FRED Reports

KENAI RIVERBANK EROSION STUDY

by
Lowell S. Barrick

Number 41

Alaska Department of Fish & Game
Division of Fisheries Rehabilitation,
Enhancement and Development

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1. FOREWORD

The Kenai River is a much studied river. Both the United States Army Corps of Engineers (COE) and the United States Geological Survey (USGS) have prepared detailed reports concerning the hydraulics, sedimentation, and erosion of this drainage system. The United States Fish and Wildlife Service (USFWS) and the Alaska Department of Fish and Game (ADF&G) have prepared several documents concerning wildlife and habitat along the river. The Alaska Department of Natural Resources (ADNR) has prepared a master plan for state park units, and the Department of Community and Regional Affairs has published floodplain and erosion reports that further describe conditions on the river. These and other reference materials are listed in the reference section of this report.

The purpose of this study is not to duplicate the work already performed by others but, rather, to extrapolate information pertinent to the ADF&G for use in the management of the wildlife and habitat of the Kenai River watershed. The first portion of the report describes observations on erosion that were made during a 3-day field trip in August 1983; the report then describes other factors that contribute to increasing or decreasing its rate. The final section summarizes the human-impact factors of erosion that are the most significant from a fish and game perspective, and it provides general recommendations for reducing erosion problem(s).

In February 1984, as this report was being written, Governor Sheffield introduced Senate Bill No. 417 into the Legislature, which established the Kenai River Special Management Area. The Resources Committee prepared a Committee Substitute for SB No. 417 (CSSB No. 417), which went before the Senate Finance Committee in May 1984. CSSB No. 417 contains the type of management control measures that are recommended in Sections 7.3.1 and 8.1 of this report.

2. FIELD OBSERVATIONS

The following observations were made during a boating reconnaissance of the Kenai River during the period 29 to 31 August 1983. The River-Mile (RM) references correspond to the river mileage shown on the Kenai Peninsula map (prepared by Alaska Road & Recreation Maps, Box 2459, Anchorage, Alaska 99510). Left or right bank describes the bank as viewed downstream.

2.1 Cook Inlet to Soldotna: RM 0 - 22 (Figure 1)

2.1.1 Natural Terrain

Tidal action appears to influence the river upstream to the vicinity of RM 12. The river in this lower area is wide (approximately 1500 feet near the mouth at high tide); at low tide, it meanders through the tidal flats. The COE (1978) has designated most, if not all, of the land adjacent to the river and downstream from RM 12 as wetlands. The wetlands are identified by the wet soil, swamps, marshes, tidal influence, and the tall grass-type vegetation that grows there. Several species of ducks, geese, and other birds were observed in this section. From RM 12 to RM 22 (Soldotna), the river narrows, becomes more sinuous, and is confined in a more definite channel with some cut banks that are 60 to 70 feet in height. There is a noticeable change in vegetation upstream of RM 12 as the marshy tideland grasses give way to large spruce and birch trees that, by eye, approach 60 feet in height and 14 inches in diameter.

2.1.2 Development

Commercial and residential development does not appear to have had a major impact on the river below RM 12. There is commercial development associated with the City of Kenai along the right bank of the river from RM 0 to 1.5. Cannery docks and wharfs are on the left bank near RM 3, and residential development is underway on the left bank bluff near RM 4. The Warren Ames Bridge (RM 5.1) and the associated roadway embankment have created some alteration of the riverbanks and wetlands in that area. There is a pioneer

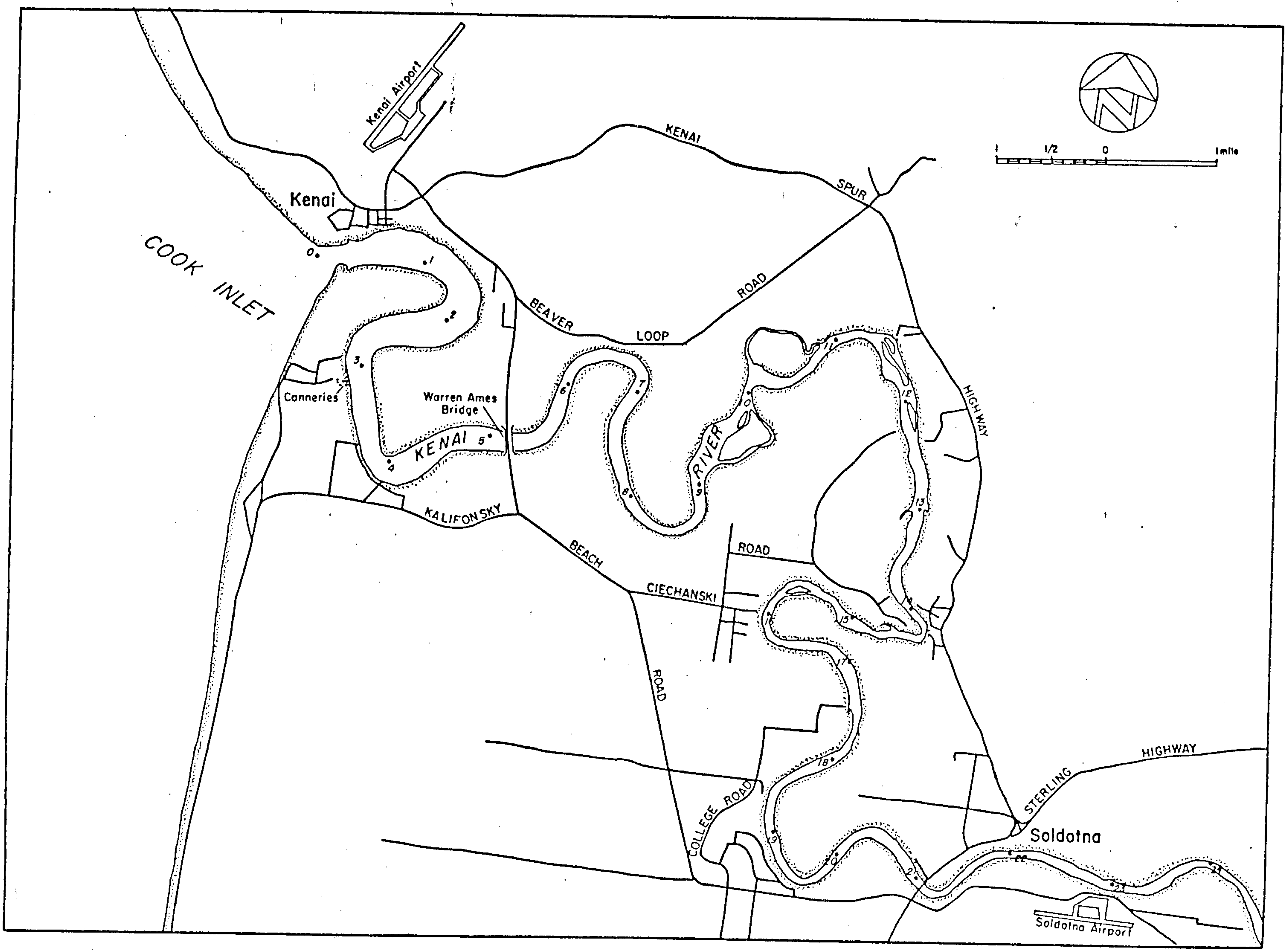


Figure 1. Kenai River from river mile 0 to 22.

trail for boat launching on the right bank at Cunningham Park (RM 6.5), and there are indications of residential development underway along Beaver Creek with boats entering the Kenai River from a slough channel at RM 10.2. The 10-mile river segment from RM 12 to 22 is, however, undergoing rapid change from both residential and commercial development. Many of the sites were large, extending several hundred feet along the river bank. Some private and commercial property owners have had portions of the riverbank excavated to provide boat canal access to the river. These canals lead to individual houses, trailers, and campsites and are used as mooring sites for numerous boats. One new development on the right bank at RM 21, immediately downstream of the Soldotna Bridge, is a vivid example of how riverfront development should not be conducted as soil fill has been dozed over a high bank (15' to 20'). The new embankment has covered the natural vegetation, killing it, and the fill is sloughing into the river. The new embankment will start eroding away with the first high water, and the property owner will probably seek a COE permit to riprap his riverfront property to protect it.

2.1.3 Riverbank Development

River Mile	Description & Comments
0 - 1.5	Right bank: Commercial development by the City of Kenai and industrial-type users; i.e., freezing and canning facility, Port of Kenai, public dock, buildings, and vehicle parking.
3	Left bank: Commercial development by fish processors; i.e., fish processing plant, wharfs, docks, buildings.
4	Left bank: Residential development along the top of a 50' bluff. About 3/4 mile of access road parallels the bluff's edge.

5.1	The Warren Ames Bridge (about 1000 feet long by 44 feet wide) crosses the river at this location. About 2 miles of N-S road (across the wetlands) connects the Beaver Loop and the Kalifonsky Beach roads.
5.1 - 10	Both riverbanks are basically free of development. A residential development is in progress on the right bank (RM 10) where Beaver Creek slough empties into the river.
10 - 11.5	Both riverbanks are basically free of development. Residential/recreational development is appearing on the right bank (RM 11.5) from access off the Kenai Spur Highway.
11.5 - 14	Both riverbanks are basically free of development. Signs of development such as Right-Of-Way (ROW) clearing for roads/lots are present on both banks near RM 12.3. Residential development is underway on the right bank at RM 14.
14 - 15.5	Increased residential development with numerous homes/cabins constructed on both banks. From 2500' to 3000' of boat canals have been excavated in the right bank at RM 15.5 at a development known as Salmon Run Acres.
15.5 - 17	A smaller canal (400' to 500') has been excavated in the right bank at RM 16. A 1-acre (about 200' X 200' sq.) boat harbor has been excavated in the right bank at RM 17 in a recreational site known as Poacher's Cove.

17 - 20	Riverbank development is minimal and is built back from the bank's edge. Bank erosion does not appear to be a problem.
20 - 22	Heavy commercial, residential, and recreational development is occurring along both banks in the vicinity of Soldotna. Pending development, in the form of flagging and brushed clearing lines, was observed.

2.2 Soldotna to Sterling: RM 22 - 37 (Figure 2)

2.2.1 Natural Terrain

Between Soldotna and Sterling, the river straightens out considerably and narrows down to 300 to 500 feet. This section of the river is an entrenched channel, which is the deepest portion of the riverbed where alignment has been established by the cutting action of the water. Compared to the river downstream of the Soldotna Bridge, the river bends are more gentle, and the banks are vegetated with high brush and grasses that provide good protection from water erosion. Beyond the riverbanks, the terrain is thickly forested with spruce, birch, poplar, and other species of trees. Many of the trees are large, growing to heights of 60 to 70 feet; some trunk diameters are 12 inches or larger. According to USGS (n.d.) the water surface gradient varies from .001 feet per foot to .003 feet per foot. Most of the bank along this section is low (3 to 5 feet above the high water marks), but in a few areas, e.g., RM 26 (left bank) and at RM 28 (right bank), there are bluffs that are 100 feet in height.

2.2.2 Development

Most of the riverfront developments in this area are single-family residences with a few of the houses showing signs of commercialism, e.g., "bait for sale" or "food and drinks" signs. An example of poor riverfront development is the DOT&PF equipment yard located on the right bank near RM 22. At

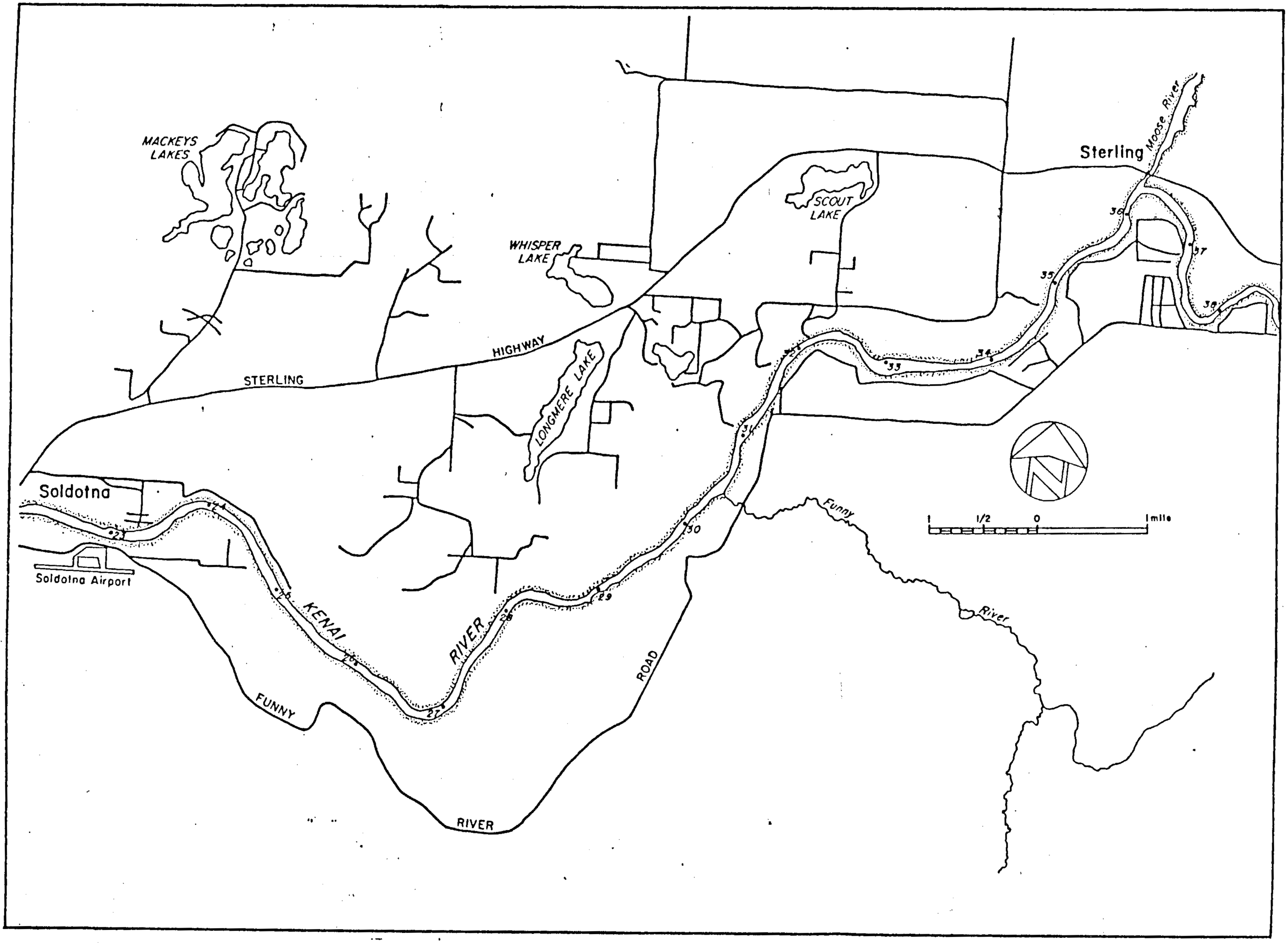


Figure 2. Kenai River from river mile 22 to 37.

this location, stockpiled gravel is sloughing off the embankment and into the river. Brushed property lines and ROW clearing for utility lines indicate that considerably more development is pending.

2.2.3 Riverbank Development

River Mile	Description & Comments
22 - 25	The primary development in this area is in the vicinity of RM 23 (both banks). This development is for the airport and residences on the left bank and for commercial and residential development on the right bank. Extensive ROW clearing along the right bank between RM 23 and 25 indicates that extensive development, possibly residential, is pending.
25 - 30	Development is virtually non-existent and the heavy vegetation covering the banks in this area is keeping most of the banks stable.
30 - 37	Sterling: Compared to RM 25-30, there has been a dramatic change in vegetative cover along the river between RM 30 & RM 37. Large tracts of land on both sides of the river have been cleared of trees. The tracts were initially cleared for agricultural uses, but now much of the riparian land is being developed for residential use. Some of the developments are displaying extremely poor conservation practices, such as pushing rock/gravel fill over the natural vegetation to create groins in the river. These banks are undergoing accelerated erosion.

