, at river mile 42 near a place known as the Kenai Keys (fig. 17). The wall, at approximate lat 60°29'19"N., long 150°37'12"W., was made of 8-inch concrete blocks. The wall is 7.5 ft tall and 36 ft long (fig. 18). It was installed along the right bank of the river just upstream from the beginning of a large meander bend and downstream from a large island in the upper anabranched reach of the river (fig. 17). The position of the wall along the outer edge of the meander bend and downstream from the island places the wall in some upstream-flowing eddy currents denoted by vectors on figure 19 and by negative velocities in table 9.

Measurement locations associated with this site (fig. 19) were adjacent to the wall near the middle of the wall (V#1); 6 ft streamward from the wall near the middle of the wall (V#2); 10 ft downstream from the wall and 6 ft streamward from a grass-covered bank (V#3).

On August 3, 1994, hydraulic characteristics at this site were complicated by ambient conditions and the velocities near the wall did not reflect the hydraulic roughness alterations predictably (fig. 19; table 9). The currents along the wall were flowing upstream and velocities were all negative (table 9). The hydraulic conditions observed at this location—upstream flow direction and velocity decrease—do not reflect the expected effects of a concrete retaining wall.

Table 9. Velocity and depth data collected at the concrete retaining wall near river mile 42 along the Kenai River

	Measurement location and data (velocity in feet per second; depth in feet; minus sign (-) indicates upstream flow)					
Date	Velocity	Depth	Velocity	Depth	Velocity	Depth
	At the structure (V#1) Adjacent to wall		At the structure (V#1) 6 feet from wall		Downstream (V#2) 6 feet from bank	
8-3-94	-0.3	1.1	-2.0	2.3	-1.5	2.2

On May 8, 1995, this wall was dry and was more than 25 ft from the edge of the water (fig. 18), so no measurements were made. At low-flow conditions a pattern of large circular eddies was present in the main channel flow.