2.3 Sterling to Skilak Lake: RM 37 - 50 (Figure 3)

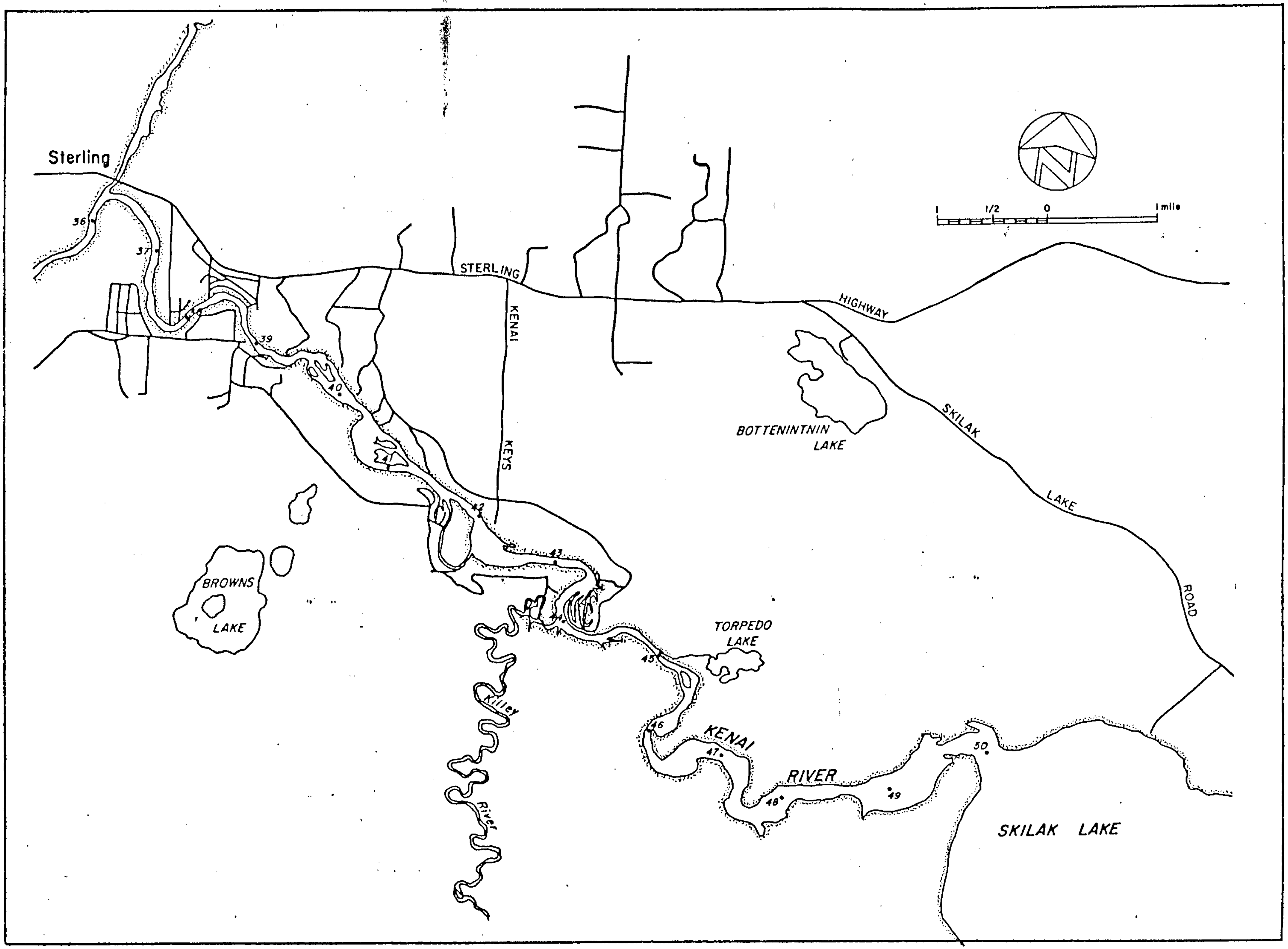


Figure 3. Kenai River from river mile 37 to 50.

2.3.1 Natural Terrain

Between RM 36.5 and RM 39 (bottom of Naptowne Rapids), the river and terrain are similar to the middle section of the river (RM 23 to 36). The river, however, is a little more meandering. Through Naptowne rapids (RM 39 to 40), the river gradient is greater than .005 feet per foot (USGS n.d). From RM 40 to the outlet of Skilak Lake, the river again becomes more meandering with several branching sloughs and islands present. Wetlands are more prevalent in this 10-mile stretch of the river. Upstream of RM 45, the river passes through the Kenai National Moose Range. No permanent development is present here; although a few tent campsites were observed.

2.3.2 Development

Between RM 37 (Sterling area) and RM 44.5 (Kenai Keys private subdivision), riverfront development increases. There are several subdivisions under construction; new access roads are going in, and there are at least three aircraft landing strips adjacent to the river. In a 1-mile section of the right bank (vicinity of RM 38), 15 rock groins have been constructed (Figure 4). Some of the groins are very large: one is nearly 100 feet long, 45 feet wide, and 6 or 7 feet high. One groin supported a fenced area and a small outbuilding. Erosion of the groins was evident, and some of them had been maintained with rubber tires, tractor rails, concrete rubble, and other types of materials. In addition to protecting the owner's property, the groins are deflecting the water flow towards the opposite bank and, thereby, causing the erosion of other properties. Moreover, the groins are trapping bedload on the downstream side, which causes loss of bank vegetation and fish habitat. One groin/boat launch development (left bank near RM 35.6) displayed a COE permit. Our reading of it indicated that the development exceeded the conditions of the permit, but a reading of the full permit would be needed before that assertion could be confirmed.

A major commercial, residential, and recreational site has been developed at RM 44 in an area that is known as "Kenai Keys" (Figure 5). Here, numerous access canals, leading to charter businesses and residences, have been

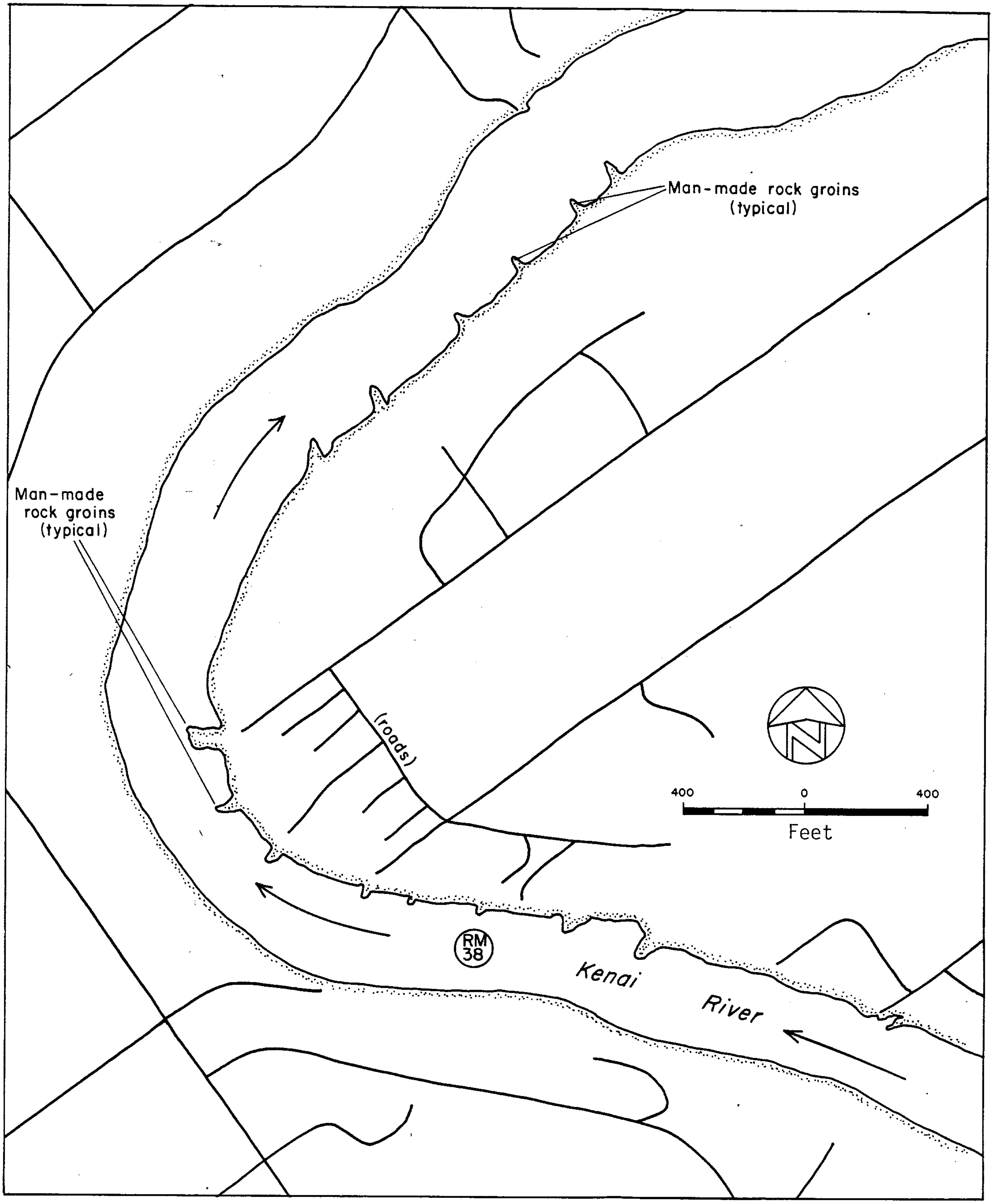


Figure 4. Rock groins in vicinity of river mile 38.

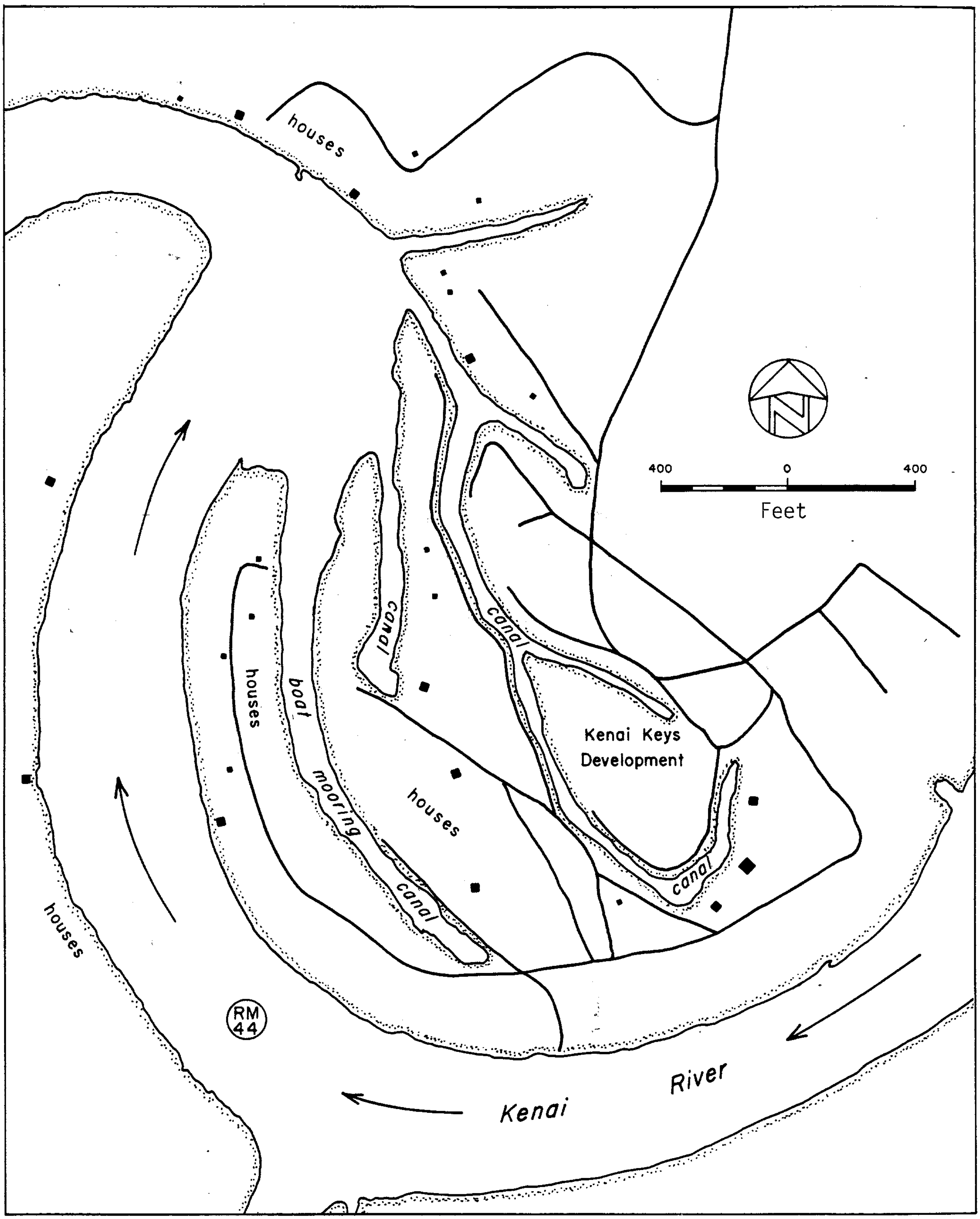


Figure 5. Kenai Keys (river mile 44).

excavated in the right bank. The canals provide river access and moorage for a large number of boats. Although the canals provide convenient boat storage and access, they also present a threat to the stability of the river. According to data depicted in the ADNR Kenai River State Park Units Master Plan (1983), these canals lie in the 100-year flood plain. In the event of a flood, there is a good chance that the river will cut through the meander and into the canals. An entirely new river channel could be formed. This same potential for river channel diversion holds true for other canal systems that have been developed on downstream properties.

2.3.3 Riverbank Development

River Mile	Description & Comments
37 - 39	Development of both banks is occurring in this area: considerable traffic is drawn to the left bank by the Funny River road. In the vicinity of RM 38, an extensive array of rock groins (15) have been constructed on the right bank. Some of the groins are very large: 100' long and 45' wide. These groins are affecting the water flow characteristics, and deposits of sediment are filling in behind each one.
39 - 45	The Naptowne Rapids are located between RM 39 and RM 40, and minimal development has occurred in this area. Upstream of RM 40, however, access roads have been constructed on both sides of the river; these roads extend to the vicinity of RM 44. Extensive development has occurred on the right bank at RM 44: a development known as "Kenai Keys." In this development area, about 1.5 miles of canals have been excavated in the right bank. These canals are used to provide

	riverboat access to homeowners in the development.
45 - 50	This land is in the Kenai National Moose Range Reservation. Riparian development has not occurred, and, except for a high bluff on the right bank near RM 45.5, the banks are heavily vegetated and are stable.

2.4 Boat Wake Induced Erosion

Prior to taking the river trip, considerable concern had been expressed, about bank erosion resulting from riverboat traffic. Because the trip was conducted during weekdays near the end of the fishing season, boat traffic was not heavy, and few instances for observing boat wakes occurred. However, we did perform a few informal boat wake tests of our own. We used two boats; one was an 18-foot, flat-bottomed, metal river boat equipped with a 35-hp motor, and the other was a 20-foot, flat-bottomed, metal riverboat equipped with a 60-hp motor. Our load consisted of four people, fuel, and miscellaneous equipment for a total of about 800 pounds. By operating the boats at variable speeds and at various distances from the banks, we were able to make the following general observations:

1) The 18-foot, 35-hp boat was able to take four people upstream (in most sections of the river) at ground speeds of about 20 mph.

2) The 18-foot, 35-hp boat was able to take four people through the Naptowne Rapids (upstream and downstream) with adequate steerage and reserve power. Note: this trip was made during a lower flow period, and passage through the rapids during periods of high flow may be impossible with a boat of this configuration.

3) The 20-foot, 60-hp boat was able to carry four people upstream or downstream at ground speeds of 40 mph or greater.

4) Wake size is a factor of boat size (hull design), boat weight (total weight including load), and boat speed (a function of engine size).

5) Wake heights of 6 inches or less at the shoreline (bank) do not appear to add to the natural erosion on banks that contained vegetative cover. All wave action caused erosion on unfoliated, steep banks that were composed of silt or clay, but the extent of that erosion was not measured.

As stated, these boat-wake observations were not based on scientific testing methods, and measurements of wake-induced erosion (soil loss) were not obtained. Our field observations did, however, establish that boat wakes are causing bank erosion. A few property owners stated that the erosion along their riverfront property has increased in direct proportion to the increase in boat traffic.

2.5 Field Observations Summarized

2.5.1 General

As of 1 September 1983, most undisturbed banks of the Kenai River, between Skilak Lake and Cook Inlet, appeared to be relatively free from extensive erosion; however, the observations were cursory in nature. The low banks, where human development has not taken place, appeared to be quite stable with their heavy covers of vegetation. The high bluff banks, consisting of silty/gravelly soils devoid of covering vegetation, are showing signs of rapid erosion. Many of the high bluff banks are located on the outside loops of meander bends where the increased water velocity causes natural erosion. Table 1 is a USGS summary of channel characteristics that are pertinent to the development of the Kenai River. The table indicates that the rates of bank erosion in the stretch of the Kenai River between Skilak Lake and Cook Inlet varies from less than a foot per year to as much as 5 feet per year. If human-induced erosion does not significantly increase

Table 1 - Summary of channel characteristics pertinent to determining sensitivity of the Kenai River to development.

Segment of channel (river miles)	Pattern & degree of entrenchment	Underfit conditions	Degree of armoring	Ft/yr of bank erosion under present regime	Relative sensitivity to development
50.3 to 45.7	meandering; slightly entrenched	channel appears "drowned"-formed at lower streambed	partly armored (stable crescentric dunes)	1.0	low
45.7 to 39.4	meandering; free to migrate	channel is product of present flow regime	none	5.0	high
39.4 to 34.8	meandering; entrenched	underfit; especially below junction with Moose River	mainly armored	<1.0	low
34.8 to 21.8	sinuous to straight; entrenched within Soldotna terrace	most underfit section of entire river	mainly armored	<1.0	low
21.8 to 17.6	meandering; entrenched within Soldotna terrace	underfit armored	mainly armored	<1.0	low
17.6 to 13.4	meandering; partially entrenched, but meanders are migrating	slightly underfit	parts may be slightly armored	2.0	high
13.4 to 9.0	sinuous and anabranching	channel is product of present flow regime	none	5.0	high
9.0 to mouth	meandering in tidal regime; channel is free to migrate	channel is mainly product of present flow regime	none	2.0	moderate

Source: U.S. Geological Survey

these rates, property owners will have a pretty good index as to how far away from the bank they need to be when constructing permanent buildings.

2.5.2 Riparian Development

Visual observations indicate that accelerated riverbank development has occurred. These observations were especially apparent where developed property adjoined undeveloped property at the upstream and downstream boundaries. In many instances, the developed properties exhibited receding shorelines in spite of the many types of erosion-control structures that had been constructed to protect them, while the adjacent undeveloped riverbanks appeared to be stable. Another striking contrast between the developed and the undeveloped land is in the amount of the vegetative cover. In nearly all cases, the riverbank along the developed property is nearly devoid of vegetative cover, while the riverbanks along the undeveloped property have a cover of vegetation. The loss of vegetation not only results in a loss of bank stability, but it may also result in the loss of habitat critical to the rearing of juvenile fish. No attempt was made to measure lineal footage of the lost riverbank vegetation, but the amount is considerable.

2.5.3 Structure Placement

An important part of riparian development is the siting of buildings. In numerous instances, the buildings have been constructed too close to the riverbank. Much of the construction on the low banks has been done in the floodplain. The Kenai Keys development (RM 44) is an example of this, and many expensive homes are threatened by flood action. Homes have been constructed near the edges of high bluff banks, and these are endangered by the potential collapse of the bank(s). Unfortunately, some of the high bluff homes have been constructed at sites where engineered erosion control measures would be extremely costly to construct and to maintain. Some of the bank protection measures that have been installed, i.e., car bodies, tractor rails, and concrete rubble, are not only failing to prevent erosion, but they may be actually contributing to the erosion process.

2.5.4 Boat Wake Erosion

Only a few boats were operating on the river during the time this fieldwork was conducted, and there was limited opportunity to observe the impact boat traffic was having on riverbank erosion. From our observations, it is apparent that the impact of boat-generated waves is a function of boat size, shape, draft, speed, engine size, water depth, and location of the boat in relation to the shoreline. The wake from our boat dislodged soil from the silty, high bluff banks, but vegetation covering the low banks masked the action of our waves, and the impact was not readily apparent. However, a wave striking the vegetated shoreline creates an undercutting action that will, in time, cause the bank to crumble. The crumbled bank will expose denuded soil to direct wave action--accelerating the erosion process. Specific data concerning boat wake erosion in the Kenai River could not be located, but Section 4.1.4.3 of this report describes some findings about boat wake erosion in the Mississippi River and its tributaries.

3. VALUE OF THE RIPARIAN ECOSYSTEM

The hydrologic cycle of precipitation, runoff, and evaporation, which links land, streams, and rivers together, is well understood. Organic and inorganic materials, which support the base of the food chain in rivers, flow continuously from the land. The quality of water and the availability of food for juvenile fish are determined by the character of soils and vegetation in the surrounding watershed. Accordingly, human activities in watersheds can have pronounced effects on the quality of the river environment. Road construction, land clearing, and other forms of development cause soil erosion, which oftentimes leads to the deposition of sediment in the riverbed. These development-type activities tend to change the flow regime, which may reduce riverbed stability, cover spawning areas, and cause riverbank erosion and other actions that are detrimental to the terrestrial and aquatic wildlife of the watershed.

The Kenai River is a productive and important habitat for fish; it is a unique and fragile system that supports a diversity of wildlife. Also, the Kenai River watershed is the focal point for such outdoor recreational activities as hunting, fishing, camping, and hiking. The commercial activities of mining, logging, farming, and land development are major sources of income for the people of the area. State agencies, such as the Departments of Natural Resources, Environmental Conservation, Community and Regional Affairs, and Fish and Game have concerns and responsibilities for the river that, in some instances, may be in conflict with one another.

As may be expected, the primary concerns of the Department of Fish and Game are the wildlife and the riparian ecosystem. Most people recognize the value of the wildlife within an ecosystem, but many people do not understand or appreciate the value of the plant and insect life within the ecosystem. The importance of riparian vegetation to fish and wildlife, however, cannot be overestimated. Riparian vegetation is a resource that is vital to the maintenance of the indigenous wildlife. The following, modified from Duff (1980), lists several of the more important values of these ecosystems:

1) Riparian vegetation regulates the energy base of aquatic ecosystems, thus, determining the quality of aquatic habitat for fish resources;

2) The structural diversity and complexity of riparian vegetation supports greater numbers and diversity of terrestrial wildlife populations than any other habitat;

3) Riparian vegetation provides a buffer zone, which acts as a mechanism for flood control, pollution abatement, erosion control, streambank stabilization, groundwater recharge, and the maintenance of water quality;

4) Riparian vegetation attracts and supports many recreational, subsistence, and educational activities including hunting, trapping, fishing, camping, photography, and nature study; and

5) Riparian vegetation has a high aesthetic value because of the combination of water, land, attractive and unique vegetation types, and abundant fish and wildlife populations.

Fish habitat is directly related to and highly dependent on conditions of the surrounding watershed, especially the adjacent riparian zone (Duff 1980; Merrit and Lawson 1978). The quality of the aquatic habitat is a result of the interaction of the riparian vegetation, the stream/river channel, the water column, and the streambank (Platts 1982). By influencing water temperature, rate of flow, and fluctuation in discharge, this vegetation determines the productivity of the system. Consequently, removal of streamside vegetation can affect the quality and quantity of fish habitat and cause a decline in production.

Riparian vegetation reduces erosion and, thus, bedload sediment by controlling surface runoff and stabilizing streambanks. An increase in bedload sediment interferes with intergravel waterflows and decreases the available oxygen to incubating fish eggs and alevins. Streambank erosion is a normal occurrence, but it must be maintained in equilibrium with the buildup of new banks. Problems begin when this balance is upset. Vegetation slows overland waterflow, traps sediment and, thereby, builds new streambanks, which minimize damage to the river channel during periods of high flows. Burger et al. (1982) found that areas along the Kenai River with bank irregularities and overhanging vegetation have produced higher catch rates of juvenile chinook salmon. Greater numbers and higher frequencies of juvenile coho salmon were captured in the Susitna River in areas with emergent or aquatic vegetation and/or overhanging or deadfall cover (ADF&G 1982). Overhanging banks and vegetation provide fish with protective cover, as do some submerged snags and boulders. Platts (1982) cites several studies that document the importance of cover to fish. Salmonid abundance declines as stream cover is reduced; as cover is added, it increases. The removal of vegetation causes a reduction in bank irregularities and a tendency toward a smooth, straight channel; moreover, it results in an increase in water velocity, a reduction in cover and, thus, a loss of habitat.

By providing shade, vegetation maintains suitable water temperatures for fish, incubating eggs, aquatic plants, and invertebrates (Duff 1980). Hynes (1970) states that water temperature is one of the foremost important abiotic factors in fish production. Temperature changes can affect the metabolic rate of fish, change the dissolved oxygen content in the water, and influence hatching success. Shaded streamside areas are a preferred habitat of juvenile salmonids (Platts 1982).

Riparian vegetation contributes to primary stream productivity by supplying the system with plant and animal detritus and nutrients, which establish the basic components of the food chain (Meehan et al. 1977). Organic debris supplies a food source to aquatic invertebrates, which are important in the diet of many fish. Riparian vegetation is also a supplier of terrestrial insects to the aquatic ecosystem (Burger et al. 1982).

By its ability to absorb water, the riparian vegetation can provide groundwater recharge to an aquatic system during periods of low flow; consequently, this can result in an increase in habitat for rearing fish. The absorption of water also mitigates high flows by reducing erosive forces.

The innocent but indiscriminate destruction of seemingly small portions of habitat causes irreparable harm to the proper functioning of the riparian ecosystem. Such degradation not only impacts fish and wildlife populations, but it decreases the property value of riparian lands, reduces commercial and sport fish profits, and decreases the volume of tourism.

4. EROSION

4.1 Definition

Erosion is any process by which material is removed from one location and deposited in another. In order for erosion to occur, an erodible material must be exposed to some form of energy or eroding force. The erodible material that is of primary concern in this report is the riparian land adjacent to the river. The major eroding forces are precipitation, current, waves, wind, heat, ice, and snow. The natural causes of erosion can be classified into three principal categories: geologic, climatic, and hydraulic. The natural forces of erosion are, however, oftentimes affected by human activities, and it is the accelerated rate of erosion, caused by these activities, which are the main concern of this report.

4.1.1 Geologic

A river's physical characteristics reflect the nature of the land through which it flows. The makeup of the riverbed is a product of the gradient, the erosional forces, and the susceptibility of the materials to erosion. In high-gradient, high-discharge rivers, rock and gravel are dominant in the riverbed because the finer particles are swept downstream. As the gradient lessens and the riverbed widens, the reduced velocities permit the sands and silts to settle out in the lower reaches of the river's course.

The soil materials through which the river channel has cut are major factors in riverbank erosion. Many heavy soils tend to shear in a vertical plane when the base has become saturated or undercut. Likewise, these soils may develop deep, dry-weather cracks that accelerate the sloughing of large sections of the riverbank during higher than normal flows. Sandy soils, with their low cohesion properties, are not resistant to the tractive forces that are created by normal flood flows and, therefore, erode easily.

Flows against gravelly or cobbly soils exert a sorting action that tends to leave the channel bottom armored or covered with cobbles as the finer particles are carried downstream. Although the channel bottom may, thus, become highly stable, the sorting action of the water flowing against the banks will continue and the channel will become wider. Channels in soil with a solid rock bottom react to flood flows in much the same manner as those that have developed an armored bottom.

4.1.2 Climatic

Storms that create flood flows of long duration are generally more damaging than those that produce short-term flood flows because of the increased time in which the erosive forces are able to act against the channel materials and because of the resulting saturation of the banks, which may cause them to slough when the flood flows recede. In the Kenai River drainage, high rates of spring runoff cause damage to the stability of the channel. Also, ice drifts may gouge out existing vegetation, or they may lodge in the channel and, consequently, divert currents from their normal courses. At restricted points along the river, ice drifts may cause complete blockage of the channel, resulting in detrimental deposits of sediment or bedload material. Where ice is a problem, it may be necessary to clear the blockage areas of trees, snags, or sand bars in order to permit free passage of the ice drifts.

4.1.3 Hydraulic

Two major forces that influence a river are gravity and friction. Gravity is the force that causes water to flow downhill, while friction is the force that tends to resist the downhill flow. The velocity that water attains is a function of the gradient, roughness of the riverbed, and the depth of flow. A large, deep river with the same gradient as a small, shallow stream will normally have the greater velocity. Resistance to flow is influenced by the following factors:

1) Size of the material in the riverbed and on the banks.
2) Amount of vegetation along the banks and in the river channel.
3) Degree of curvature (meandering/sinuous) and frequency of pools and riffles.
4) Obstruction to flow, such as log jams and rock outcrops.

As the water velocity increases, these four factors provide progressively more resistance to the flow, and the resistance tends to increase as the square of the velocity.

In general, the erosive and transporting powers of streamflow increase with increases in velocity, turbulence, depth of flow, and gradient of the channel. The ability of riverflow to detach and move soil materials varies inversely with the amount of sediment the stream is carrying. Streamflow that is carrying its maximum debris load, including both suspended and bedload materials, can travel at a higher velocity without accumulating scoured material than a stream carrying less than its full capacity debris load.

4.1.4 Induced Erosion Forces

Many human activities have a direct effect on the erosion rate of lakes, rivers, and streams. Activities such as land clearing, mining, highway construction, housing development, construction of in-stream structures, and increases in traffic (both on land and water) oftentimes increase the rates of erosion. These types of activities are occurring along the Kenai River.

4.1.4.1 Land Clearing and Development

Recently, an accelerated rate of development has occurred in the Kenai River area. Much of it has resulted in tree and vegetation removal from the land adjacent to the river. This development consists of the construction of buildings, roads, boat docks, groins, and other structures, and it poses an immediate threat to the river's ecosystem. The increased runoff from these areas carries high sediment loads, which increase turbidity, change the salinity and water temperature, reduce the dissolved oxygen content, and increase the Biochemical Oxygen Demand (BOD) of the river.

Mining, logging, and agriculture can destroy vast areas of vegetative cover and, thereby, expose large amounts of soil to the erosive powers of wind and rain. Discharges from these activities can contain chemicals, petroleum products, and heavy metals. Table 2 lists the effects that agricultural practices in Alaska can have on water quality.

4.1.4.2 Boat Wakes

A literature search failed to locate any qualitative information concerning boat wake-induced erosion in the Kenai River. However, the U.S. Fish and Wildlife Service Resource Publication 149 (n.d.) contains considerable data concerning the effect of boat waves in the Mississippi River system. Much of this study was based on observations of commercial barge traffic, but the following excerpts include data on recreational boat traffic, which may be helpful in assessing wake erosion in the Kenai River.

Physical impacts of waves that are generated by boats depend on the size and shape of the boat, boat speed and draft, water depth, location of boat in relation to shoreline, and width of the channel (Hay 1969; Bumm et al. 1973; Schulz 1978; Bhowmik 1975; Karaki and Van Hoften 1974; Johnson 1969; Camfield et al. 1980; Das and Johnson 1970). Generally, when a boat is traveling fast in shallow water near the shoreline, it generates the highest waves (Sorenson 1973). High waves in narrow channels impact upon the shoreline with considerable energy and have a potential to cause substantial erosion. The Illinois State Water Survey (Bhowmik et al. 1981) has collected data on the effects of near-shore waves in the Illinois and Upper Mississippi Rivers that resulted from 41 tow passage events. Additional data were collected for a cabin cruiser and a towboat without barges. The maximum wave heights ranged from 0.1 ft to 1.05 ft. Recreational boats travel faster than commercial vessels and generate waves that are higher but of shorter duration than those generated by tow boats. The observed wave

Table 2 - Potential primary and secondary water quality effects resulting from agricultural practices in Alaska (adapted from Rummel 1982).

Primary Effects	Secondary Effects		
	Plant & Animal Communities	Drinking Water Supply	Recreational Potential
CHANGES IN TEMPERATURE	increased biological production to a limit; then decrease	--	warmer surface waters in summer
INCREASED SUSPENDED LOAD	interference with benthic invertebrates (fish food) and fish development	interference with water supply requiring filtration	--
INCREASED SEDIMENTATION	decreased reproduction success of anadromous fish from clogging of spawning beds	--	--
DECREASED LIGHT TRANSMISSION	decreased primary production interference with food finding	--	muddy appearance of surface waters
CHANGES IN pH	some physiological effects	may require treatment of supply water	--
DECREASED DISSOLVED OXYGEN	decreased fish production; decreased growth in fish developmental stages	--	--
INCREASED NITROGEN AND PHOSPHORUS	increased growth of nuisance plants	contamination of water supplies from nitrates and nitrites	--
INCREASED CONCENTRATIONS OF PESTICIDES	wide variety of effects; from changes in behavior of aquatic organisms to developmental defects to death	contamination of water supplies	--
PATHOGENS	propagation of disease	propagation of disease	propagation of disease

heights and energies of both tow boat and pleasure craft are sufficient to cause bank erosion.

Lubinski et al. (1981) accounted for a sizeable proportion of the erosion attributable to navigation on certain sections of the St. Clair and St. Lawrence Rivers. The criteria are as follows:

1) If the center of the navigation channel is 2,000 ft or less from the bank, 50% or more of the bank erosion is due to navigation.