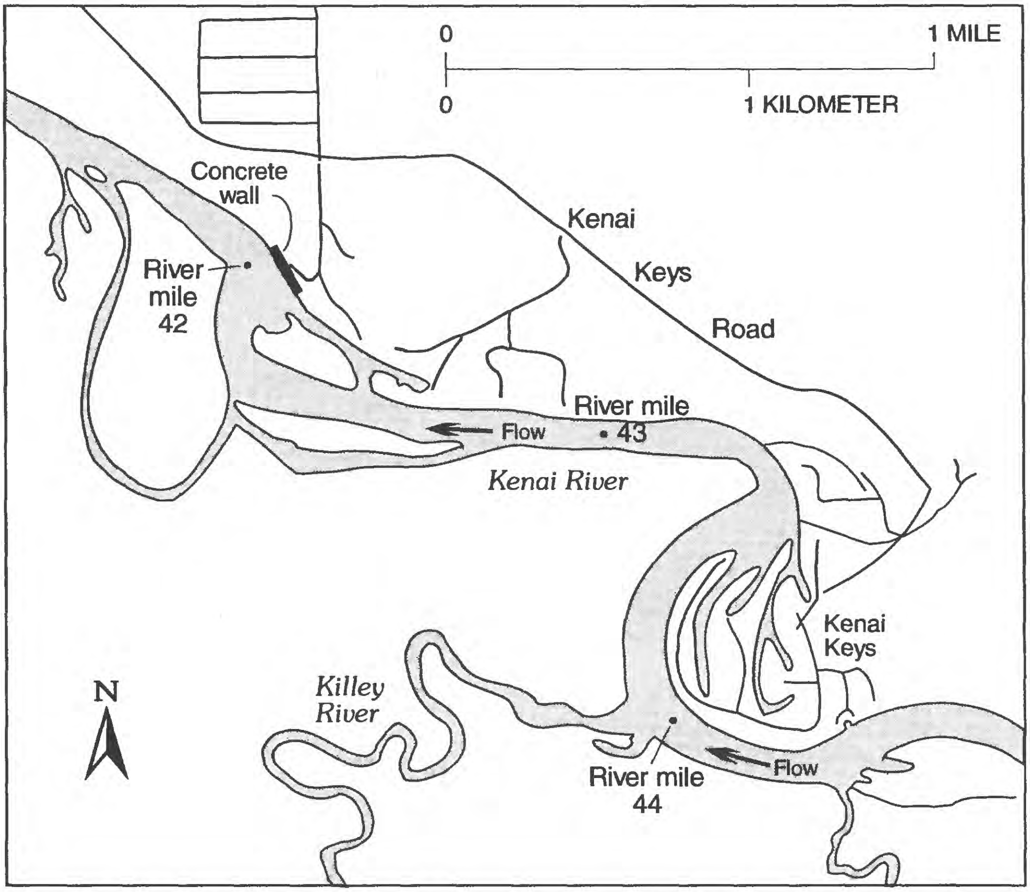


Figure 17. Location of concrete block retaining wall along the Kenai River. See figure 2 for location.

Figure 18. Concrete block retaining wall near river mile 42 along the Kenai River. View is looking downstream on right bank May 8, 1995.