2) If the center of the navigation channel is between 2,000 and 3,000 ft from the bank, less than 50% of the boat erosion is due to navigation.

3) If the center of the navigation channel is more than 3,000 ft from the bank, erosion is essentially due to natural causes.

According to Bhowmik et al. (1980): "vessel-generated waves have a direct effect on bank erosion and sediment suspension in the near-shore zone. The waves travel with little energy loss, but do dissipate with distance from the vessel track. Thus, vessel-generated waves are more important in narrow channels or where the sailing line is close to the shore." Bhowmik and Schicht (1980) concluded that most shoreline erosion is caused by wind-induced waves and boat traffic.

Simons et al. (1979) rated the relative magnitude of bank erosion factors: shear stress or velocity was first; pool fluctuation was second; and boat-generated waves were third. Moreover, average boat waves generate erosive forces on riverbanks of the Connecticut River with a magnitude on the order of 9% to 12% of the shear stresses caused by the flowing water in an unrestricted channel system.

Sparks (1975), who investigated the effects of wave wash and resuspension of sediments caused by boat traffic in the Illinois River, found that wave action can have considerable impact on some of the most productive river areas, i.e., backwaters and littoral zones. These areas serve as nurseries for larval fish and produce large amounts of macroinvertebrates and plankton. Moreover, the greatest intensity and frequency of wave action caused by heavy boat traffic (commercial and pleasure boats) during the warmer months occurs during the most productive season for animals. Wave action may affect the fauna and flora in a variety of ways. Larval and small fish and benthic organisms may experience stress from excessive wave action; the shock wave may actually knock invertebrates from plants and substrates, causing physical injury and exposing them to predation. Invertebrates may be more likely to be entrained in drift along steep shorelines that are exposed to currents sufficient to sustain drift. Plants may be uprooted by wave action, and the wave action may make it difficult for them to remain established in a given area.

Waves created by a boat moving through the water can cause soil bank erosion and subsequent increases in turbidity and sedimentation (Karaki and Van Hoften 1974; Sparks 1975). Bhowmik (1975) wrote: "As the wave approaches upward onto a sloping beach, the lower part of the wave is retarded by the friction and pressure of the beach, while the top part continues with almost its original velocity. After breaking against the shore, waves sometimes throw water high in the air, depicting the tremendous amount of energy they contain. The breaking waves follow a downward path along the bank ... and may wash away the fine sands and start the failure of the bank."

Wave-induced river bank erosion may be caused by three processes (Simons et al. 1979):

1) The impact of the wave on the bank.
2) The wave runup and rundown on the bank.
3) Fluctuating water levels (induced by wave action). Such fluctuations may cause piping or differential hydrostatic pressure (piping refers to the process of dislodgement of bank particles, which results in the undermining of the bank).

The force of the wave impact and wave runup on the bank is a function of the embankment slope and wave characteristics (e.g., relative steepness). Erosion, due to fluctuating water levels, is largely dependent on soil type, soil compaction, and soil moisture.

4.2 Understanding Streambank Erosion

The control of the interrelated forces causing streambank erosion is very difficult. From a cursory examination, engineers can not consistently predict the behavior of a river at any given location. To reliably determine the specific behavior of a given river reach, it is necessary to conduct detailed field studies or to conduct physical model tests. The expense involved in these kinds of tests usually preclude their use in all but the largest projects. An experienced engineer can often diagnose and prescribe one or more workable solutions to an erosion problem, but costs generally preclude the use of the best solution, and the use of alternate and inferior solutions will reduce the chances of success. However, there are cases where minimal erosion control measures have succeeded, but there are also cases where substantial erosion control measures have failed. An individual embarking on a bank erosion control project should be aware of the risks involved.

When attempting to control or modify the nature of a river, the environment must be considered. Regarding the possible impacts of streambank erosion control measures on the aquatic and terrestrial ecosystems of streams, environmental studies, unfortunately, have been limited.

Summarized below are some important facts that an individual property owner should know before beginning a bank erosion control project:

1) The forces contributing to bank erosion and meandering of rivers are powerful and persistent and, therefore, they are difficult to deter.

2) Positive control of these forces generally requires substantial structures involving significant investment.

3) Other than expensive model testing, the most effective remedial measures can best be determined by an engineer that has had experience with bank erosion problems.

4) Because individuals generally have limited funds to spend on erosion control projects, they are forced to construct minimally effective structures that frequently fail to arrest the erosion.

4.3 Planning Considerations

4.3.1 Define the Problem

The factors affecting streambank erosion are the orientation of the streambank, the velocity and depth of the river, and the soil composition of the streambank. An individual assessment of each particular situation should consider the type of erosion being dealt with, the types of protection that would best remedy the situation, the value of the property in jeopardy, and the cost of the structures needed.

4.3.2 Planning Protective Measures

Many alternative measures have been used with varying degrees of success. Sometimes a do-nothing approach may be acceptable. In these cases, relocation of the threatened facilities may be the best solution. Sometimes, a channel relocation is the apparent solution. Generally, however, this causes similar problems elsewhere. Solutions for erosion prevention fall into two categories: (1) the physical protection of the bank by use of rock (riprap), snowfence, or various types of mats, and (2) river works designed to deflect the current and/or produce sediment deposits: these measures include wing dams, jetties, permeable retards, and brush cabled to the bank.

The availability of materials will dictate the type of structure and its cost. Some materials are very good, e.g., quarried rock, interlocking steel pile, and creosoted wood timbers; however, other materials may not be as acceptable, such as junk cars, old tires, and thin concrete slabs. Between these extremes, there is a range of materials that can be used if care, discretion, and ingenuity are applied. Materials can be used in conjunction with other materials, e.g., wire fencing and rock; quarried rock, cloth bags and grout; or steel sheet piles and quarried rock. The life of the structure also dictates its type. Obviously, untreated timbers should not be used in a structure that is designed to last 50 years. Conversely, a permanent rubble-mound structure would not be required if the need for protection was of a temporary nature. The durability of the structure and its ability to absorb hydraulic forces are the most critical factors to consider when choosing materials.

4.3.3 Investigations

The behavior of rivers at or near flood stage is unpredictable. Appropriate engineering study, therefore, is required prior to implementing any project that would alter the flow characteristics of the river.

Before treatment of any riverbank is started, several things must be considered:

1) Size of watershed draining into the stream.
2) Expected runoff and flood peaks.
3) Expected duration of flood flows.
4) Soil materials at the site.
5) Size and shape of existing channel.
6) Nature of flow in the stream.
7) Climatic conditions of the area.
8) Degree of protection required.
9) Expected debris load carried by the stream.

10) Causes of existing meandering and erosion:

a) Fallen trees deflecting the water from its normal direction of flow.

b) Trees or brush growing on the inside of a curve and deflecting water against the cutting bank.

c) Water from a smaller stream entering the river channel, depositing sediment and, thus, deflecting the water against the cutting bank.

d) Flow pattern changes caused by the construction of bridge abutments, groins, or other instream structures.

e) Bedload drifts.

f) Ice drifts.

g) Damage to banks by riparian development, boat traffic, other means.

4.3.4 Design Considerations

4.3.4.1 Design Frequency

Maximal flood data are rarely considered in the design of riverbank protection projects; ten-year flood frequency information is advisable for these projects, but flood frequency information of longer duration needs to be considered for bridge protection or flood control projects. In other areas, the design frequency should be in line with the value or safety of the property or improvements being protected.

4.3.4.2. Design Velocities

Where the flow entering the section to be protected carries only silt and fine sand in suspension, the maximum velocity should be limited to that which is nonscouring on material of the smallest size occurring in the riverbed material. The minimum velocity should not be less than that required to transport the suspended material. Where the flow entering the section is transporting bedload, the minimum velocity should be that which will transport the entering bedload material through the section.

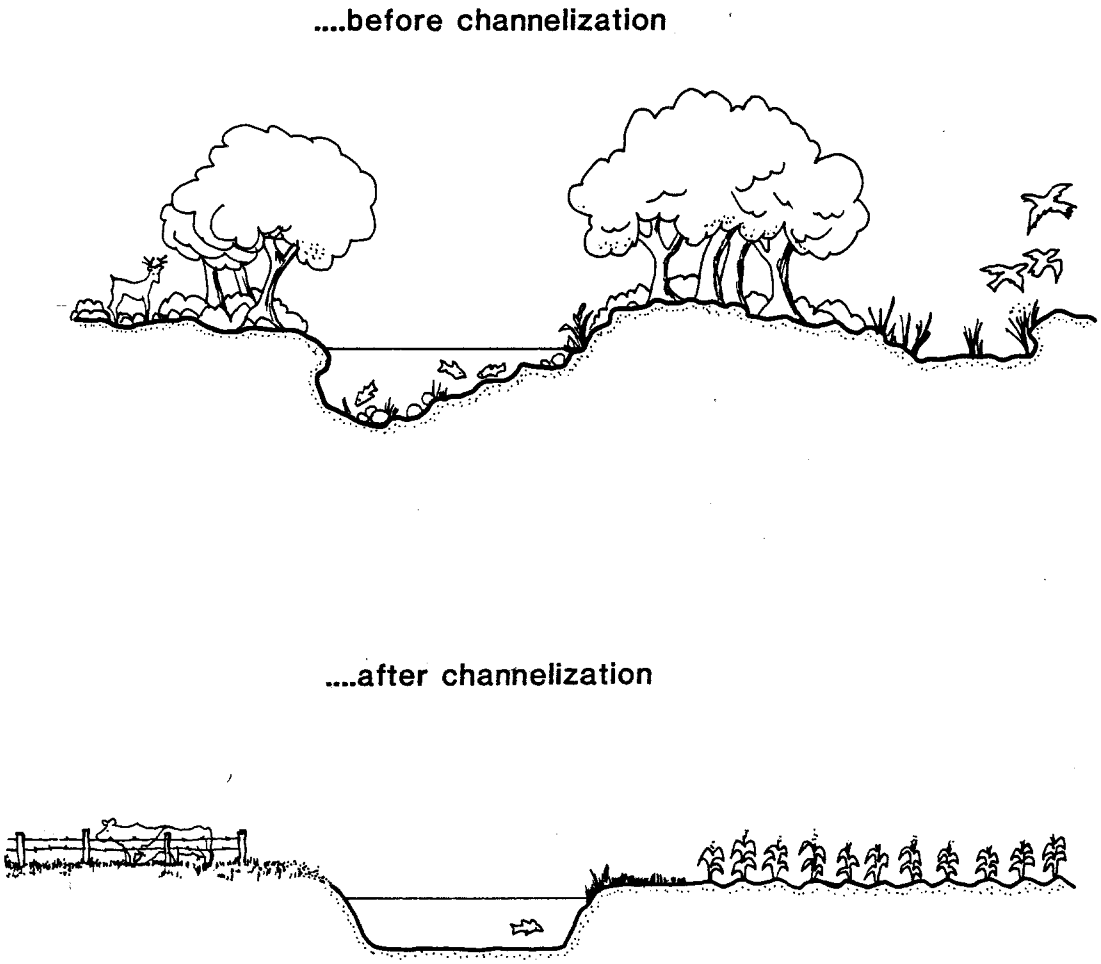
4.3.4.3 Channel Changes

Changes in channel alignment cause changes in the flow characteristics. Straightening a channel does not necessarily eliminate its tendency to meander, and erosion often results because of velocity increases, bar formations, and current direction changes. The alignment of a reach must be considered when designing the protective measures.

Bank protection for channel sides having straight alignment is usually in the form of a continuous scour-resistant lining or revetment. The lining may be placed on banks which have been sloped sufficiently to be stable under the particular type of lining to be used. For nonrigid types of lining, the slope must be flat enough to prevent sliding of the lining material. The principal function of the lining of straight banks is to prevent the normal side scour of streamflow that would otherwise cause widening of the channel bottom.

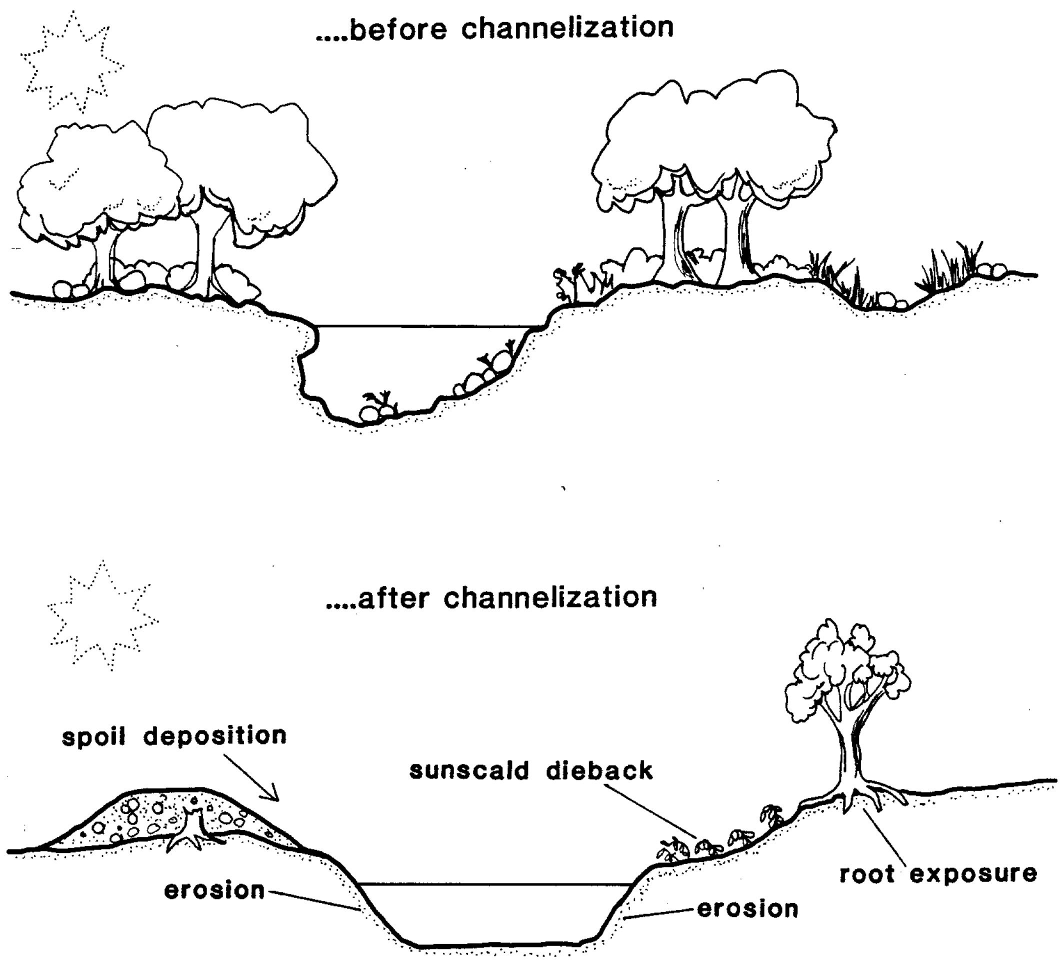
In general, more substantial and permanent types of construction need to be used on curved sections, since revetment failures at these vulnerable points could result in much greater damage than along unobstructed straight reaches of the channel. Curved revetments are subjected to high velocity currents acting against them.

Figures 6 and 7 depict typical changes in the terrestrial ecosystem caused by channel changes.



(Adapted from U.S. Fish and Wildlife Service Manual)

Figure 6. Effects of channelization on land use of associated terrestrial ecosystems.



(Adapted from U.S. Fish and Wildlife Service Manual)

Figure 7. Effects of vegetation; clearing, dredging, and soil deposition on associated terrestrial ecosystems.

4.3.4.4 Undermining of Revetments

Undermining or scouring of the foundation material by high-velocity currents has been the original cause of most bank protection failures. In addition to providing protection down to the lowest expected stable grade, footings must be placed deep enough so that they cannot be scoured out by temporary high velocity flows or lose their stability through saturation. Regardless of the type of protection installed, deep scour may be expected whenever it is constructed on erodible material and whenever high-velocity currents flow against it.

Methods commonly used to provide protection against undermining:

1) Extending the toe trench down to a safe grade and backfilling with heavy rock.

2) Anchoring a heavy, flexible mattress to the bottom of the revetment to extend it out into the channel. As scour takes place, this mattress will settle progressively and will protect the revetment foundation.

3) Installing a massive toe of heavy rock where excavation for a deep toe is not practical so that the rock forming the toe will settle in place as scour occurs.

4) Driving sheet piling to form a continuous protection for the revetment foundation. Such piling must be securely anchored against lateral pressures. Piling should be driven to refusal or well below the expected depth of scour.

5) Installing pervious toe deflector groins to deflect high velocity currents away from the toe of the revetment.

4.3.4.5 Ends of Revetment

The location of the upstream and downstream ends of revetments must be selected carefully to avoid outflanking by erosion. Whenever feasible, the revetment should be continuous between stable anchorage points, e.g., rock outcrops. If this is not practical, the upper and lower ends of the revetment must be positioned well into a slack water area along the bank where bank erosion is not a problem.

4.3.4.6 Freeboard

Additional freeboard should be provided to prevent overtopping at curves and other points where high velocities contact the revetment. Waves are set up by super-critical velocities in these areas, and the climb on sloping revetments can be appreciable. Since there are no accurate means of determining freeboard requirements for sloping revetments in critical zones, the allowance for freeboard should be based on experience and sound judgement.

4.3.4.7 Removal of Debris

An important part of riverbank protection is the removal of debris, such as stumps, fallen trees, sediment bars, or other obstructions.

5. BANK PROTECTION MEASURES

Bank stabilization is used for a variety of reasons, e.g., protection of property and structures and channelization for navigation. Protection of the bank from erosion, however, inhibits lateral migration of the riverbed; therefore, the energy of the water is dissipated by the scouring of the bed and the deepening of the channel. Erosion may result from the forces of precipitation, current, waves, wind, ice, slope failure, and other causes. These forces, as well as the hydraulic forces within the bank, affect the shoreline in different ways: the relative contribution of any one factor to bank failure is highly site-specific and varies according to bank materials, vegetation, climatic conditions, stage of river flow, amount of riparian development, and other factors.

There are two general types of bank protection:

1) Those which retard flow along the bank and thereby promote deposition. Permeable groins and revetments constructed of piling, rock, tetrahedrons, concrete, trees, or other materials are examples of protection that cause deposition. Groins may be designed to deflect the current away from the bank. Revetments are placed on or parallel to the bank. Both are designed to reduce the velocity of flow adjacent to the bank so that erosion will be halted.

2) Those which protect the bank from direct erosion and scouring. Living vegetation, brush matting, riprap, concrete slabs, and asphalt lining are examples of revetment or protective bank cover. The type of protection needed for a specific case is determined largely by the characteristics of the stream.

5.1 Vegetation

Vegetation can attenuate wave action, reduce current velocities, buffer the bank against the impact of floating ice and debris, act as a shoreline sediment filter, add structural support (roots) to the bank, and provide habitat for aquatic and terrestrial wildlife. Vegetation is the least expensive, most visually attractive, and the least complex method of stemming bank erosion. The major disadvantage of vegetation is that its usefulness as the sole method of bank protection is limited in areas where velocities are great and banks are steep and high. Two significant problems in attempting to use vegetation as the sole bank protection are (1) establishing the stand and (2) stabilizing the section of the bank below normal water surface so that vegetation will not be undercut and the bank will not slough into the stream.

To retard velocity, vegetation is used most successfully above the waterline on properly sloped banks and on the flood plain adjacent to the banks. Vegetation always should be used in back of revetments (the area where silt deposition occurs), on the banks above design flows, and on slopes protected by brush mats.

Many species of plants, shrubs, or trees are suitable for riverbank protection. The locally available, erosion-resistant species best adapted to the soil, moisture, and climatic conditions of a particular site should be used. Adaptable types of vegetation, properly placed, can provide desirable bank protection. Perennial grasses should be used rather than annual grasses. The trees, brush, vines, or grasses selected for use as vegetative protection should be of some useful variety that will resist erosion, and withstand sedimentation and prolonged inundation.

Protective vegetation cover also expands wildlife habitat, enhances recreational opportunities, and improves water quality; it is the only self-renewable method of bank protection. Advice on the types of vegetation to be used, methods of planting, and the proper times for planting should be obtained from agencies that specialize in that type of work. The U.S. Soil Conservation Service is a good place to obtain this information.

5.2 Channel Clearing and Snagging

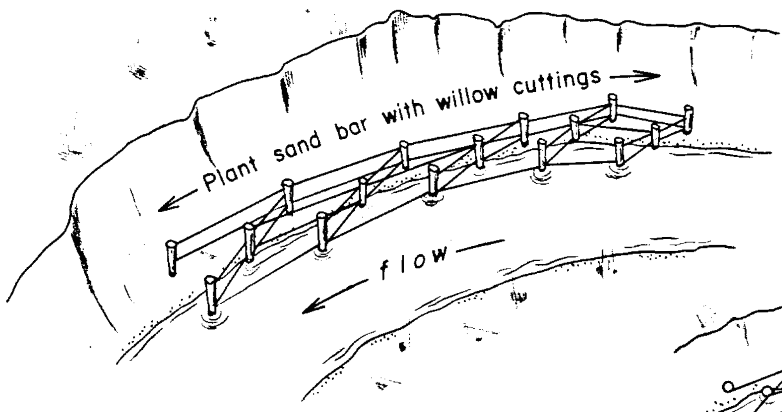
Unless they are providing fish habitat, sediment bars, snags, stumps, debris drifts, trees, and brush should be removed from the river channel when they disrupt the flow. When a bank is endangered by trees (4-inch diameter and larger) that have been undercut and are falling into the channel, they should be considered for removal; this also applies to those trees that might collect debris and ice drifts along the riverbanks. In some cases of unstable soils, the weight of growing trees near the channel causes the sloughing of large sections of riverbank; these trees also are candidates for removal. Cleared trees may be used to construct a revetment at the site or at an adjacent site.

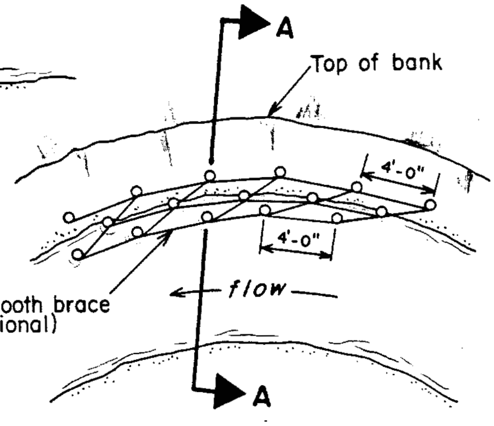
5.3 Jetted Willow Poles For Bank Protection

Willow poles are driven or jetted into the eroding bank at or above the normal waterline. Two or more rows are placed with the poles 2 to 4 feet apart and staggered between rows (Figure 8). The poles should be 6 to 9 feet long and 3 to 5 inches in diameter. About two-thirds of the pole length should be inserted below the ground line. Finally, the surrounding area is planted with willow cuttings or erosion resistant plants. This type of protection is particularly effective on smaller streams where ice damage will not be a problem, so its use on the Kenai River would be minimal.

5.4 Tree Revetment

A pervious revetment that is made from whole trees cabled together and anchored by deadmen buried in the bank is probably the cheapest form of semipermanent protection. Trees having a trunk diameter of 12 inches and larger are required to provide a good barrier. The trees should be laid along the bank with the butts upstream and with enough overlap to ensure continuous protection to the bank. The trunks are anchored to deadmen set in the bank by means of cable. Piling can be used in lieu of deadmen provided they can be driven well below the point of maximum bed scour.





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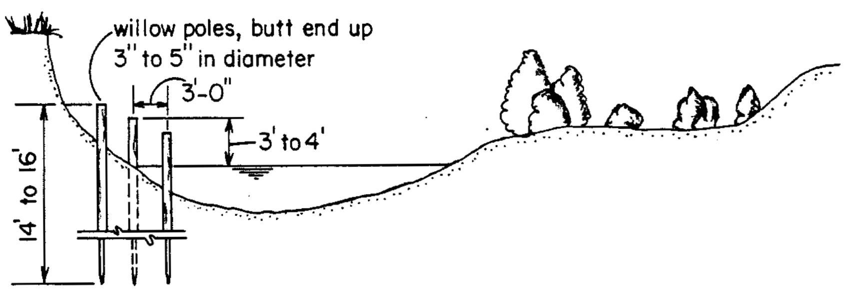

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Method:

Prepare a hole with jet pipe and hose by working the jet up and down to a depth of 10' to 12'. Leave jet in for half minute or so to be sure enough sand has been displaced to allow easy placing of pole. After the pole has been placed it should be secured by shoving the jet in a few times at an angle near the top of the hole. Use two rows of poles on long curves and four or five rows in sharp bends. Sand bar willow cuttings should be planted to form a living revetment. Protect against livestock until willows or other applicable species are established.

Equipment:

Centrifugal or other suitable pump, 150 G.P.M., (10' head), 2" discharge, 45' discharge hose, 15' inlet hose and 6' of 1¼" pipe for a jet.

Application.

This method is used in the smaller streams where there is no heavy ice or debris load and where the stream bed is sand or fine gravel.

Performance:

In a typical job, 800 feet long, 15 man days were used to cut and jet poles and tie the brace wires, jet pump was operated a total of 9 hours.

(From U.S. Soil Conservation Service Field Manual)

Figure 8. Jetted willow poles.

Trees have a limited life and must be replaced periodically. In the Kenai River, where heavy ice flows occur, considerable damage may be done to the trees. Loss of trees through damage or deterioration will again expose the bank to the current, and it will continue to undercut and erode unless the revetment is repaired.

The stability of the bank above the normal water level can be increased by planting trees and shrubs. Planting should be delayed until deposits of silt have formed behind the trees. The rapidity with which silting occurs in the revetted area depends on the amount of sediment transported by the streams.

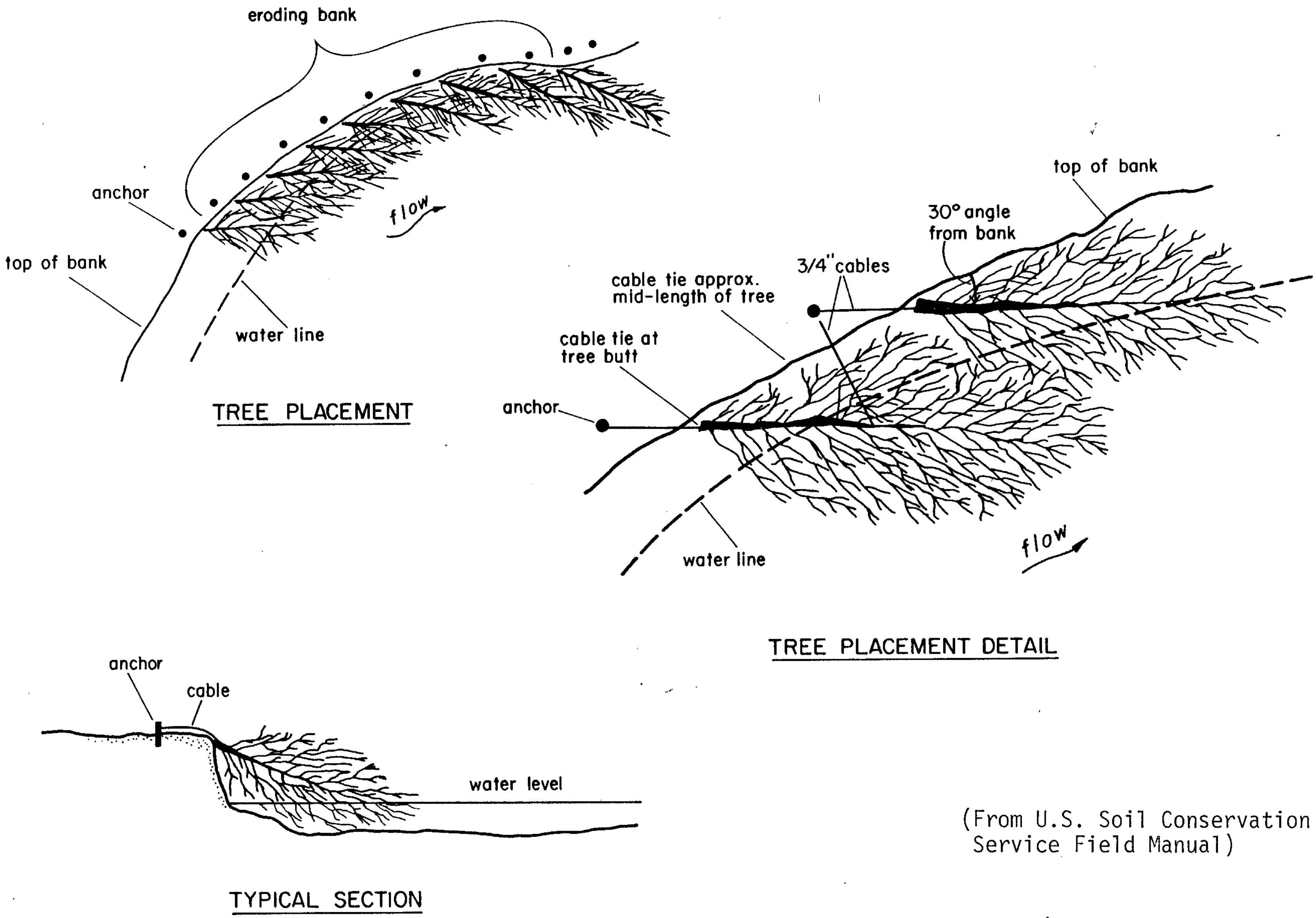
This type of protection is not good for use in the narrow side channels where channel width will be materially reduced by placement of trees. A typical tree revetment plan is shown in Figure 9.

5.5 Piling Revetment with Wire Facing

Continuous piling revetment with a facing of woven wire is a common type of protection. It is particularly adaptable to rivers where the depth of water next to the bank is in excess of 3 to 4 feet. In deep water, it has an advantage over riprap and brush mat construction because it is more economical, and it eliminates the problems involved in building a stable, underwater foundation. This type of protection is easily damaged by ice flows or heavy flood debris and should be used with caution where these conditions occur.

The piles are spaced from 6 to 8 feet on centers. Timber piles should have a diameter that is sufficiently large enough to permit driving to the required depth. Railroad rails or pipe may be used when available. The pilings are driven to a depth of approximately one-half of their length below the point of maximum scour. The pilings are carried to the height required to protect the bank.

A heavy grade of woven wire is fastened to the streamside of the pile. Its purpose is to collect debris and trash, which forms a permeable wall and



(From U.S. Soil Conservation
Service Field Manual)

Figure 9. Tree revetment.

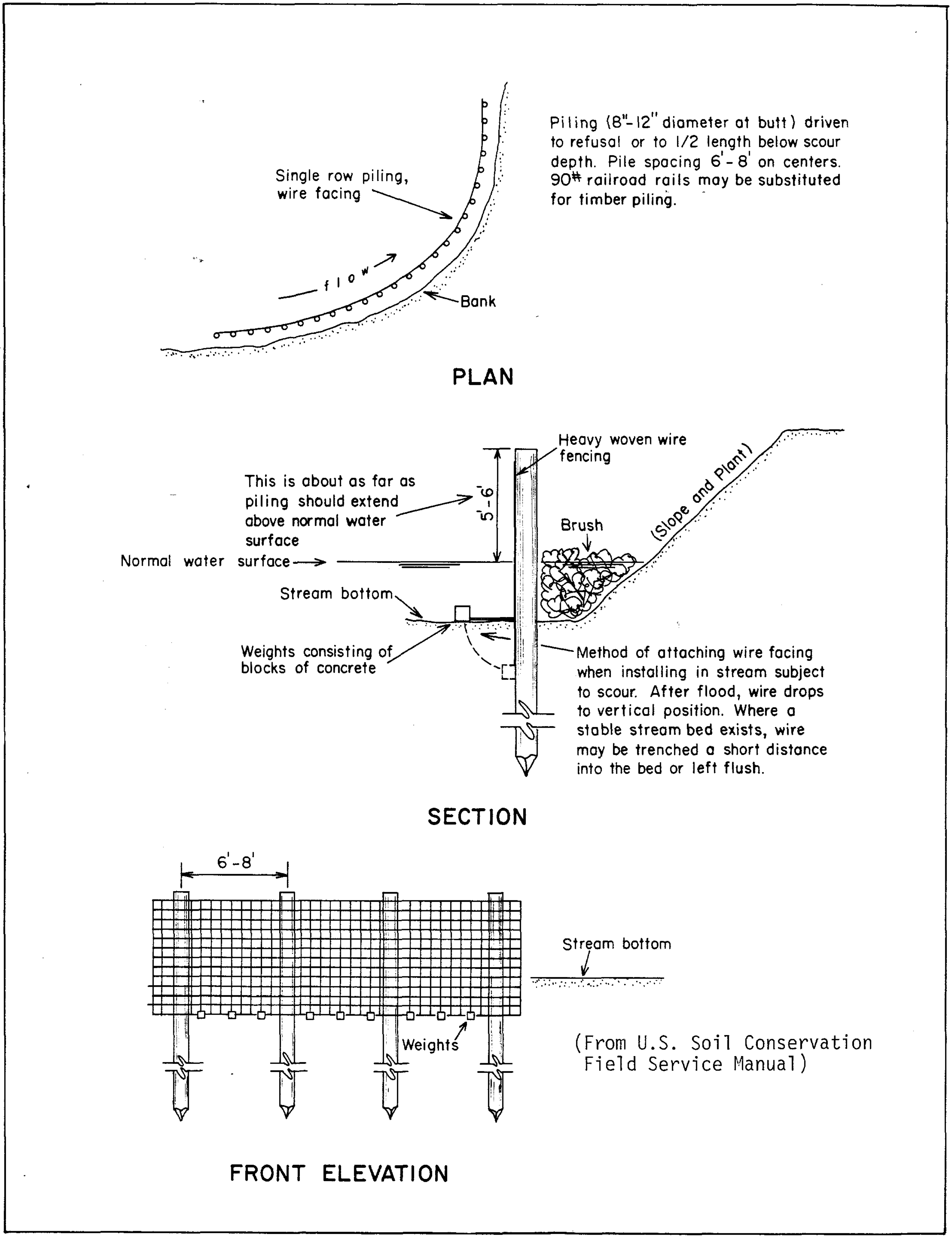
reduces.the water velocity on the bank side. If the river is subject to scour, the woven wire is extended horizontally along the riverbed for a distance that is at least equal to the anticipated depth of scour. Concrete blocks or other weights are attached to the bottom at regular intervals. When scouring occurs during floods, the weights will cause the wire to settle in a vertical position along the face of the pile. The piling can be strengthened considerably by connecting the tops with waling or by installing a system of cross bracing. The placement of brush and debris in back of the piling will increase the effectiveness. Typical details of a piling revetment are shown in Figure 10.