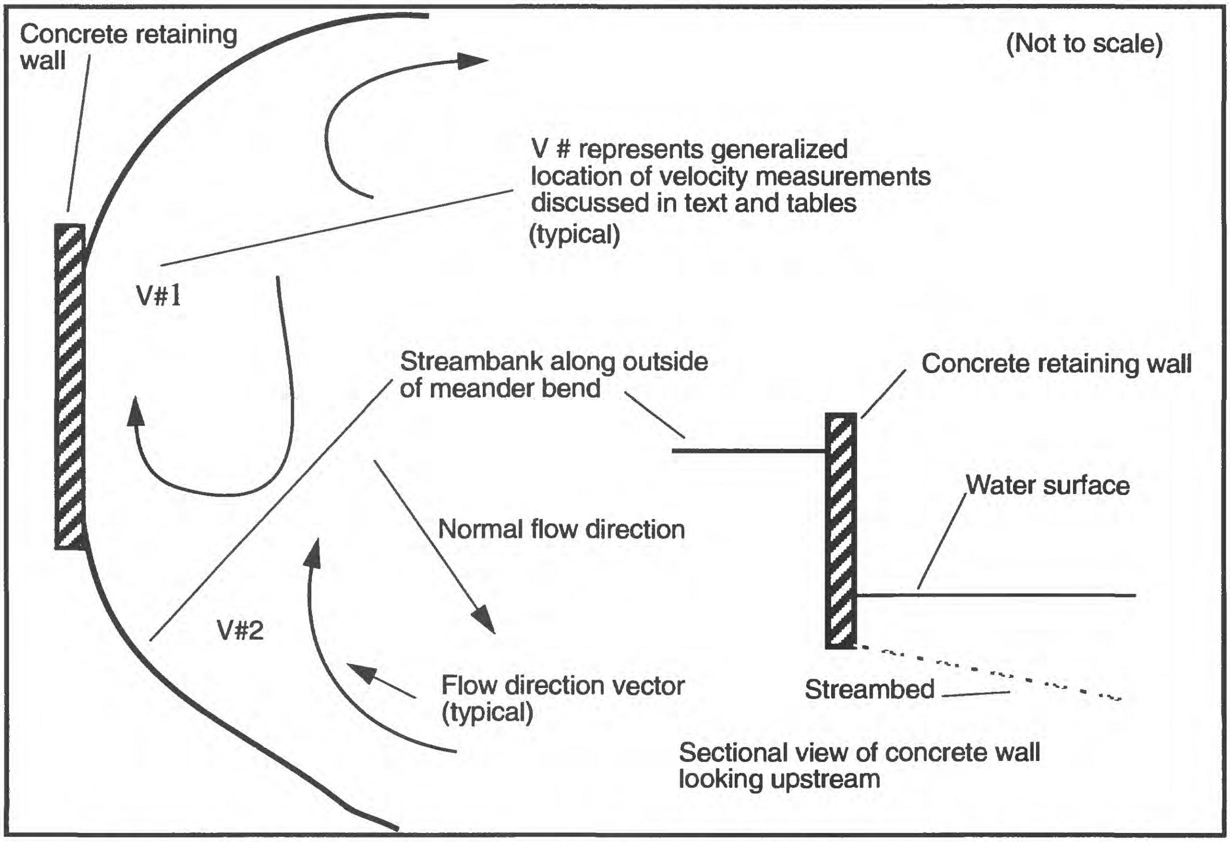


Figure 19. Schematic of concrete retaining wall near river mile 42 along the Kenai RIver.

Because concrete is about 10 times smoother or less rough than a natural stream channel and because this concrete wall did not project into the flow, it is unlikely that the presence of this wall affected the velocity or flow direction as significantly as the measurements indicated. Although not verified with data in this report, observations made at other concrete walls along the Kenai River more closely follow the expected hydraulic conditions: increasing velocities and not significantly affecting flow direction (G.S. Liepitz, habitat biologist, ADF&G, written comun., 1995).

Soldotna Creek Bio-engineering Project

The Soldotna Creek Bio-engineering Project is a pilot project near river mile 21.9, about 0.9 mi upstream from the Sterling Highway Bridge (fig. 2). This project utilizes a variety of natural living and non-living plant materials and unique installation techniques to help stabilize a 650-foot reach of the right bank of the Kenai River downstream from the mouth of Soldotna Creek (fig. 20). The biologically engineered bank stabilization techniques utilized at this site were designed to restore natural bank characteristics and protect the bank from future erosion caused by water action and foot traffic, while providing productive habitat for juvenile chinook salmon. Several different techniques using indigenous Alaskan willows and grasses in combination with boulders, root wads, and special walkways, are in place in a heavily used park area (fig. 20). With the exception of the root wads, boulders, and a downstream section of the vegetation, much of the bank stabilization and the walkway were installed at an elevation commonly higher than the ordinary water surface, and therefore have little influence on the flow velocity or direction of the river (fig. 21).