A more expensive type of construction, which gives more protection, is one that uses two rows of piling with rock and brush between them. The rock and brush are placed in wire baskets, which must be set in a trench that has been excavated to at least one-half or more of the depth of the anticipated scour. If the baskets settle, more material may be added to keep the brush and rock level with the top of the pile.

5.6 Riverbank Control with Jacks

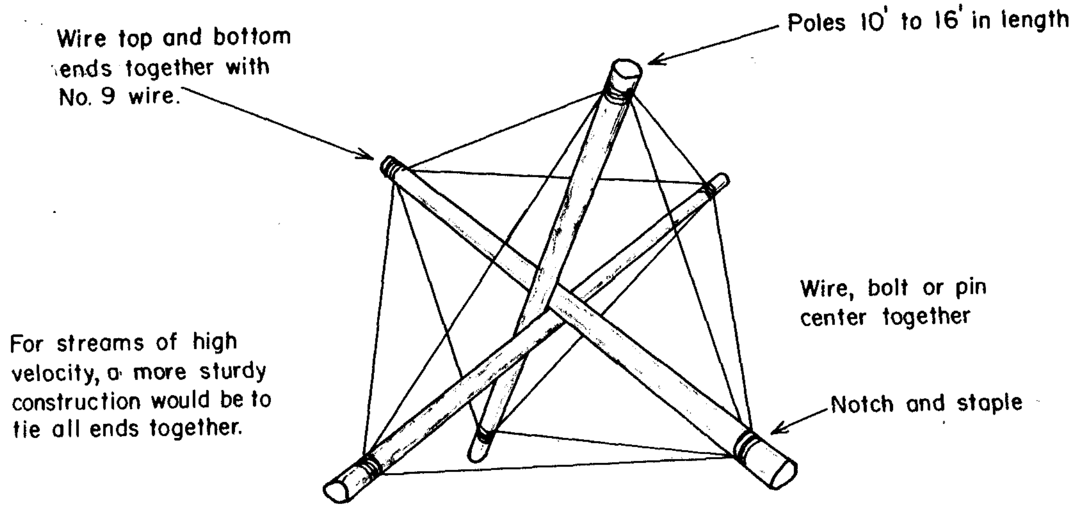
A method of riverbank control that can be used easily by property owners consists of the placement of one or more rows of "jacks" along the riverbank. These jacks are constructed out of three poles that are 10 to 16 feet in length, depending on the depth of the stream. The poles are crossed and wired together at the midpoints. The ends are then tied together with No. 9 wire, as shown in Figure 11.

The jacks should be spaced closely together (approximately one jack space apart). This will provide an almost continuous line of revetment (Figure 12). The jacks are held in place by a main cable that is clamped to the center of each jack. The upper and lower ends of this cable are tied to a deadman, which, in turn, anchors all the jacks as a unit. The cable should have a 1/2- to 3/4-inch diameter. The deadman should consist of a 6-foot timber, approximately 8 to 10 inches in diameter. Each jack should be weighted by rock, which can be wired onto the poles.



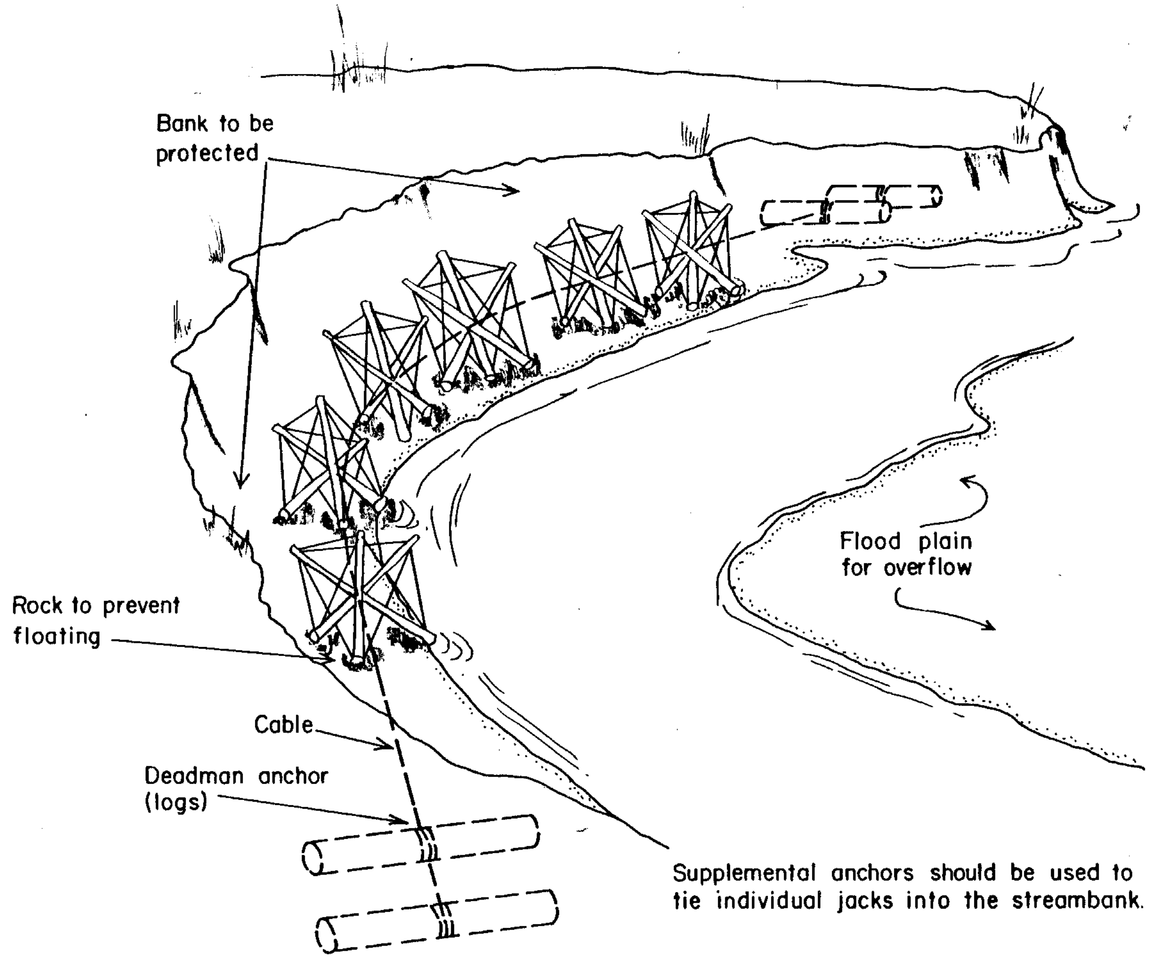
(From U.S. Soil Conservation Field Service Manual)

Figure 10. Piling revetment with wire facing.



(From U.S. Soil Conservation Service Field Manual)

Figure 11. Detail of jack.



(From U.S. Soil Conservation Service Field Manual)

Figure 12. Streambank control with jacks.

Where permanence is desired and when wood poles will not furnish the desired life span, angle irons, railroad rails, or reinforced concrete posts can be substituted for the poles.

5.7 Brush Mat Revetment

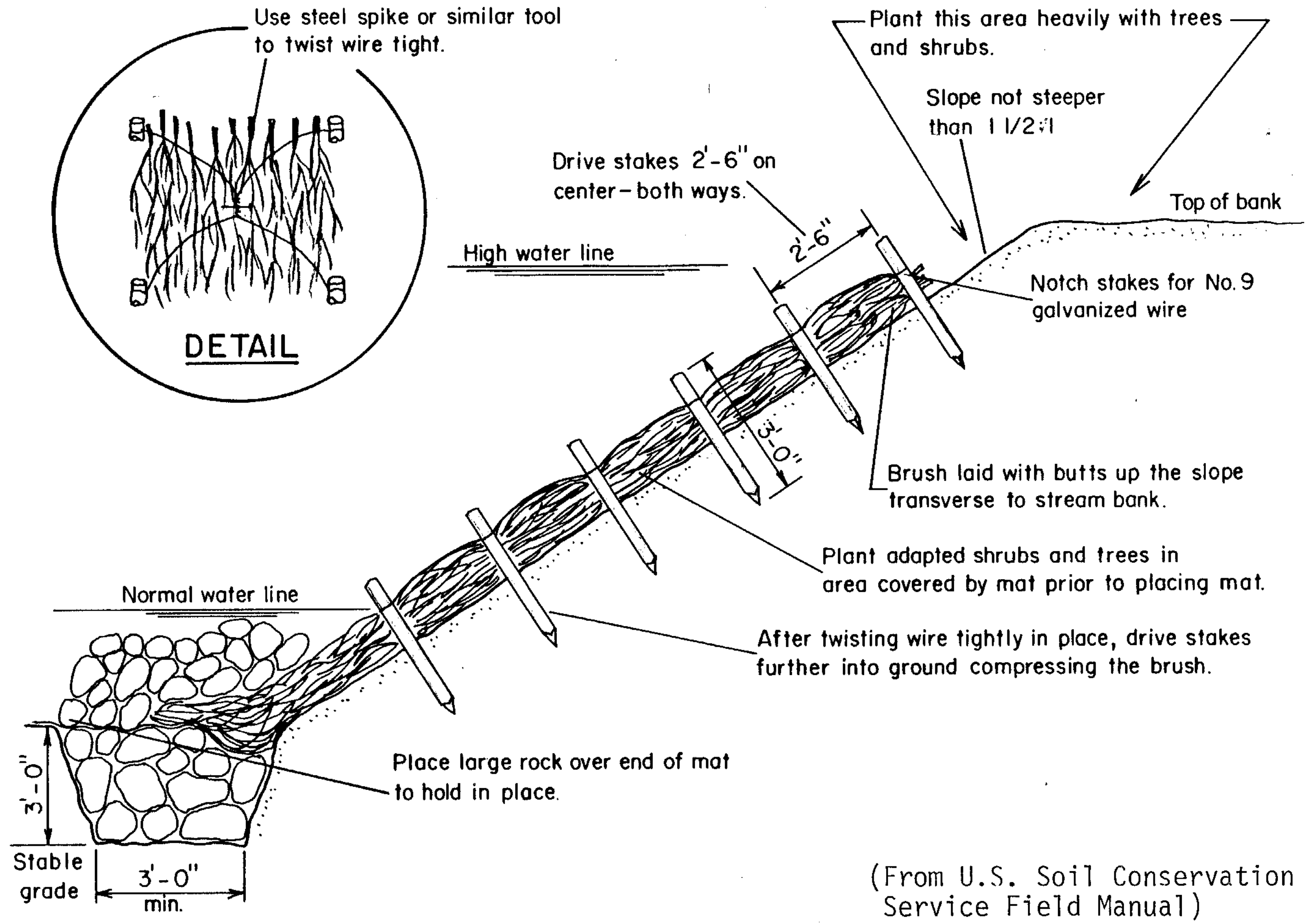
As a brush mat has a short life, its main value is to afford a mulch that will permit a dense growth of vegetation to take over. It is practical only at locations where willow brush and rock are available in quantities sufficient to meet the needs of the job.

Because it will be used as the base for the brush mat, the rock toe is placed first; it should be carried to the low point of the channel and be at least 18 inches thick to remove the danger of displacement during flood flows. It is, however, not practical to use a rock toe in rivers subject to channel scour during flood flows.

The sloped banks should be planted before the brush matting is applied. It is difficult to obtain a reasonable stand when planting new cuttings through a mat. The brush should be placed over the exposed soil as soon as possible after the bank is planted. The brush is laid shingle fashion with the butts pointing up the bank. The brush should be straight enough to lie flat on the bank. The mat should be 6 to 18 inches thick. After the wire is attached, the stakes are driven deeper, which tightens the wire and binds the mat firmly. The details of a brush mat riprap are shown in Figure 13.

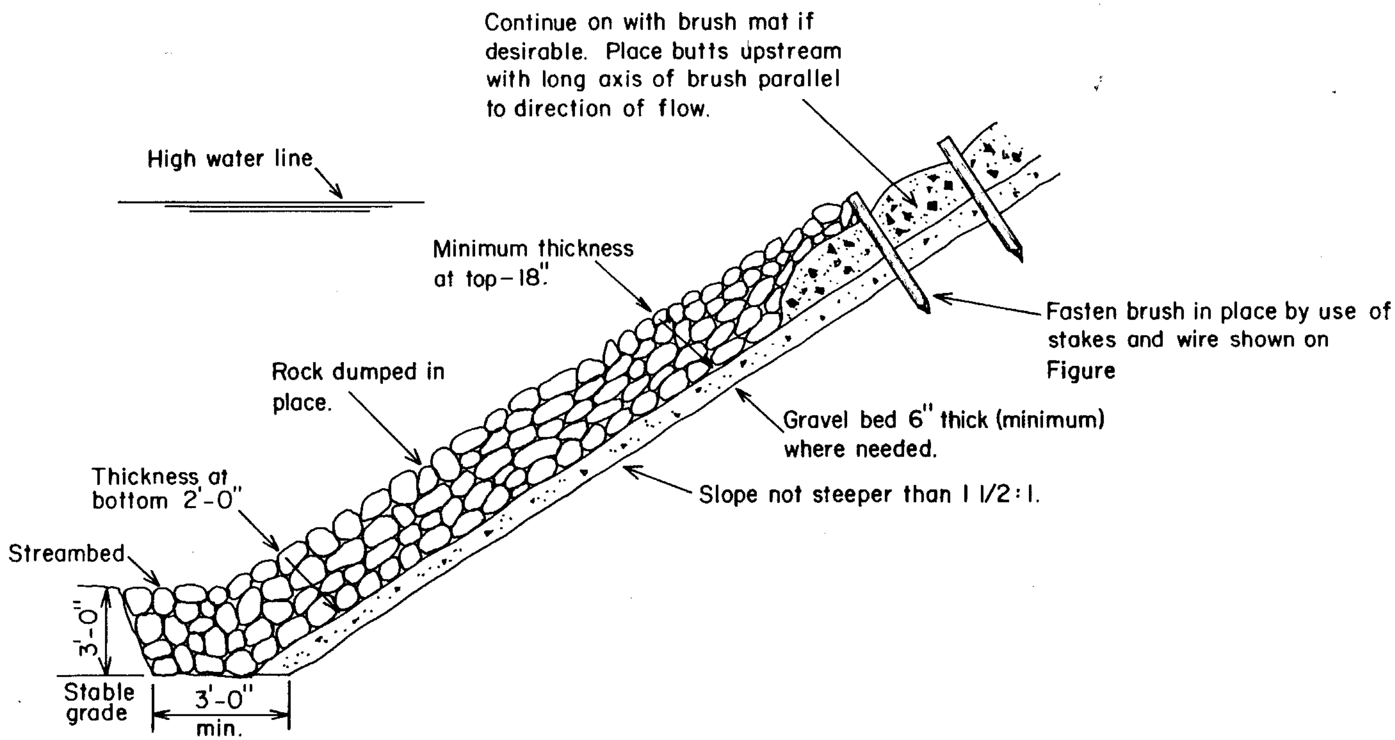
5.8 Riprap

Properly placed riprap is an effective method of riverbank protection. It is costly because of the difficulty of quarrying, transporting, and placing the stone. However, where stone of a suitable quality and gradation is available within 15 miles of the job, this method of protection should be given consideration. Remember, however, that riprap displaces bank vegetation and, thus, may destroy fish habitat (See Figure 14).