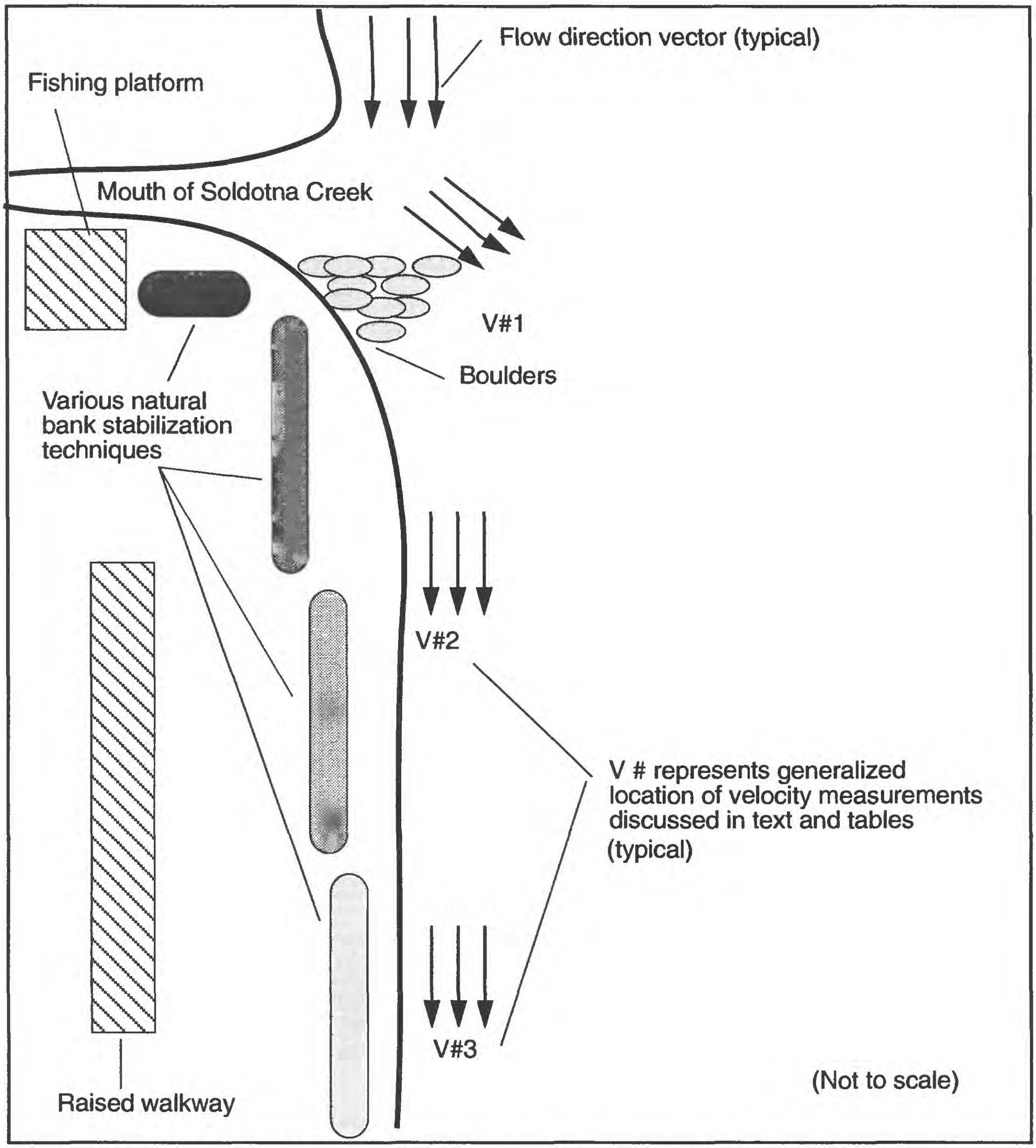


Figure 20. Schematic of the Soldotna Creek Bio-engineering Project near river mile 21.9 along the Kenai River.

The river reach in this area is generally straight and flow is essentially parallel to the bank. An exception to this is near the mouth of Soldotna Creek at the upstream end of the bank stabilization project. At this point, the near-shore river flow is diverted towards the middle of the channel by an alluvial fan of large boulders (fig. 20). This diversion creates a still- or slow-water area downstream from Soldotna Creek that extends nearly the entire distance of the project. Another contribution to velocity reduction comes from the numerous boulders and root wads installed near the shore along the length of the project.

Figure 21. Soldotna Creek Bio-Engineering Project near river mile 21.9 along the Kenai River. View is looking downstream on right bank May 9, 1995.

Measurements of hydraulic characteristics at this site (table 10) were made at locations downstream from the mouth of Soldotna Creek and upstream from the project (V#1); near the center of the project (V#2); and downstream from the project (V#3) (fig. 20).

During medium-flow conditions on June 9, 1994, velocity was slowing all along the project. The fastest velocity was measured at the upstream site and the slowest was at the downstream site. Surface flow at this site was generally parallel to the bank along the project with the exception of an area about 20 ft long just downstream from the mouth of Soldotna Creek, where water was directed away from the bank by the boulders (fig. 20).

On August 2, 1994, during high-flow conditions, the pattern of slowing water along the project was still prevalent and surface flow patterns were similar to those observed during medium-flow conditions.

Table 10. Velocity and depth data collected at the Soldotna Creek Bio-engineering Project near river mile 21.9 along the Kenai River

Date	Measurement location and data (velocity in feet per second; depth in feet)					
	Velocity	Depth	Velocity	Depth	Velocity	Depth
	Upstream (V#1) 6 feet from bank		At the structure (V#2) 6 feet from project		Downstream (V#3) 6 feet from bank	
6-9-94	1.8	0.7	0.5	0.7	0.4	0.7
8-2-94	2.0	1.5	0.8	2.0	0.2	1.5
5-8-95	3.9	2.5	0.1	0.9	1.2	0.9

During low-flow conditions on May 8, 1995, the velocity was the slowest near the root wads and boulders along the project, and it was faster at either end of the project. Surface flow was diverted less around the boulders near Soldotna Creek during low flow than during higher flows. The project site was also visited in March and April, but was ice covered or dry.

Except for the single velocity measurement at V#1 during low flow, all velocities are less than the sustained swimming abilities of juvenile salmon. The slow water and protective cover adjacent to the boulders, root wads, and willows of this project provide some potentially productive habitat for juvenile chinook salmon. However, it is unlikely that the measured decrease in velocity can be attributed to any one component of this project. The greatest velocity influence at this site probably results from the diversion of water away from the near-shore areas by the alluvial fan at the mouth of Soldotna Creek.

DISCUSSION OF STUDY RESULTS

The investigation of velocity magnitudes and flow patterns at the study sites selected by ADF&G yielded information from which some general conclusions can be drawn about the local hydraulic effects of streamside structures. Observations confirm that, from a hydraulic perspective, streamside structures can influence local velocity fields either by modifying channel area, by modifying channel roughness, or by a combination of both. Of the two types of modifications, structures that change river cross-section area were found to have the greater potential to disturb natural velocity patterns, but the extent of the effects of either modification often depends on complex relationships between the structure and the local hydraulic setting.

For example, the rock retaining wall site presented a condition that generally decreased the cross-section area of the river. Ordinarily, a decrease of cross-section area translates to an increase in average velocity. No measurements were made to determine if the average velocity did indeed increase, but the relatively minor reduction of cross-section area probably had little effect. More importantly for this study, however, the irregularly projecting sections of the rock wall created localized disturbances that actually resulted in slower velocity, at least at the point where the measurements were made.

Conversely, in the case of the jetty, the relatively large modification of the near-bank channel geometry resulted in both significant and expected effects: slower velocity and eddies on the upstream side, rapidly accelerated velocity at the constriction, and a slowing of velocity and generation of eddies in the expansion downstream. Likewise, one of the boat launch sites (the canal site) also exhibited the expected effects of the modification. The abrupt expansion of cross-section area caused a slowing of the current and eddies in the immediate vicinity of the launch.

Many streamside structures along the Kenai River contain multiple elements. For example, in this study, The Pillars boat launch site contained a small rock jetty. At both the floating dock and the pile-supported dock, the streambank was lined with rock and (or) log retaining walls. Sometimes, as in the case of these examples, the "secondary" elements of the structure are the ones that have the greater effect on local velocity patterns. When evaluating any of the structures (especially the "channel roughness"-type modifications like docks and some retaining walls), it is important to also evaluate the more influential "cross-sectional area" modifications that may also be in the design.

In many other cases, the effects of streamside structures are simply not detectable in the context of ambient hydraulic conditions. For example, velocity patterns in the vicinity of the floating dock, the pile-supported dock, and the concrete retaining wall were completely dominated by the local channel and reach geometry. Other than creating minor disturbances a few inches or feet away, these structures produced no discernible effect on the near-bank flow patterns. Likewise, the Soldotna Creek Bio-engineering Project, a bank restored to "natural" conditions, showed velocity patterns consistent with those expected near the confluence with a tributary stream.