(From U.S. Soil Conservation Service Field Manual)

Figure 13. Brush mat revetment.



(From U.S. Soil Conservation Service Field Manual)

Figure 14. Dumped rock riprap.

5.8.1 Toe Protection

For successful riprapping, the toe of the revetment must be firmly established. This is important where the stream bottom is unstable or subject to scour during flood flows.

5.8.2 Bank Sloping

Banks on which riprap is to be placed should be sloped so that the pressure of the stone is mainly against the bank rather than against the stone in the lower courses and toe. This slope should not be steeper than $1\frac{1}{2}$:1.

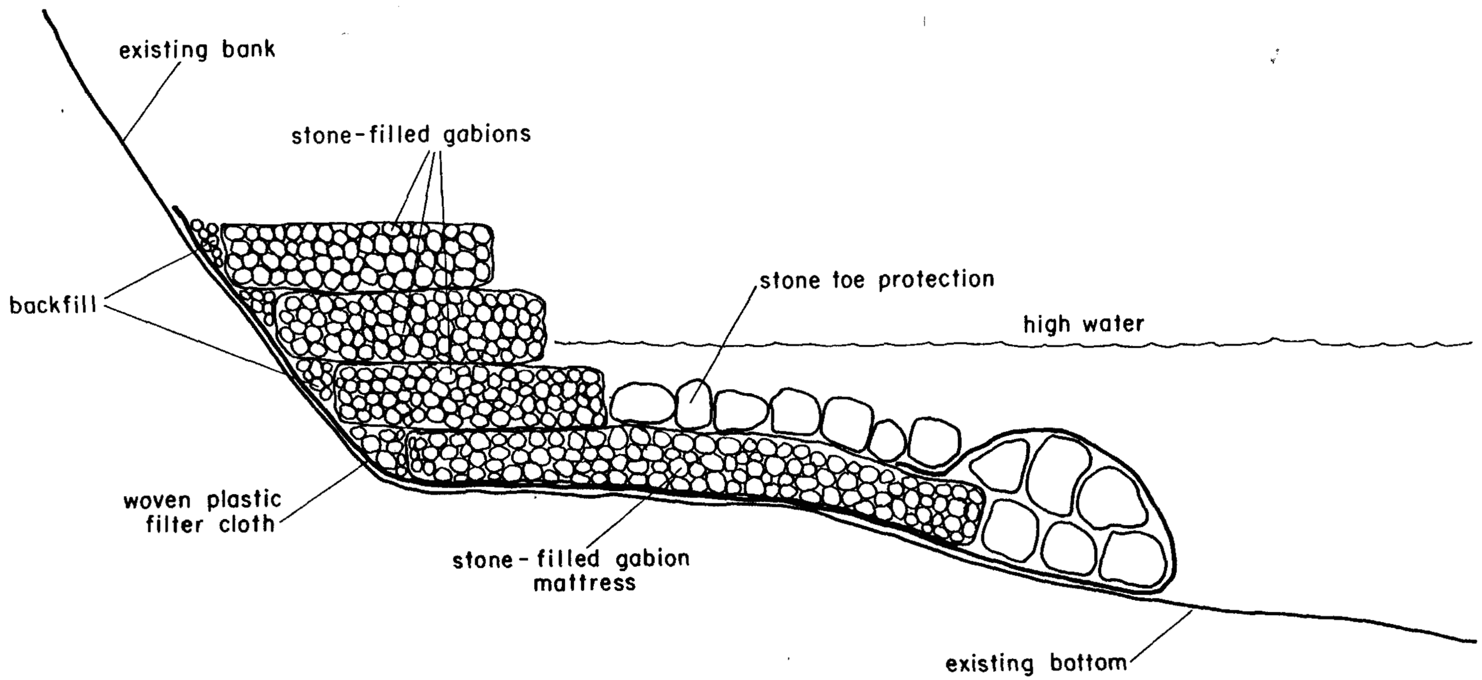
5.8.3 Filter Layer

A filter blanket must be placed between the riprap and the bank, except in those cases where the material in the bank to be protected is so graded as to constitute suitable filter material. This will prevent the removal of fines from the bank material by current and wave action and sloughing of the bank due to sudden dropping of the water level in the stream. Figures 15, 16 and 17 show the use of filter blankets with various types of "rock" revetments.

River material can be used if it is composed of relatively clean sand and gravel and if its removal does not destroy spawning beds. Where natural materials are not available, it will be necessary to use a manufactured filter.

5.8.4 Placing Stone

It should not be necessary to hand place the stones in a revetment. However, dumping on a slope must be done in a manner that will not cause separation of the small and large stones. The finished surface should not have pockets of finer materials that could flush out and weaken the revetment. Sufficient hand placing and chinking should be done to provide a good keyed surface.



(From U.S. Corps of Engineers pamphlet "Help Yourself")

Figure 15. Gabion revetment with plastic filter cloth.

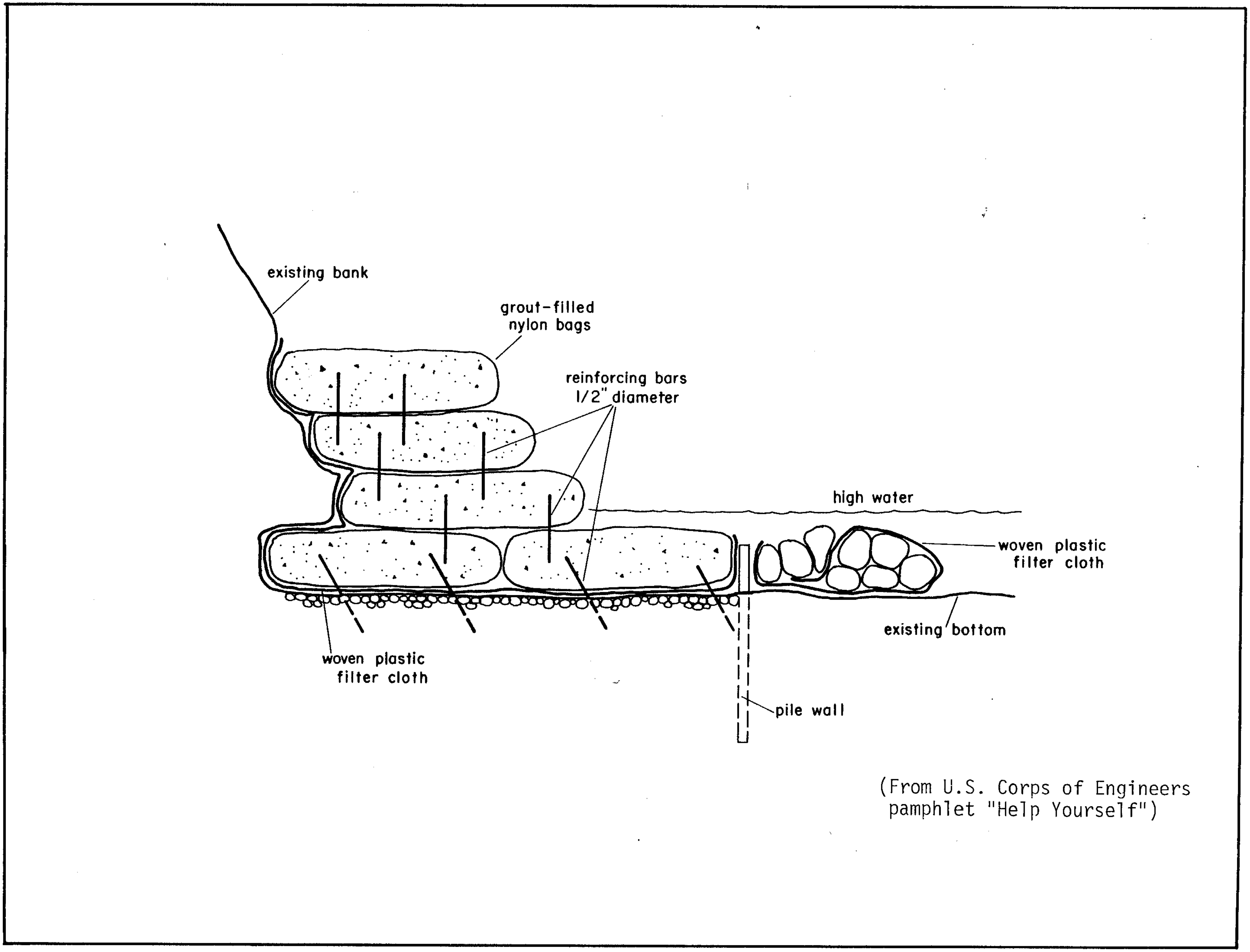
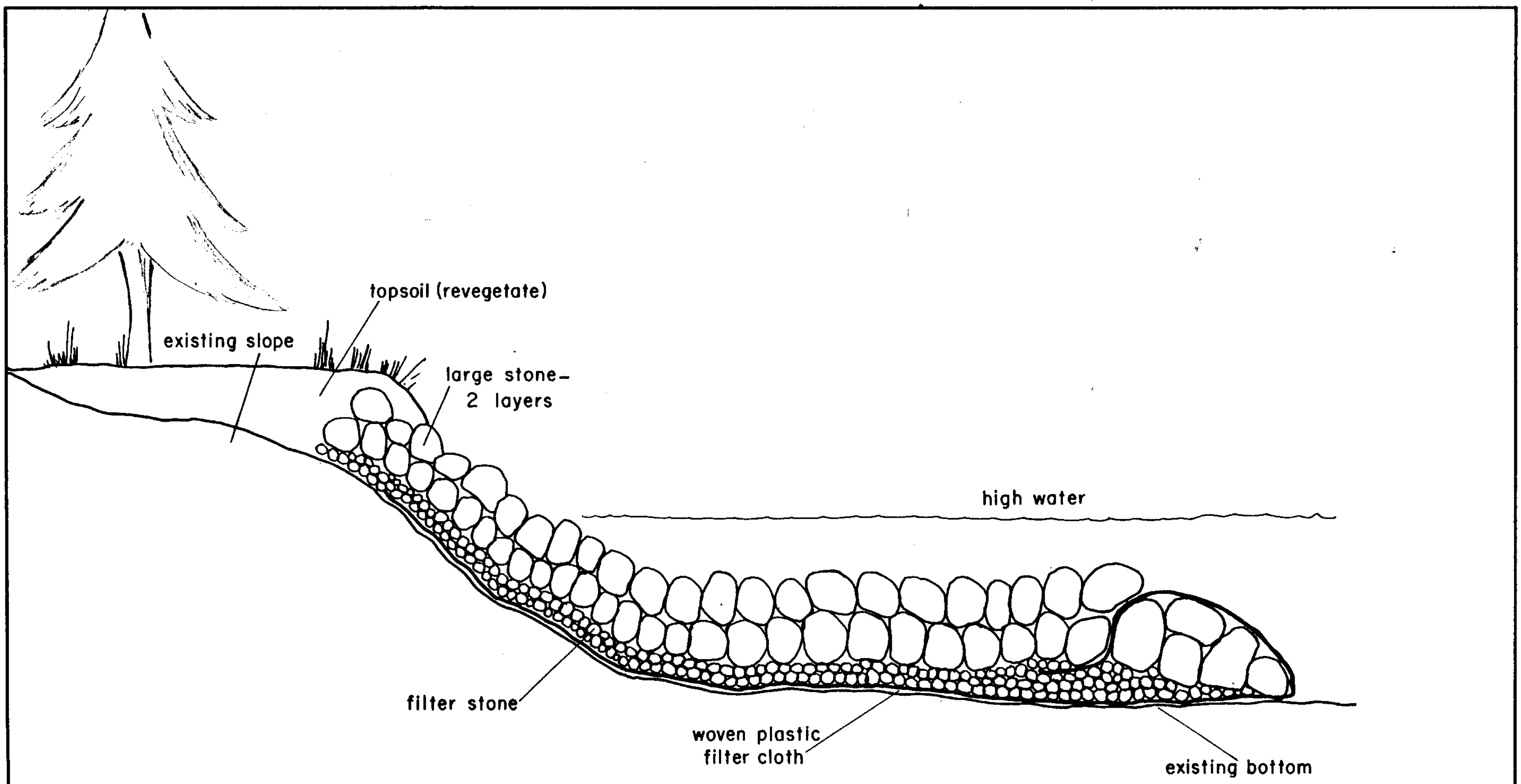


Figure 16. Grout-filled bags revetment with plastic filter cloth.



(From U.S. Corps of Engineers pamphlet "Help Yourself")

Figure 17. Stone revetment with filter blankets.

In all cases, the riprap should extend up the bank to an elevation where vegetation will provide adequate protection.

5.8.5 Stone Sizes

Stone size requirements vary. In some parts of the country, the river channels accumulate large columns of coarse material, ranging from gravel to large cobbles. As a result, the banks erode and widen. Successful bank erosion control can be accomplished by bulldozing the coarse material from the channel bottom, when it does not harm spawning beds, and spreading it over the raw banks. This provides cheap bank protection, but the process may have to be repeated after each high-water stage.

Stone size is determined by the debris, impact, and the velocity to be withstood by the protection system. However, stones for riprap use on the Kenai River will be in the 6- to 14-inch diameter range and will weigh from 25 to 175 pounds each.

Both the State of California Bank and Shore Protection manual and the U.S. Soil Conservation Service Engineering Field Manual for Conservation Practices (see reference section) provide excellent specifications concerning the design and the construction of rock, slope protection measures.

6. BANK PROTECTION MAINTENANCE

Continued maintenance of completed riverbank control measures is essential to avoid further riverbank damage. In planning for maintenance, it is important to keep the following points in mind:

1) Control measures, once installed, are not necessarily permanent. Usually, it is not economical to establish absolutely permanent controls.

2) The nature of the maintenance differs in accordance with the extremes in physical characteristics of the river and its tributaries.

Because the wandering of currents at flood or high-water stages cannot be precisely determined in advance, the amount and intensity of treatment cannot be completely foreseen. Therefore, careful examination of plantings and structures during the first few years following installation will disclose points of weakness.

7. DISCUSSION OF HABITAT PROTECTION MEASURES

7.1 Overview

The Kenai River is valued by different user groups for different reasons. The fisherman recognizes the value of the fish in the river but, perhaps, does not recognize the value of riverbank vegetation. The homeowner recognizes the erosion retarding value and the pleasing aesthetics of the riverbank vegetation, but may not be particularly interested in catching the fish; land developers have one interest, miners another, and additional examples are endless. All these interests are legitimate and, in most instances, interrelated. Sometimes, however, they are conflicting.

Similarly, there is often regulatory conflicts among the nearly 20 public agencies having jurisdiction over the river. Understandably, each agency feels that because its interests are of utmost importance, they should be given priority over other interests. With the increase in river use and because of the lack of a unified governing authority, many of the existing regulations are not being enforced. The following section describes the concerns for the Kenai River as viewed from the perspective of the Department of Fish and Game.

7.2 Alaska Department of Fish and Game Perspective

The ADF&G is responsible for protecting and enhancing the fish and game resources of the state. Accordingly, the highest value attributable to the Kenai River is its function as a producer of fish, and every possible effort must be made to protect this value. The ADF&G contends that in order to maintain the fish populations at their present levels, the riverbanks must be maintained in their natural state. Burger (1982) found that juvenile chinook salmon occupy a narrow range of river habitat, which is typically associated with pools along the margins of riffles or current eddies. In the summer months water velocity appears to be the greatest limiting factor for juvenile chinook salmon in their utilization of Kenai River habitat. The close association between juvenile chinook and low-water velocities necessitates the availability of irregular bank habitat during high discharge periods. Bank irregularities form small pools and current eddies and create optimum water velocity zones downstream of the irregularities. Moreover, these irregularities, together with overhanging vegetation, have contributed to higher catch rates of juvenile chinook. Channelized banks and banks that have been altered result in smooth bank profiles that increase water velocities beyond the useable limit for rearing chinook.

7.3 Specific Protection Measures

7.3.1 Regulation Measures

Currently, there are nearly 20 federal, state, and local government agencies having some form of regulatory authority over the river. A summary review of the various existing regulations indicates that adequate protection measures are in place. For instance, the Corps of Engineers, through Section 10 of the River and Harbor Act of 1899 and through Section 404 of the Federal Water Pollution Act, as amended by the Clean Water Act of 1977, can prevent the discharge of fill into rivers, prohibit any activities that have an adverse effect on fish and wildlife, prevent activities that increase erosion of streambank or tidal flats, and prevent other types of activities that are detrimental to the environment. In anadromous fish waters, the state's Title 16 (AS 16.05.870) permit program, administered by ADF&G, controls activities that "...use, divert, obstruct, pollute or change the natural flow or bed of a specified (anadromous) river, lake or stream...".