Some general conclusions can also be drawn about the relative effects of structures with respect to flow conditions. During the low-flow season, the nature and setting of many structures leaves them completely out of contact with the river, where they obviously would have no effect on near-bank hydraulic conditions. Other structures appear to have an increasing effect on the velocity as flow in the river rises. The jetty site in this investigation acted to constrict the channel proportionately more during high flow than at lower flows, and thus caused dramatically larger disturbances under high-flow conditions.

For structures that are in contact with the river over the full spectrum of flow, it is important to recognize the different hydrodynamic properties of the river under different flow conditions. Although this investigation had no specific examples, the channel along the rock retaining wall site (the wall was out of water during low-flow periods) exhibited completely different natural flow patterns during low-flow conditions than under high flows. A gravel bar upstream from the site is a major influence on low-flow velocity patterns, but is completely drowned out during high-flow periods and ineffective on high-flow patterns. If a structure built in this particular reach were to extend into the low-flow channel, its effects on the local velocity would likely be considerably different during low flows than during high flows.

Similarly, velocity measurements made near the mouth of Soldotna Creek at the upstream end of the Bio-engineering Project showed the relative influence of tributary discharge on velocity patterns in the main river. The apparently anomalous higher velocity reading during the low-flow period is due mainly to Soldotna Creek's relatively higher discharge into a relatively lower stage on the Kenai.

With respect to velocity being in the acceptable range for juvenile chinook salmon habitat, velocities that were beyond the 2.1 ft/s threshold during the August 1995 high-flow period were measured in the vicinity of a number of the sites, namely near the rock retaining wall, the pile-supported dock, and the jetty. As mentioned above, a high velocity measurement was also made during the May 1995 low-flow period near the mouth of Soldotna Creek. At the jetty site, the velocity was also higher than the threshold during the medium-flow measurement in June 1994. In all cases except for the jetty site, the higher-than-threshold velocities can be attributed to natural ambient hydraulic conditions.

The ADF&G's Habitat and Restoration Division has reviewed the velocity data collected as part of this investigation and compared this information with the velocity data used in the Kenai River Cumulative Impacts Assessment's HEP analysis. The velocities measured are representative of those used in the HEP analysis and have confirmed that the modeled velocity parameters are applicable (Gary Liepitz, ADF&G, written commun., 1995). The HEP modeling completed in the cumulative impact analysis of the Kenai River used conservative velocity changes for floating and pile-supported structures, and an elevated velocity for structures such as jetties, which protrude out from the bank into the higher velocity waters. Therefore, no additional modification of the HEP analysis is required and the assumptions used in the HEP analysis are valid.

Finally, observations of flow patterns near structures have implications regarding bank erosion. It was noted that at several of the sites, bank modifications diverted the flow from its original course away from the bank, and set up eddy patterns downstream. The alteration of flow patterns was particularly significant at the jetty site. The evaluation of the effects of these perturbations is beyond the scope of this study.

SUMMARY

Hydraulic conditions at streamside structures affect the value of the sites as habitat for fish. Although numerous types of fish live in the Kenai River, the hydraulic effects of streamside structures are being considered in regard to the habitat needs and abilities of juvenile chinook salmon, because of their importance and vulnerability. This investigation of hydraulic characteristics at streamside structures along the Kenai River verified that when not overwhelmed by local river hydraulics, two general effects dominate the instream conditions near streamside structures: (1) the most significant effect is modifications of the channel area by the structure; (2) a more secondary effect is modifications of hydraulic roughness. When local hydraulics—such as large meander bends, islands, inflowing tributaries, or streambank alignments—control the conditions in the river, evaluations of hydraulic characteristics near a structure are difficult. These factors likely will require very detailed investigations on a case-by-case basis to separate the effects of the structure from those of the local setting.

Measured hydraulic characteristics near all the structures investigated are summarized for comparisons among sites (table 11). Measurements made during this investigation at a jetty and rock wall confirm that structures that protrude into the flow and reduce stream channel area have the greatest influence on stream hydraulics. Other structure types did not alter stream channel area significantly. The rock wall slowed water velocity from 2.7 to 1.5 ft/s during high-flow measurements on August 2, 1995. The jetty narrowed the river channel approximately 50 ft and increased

Table 11. Velocity, depth, and flow direction data collected at points 6 feet streamward from the bank at streamside structures along the Kenai River, June and August 1994 and May 1995

[ND, no data; minus (-) value, upstream flow; velocity in feet per second; depth in feet]

Structure	Location (river mile)	Date	Measurement location and data (velocity in feet per second; depth in feet)						Flow direction remarks
			Velocity	Depth	Velocity	Depth	Velocity	Depth	
			Upstream		At the structure		Downstream		
Road type launch	12.2	8-2-94	1.0	1.3	3.1	2.2	-1.2	2.2	Eddy generated by rocks at the upstream edge of launch
Canal-type launch	16.0	8-2-94	2.0	1.8	1.8	3.2	ND	ND	Small eddy in canal entrance
Floating dock	16.6	6-9-94	ND	ND	0.2	1.3	ND	ND	Small or no disturbance of surface flow
		8-2-94	2.0	2.2	1.3	3.8	0.7	3.6	
		5-9-95	0.4	1.0	0.4	1.0	0.5	1.2	
Rock retaining wall	16.8	6-9-94	1.1	1.0	0.6	0.8	ND	ND	Flow diversion towards center of channel extends downstream for 10-15 ft
		8-2-94	3.7	2.6	1.5	2.8	ND	ND	
		5-8-95	ND	ND	0.0	0.7	0.5	0.8	
Pile-supported dock	17.4	8-3-94	0.4	2.0	0.1	1.8	1.7 2.3	1.2 2.2	Small flow disturbance near piles
Jetty	37.9	6-9-94	ND	ND	3.6	1.6	ND	ND	Large eddies upstream and downstream for 5-10 times the projection length into the river; flow directed at downstream bank
		8-2-94	-1.1	5.0	4.7	1.9	-0.5	3.6	
		5-8-95	0.1	1.6	2.0	2.3	0.1	1.0	
Concrete wall	42	8-3-94	ND	ND	-2.0	2.3	-1.5	2.2	Meander bend and islands affecting flow
Soldotna Creek Bio-engineering Project	21.9	6-9-94	1.8	0.7	0.5	0.7	0.4	0.7	Diversion of flow at mouth of Soldotna Creek affecting velocities and flow direction
		8-2-94	2.0	1.5	0.8	2.0	0.2	1.5	
		5-8-95	3.9	2.5	0.1	0.9	1.2	0.9	

water velocity during all flows. At the jetty, the greatest observed increase in velocity was 5.8 ft/s, measured during high-flow conditions on August 3, 1994. At this time, the velocity measured upstream from the jetty was -1.1 ft/s, and streamflow was moving in an upstream direction at the measurement site. At a point 6 ft streamward from the jetty tip, the water was moving downstream and the velocity was 4.7 ft/s. During measurements on June 9, 1994 and August 3, 1995 velocities at the tip of this jetty were greater than the sustained swimming abilities of juvenile salmon reported by Bell (1986). Other structures did not demonstrate as great an influence on velocity as the jetty or rock wall did.

Flow directions were altered somewhat by all structure types. The floating dock, concrete wall, and pile-supported dock demonstrated the smallest amount of disturbance to surface flow. The rock wall diverted flow away from the streambank for a few feet and this effect continued downstream for approximately 10 to 15 ft. The jetty forced water away from it towards the opposite bank for a distance of at least one jetty length beyond the jetty tip into the river.

Measurements at the Soldotna Creek Bio-engineering Project demonstrated that velocities along the project were commonly in the suitable range for juvenile chinook salmon. Although other factors play a role at this site, the root wads and boulders in the near-shore areas slowed streamflow.

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