Alaska Department of Environmental Conservation regulations prohibit the installation of septic systems closer than 100 feet from water bodies, and other agencies have similar water quality protection regulations.

The habitat degradation problem (bank erosion and habitat destruction) is not due to the lack of regulations; rather, it is due to the lack of enforcement of existing regulations. However, the increased threat of development and the serious adverse impacts involved necessitate special management action.

The Kenai River Task Force (unpublished paper) recommended the creation of a unified commission to replace the diversified agencies that are now attempting to regulate activities along the river.

7.3.2 Riparian Development

During the river inspection trip of August 1983, many instances of bank damage were noted. Some of the problems include clear-cutting of forested areas, the alteration of riverbanks (vegetation removal), the construction of boat launching ramps, mooring piers, groins, and retaining walls, and the destruction of riparian vegetation by vehicles and foot traffic. Water pollution from septic tank effluent, oil spills, and waste materials are development-related problems that are also contributing to the river's degradation.

7.3.2.1 Building Line Limits

Presently, there are few regulations governing the proximity of a building to the river's edge. The COE recommends a 100-foot setback for structures located on high bluffs (Figure 18), but it does not appear that many home builders are following that recommendation. Even on low banks, where erosion may not cause catastrophic bank failure, structures have been built much too close to the river's bank. Many of the low bank structures have been constructed in the floodplain where erosion hazards are often indistinguishable from flood hazards. Because there is a large variation in the topography along the river and because different geological factors resist erosion to different degrees, each river lot may need its own building line limit. However, certain minimal setback limits are justifiable. Structures that are to be built on low banks should not be constructed closer than 100 feet to the river; structures that are to be built on

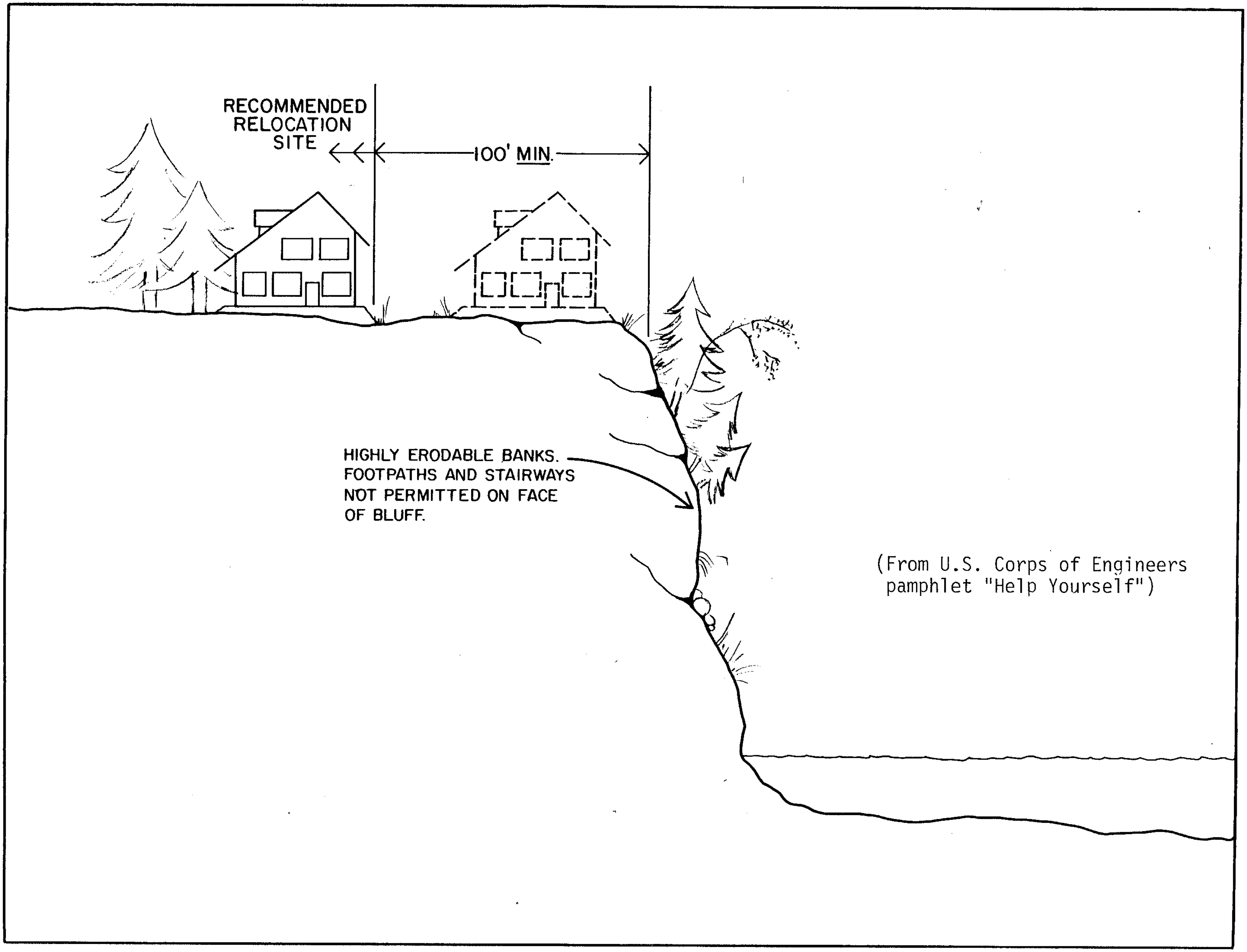


Figure 18. High bluff setback limit.

high bluffs should not be constructed any closer than 150 feet to a bluff's edge.

7.3.2.2 Riparian Land - Bank Buffer Zone(s)

If the Kenai River is to continue to function as one of the state's major salmon producing rivers, it is imperative that the riverbanks be maintained in their natural state. The destruction of the river's vegetation, by any means, should not be allowed.

An excellent management practice to protect riparian ecosystems is to leave a buffer zone of natural vegetation along the river's course. Preferably, the buffer zone would be retained in public ownership, but this is not mandatory if an acceptable agreement for maintenance can be established with the property owner(s). The zone must be of sufficient width to protect water quality and quantity, to provide terrestrial habitat, and to provide for a variety of recreational opportunities. The width of the buffer zone(s) should be determined according to the slope of the land, severity of erosion problem, type of existing vegetation, and the type of development expected.

Many local and state governments have adopted criteria establishing buffer zones along water bodies. Some buffer zones extend from a minimum of 25 feet to as much as 300 feet. The United State Forest Service (USFS) suggests a minimum buffer of 54 feet (Barnes 1973). Furthermore, Table 3 provides the U.S. Agricultural Service buffer zone recommendation for areas of high sedimentation. It is our recommendation that buffer zones be established along the Kenai River (Figure 19).

7.3.2.3 River Access

The full value of the river cannot be realized unless there is access to the river for user groups; however, all access must be controlled to the extent that the ecosystem is maintained in a healthy state. Following are

Table 3 - Minimal buffer zones widths for protection of riparian land recommended to the U.S. Agricultural Research Service (Adopted from Barnes 1973).

Slope (%)	Slight Erosion (ft)	Moderate Erosion (ft)	Severe Erosion (ft)
0	30	35	45
10	55	65	80
20	80	95	115
30	105	125	150

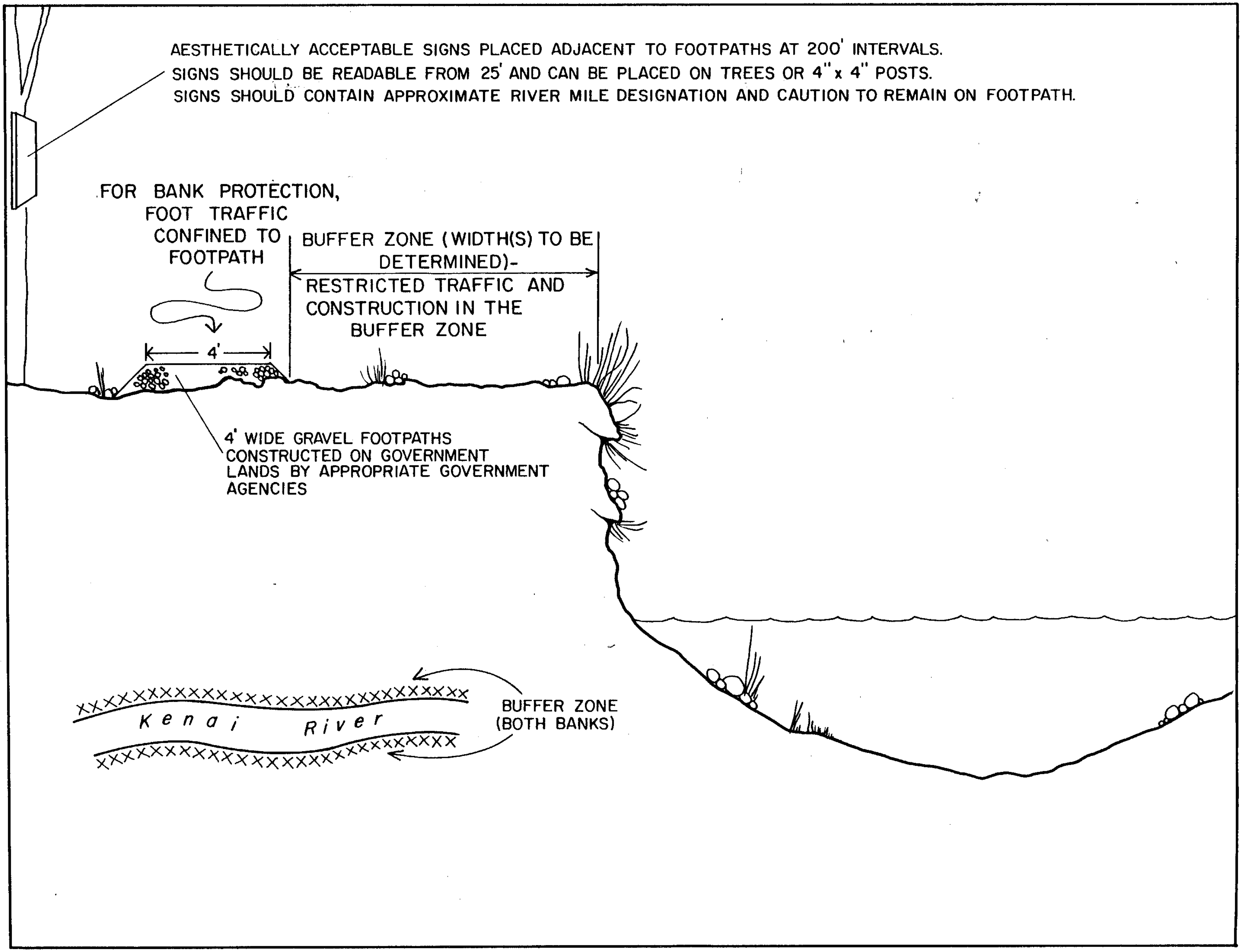


Figure 19. Riverbank buffer zone.

descriptions of types of access that will allow entry to the river with minimal degradation of the ecosystem:

1) Public Boat Launching Facilities

Because all riverbank alterations cause the loss of irreplaceable fish habitat and accelerate the rate of bank erosion, the construction of boat launching facilities should be limited to those sites where construction will have minimum impact on the bank stability. Not only is it extremely important that the facilities be properly designed, but it is vital that they receive proper and continued maintenance. These facilities should be strategically sited to allow convenient access by all user groups and to minimize degradation of the habitat. They should be designed to minimize operational and maintenance costs. Siting of the facilities will require coordinated planning to incorporate the needs of other agencies, e.g., the Department of Natural Resource's Division of Parks, which is planning construction and/or improvement projects for 12 state parks along the lower Kenai River. In some instances, the parks may require the construction of boat launching facilities, and coordinated planning would prevent the duplication of facilities.

2) Riparian Landowner's River Access

It would be best not to alter the natural condition of the riverbanks by constructing numerous boat launching ramps, docks, jetties, revetments, or other structures. Individuals having riverfront property should consider gaining access to the river via the launching facilities described above. They could have direct access to the river via shore-placed docks of designs similar to the concept depicted in Figure 20.

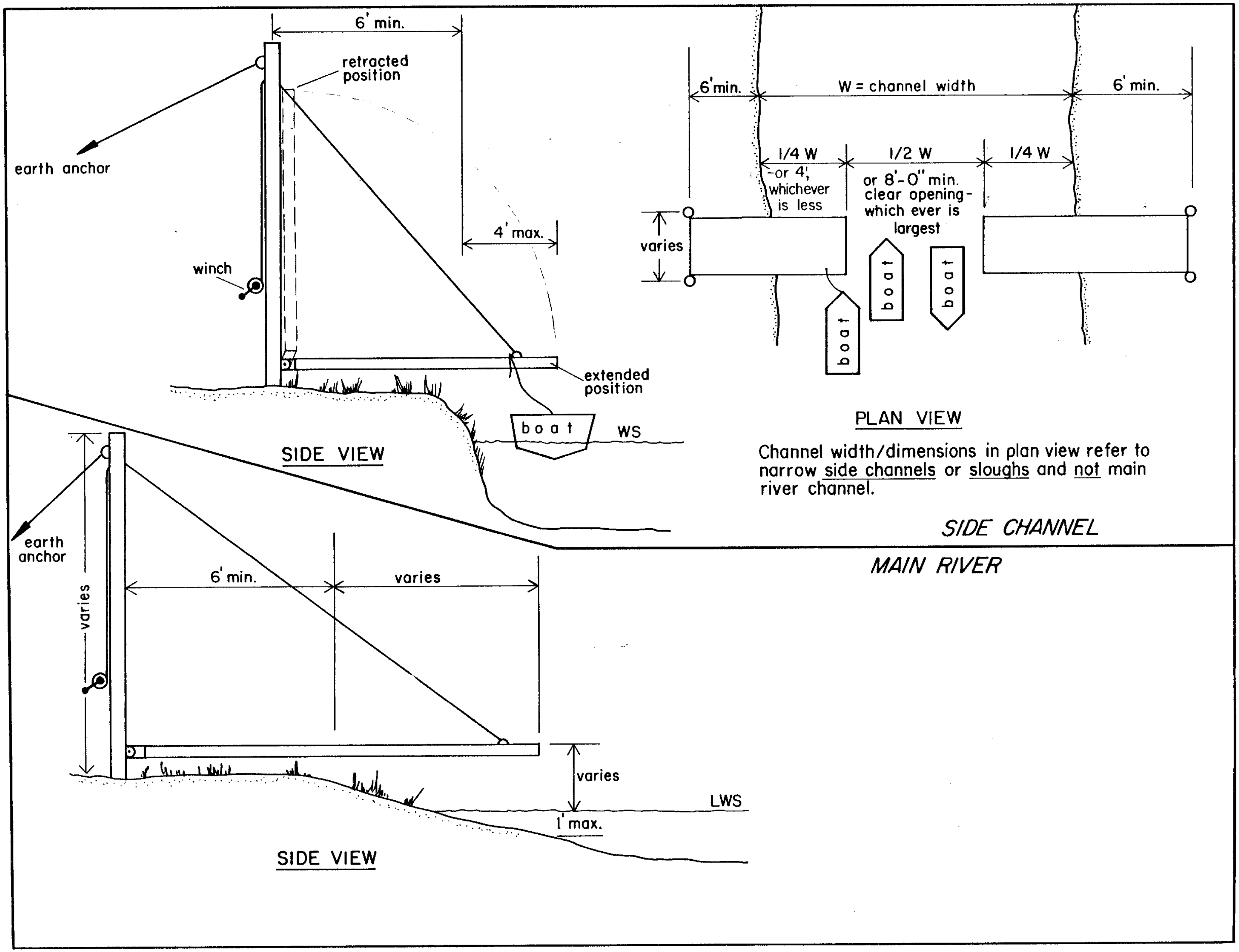


Figure 20. Retractable boat dock.

3) Foot Traffic

Field observations of well-used foot paths indicate that a sizeable amount of foot traffic is developing along the river. In many places the bank vegetation has been destroyed, and erosion has started. If the foot traffic can be diverted to the inland side of an established buffer zone (see 7.3.2.2), much bank vegetation could be saved. Public foot paths could be constructed along the inside edge of the buffer zone. Location signs could be placed at convenient intervals. Lateral access paths could be constructed to fishing holes or viewpoints (see Figure 19). To inform the public about the frailty of riverbank vegetation, educational materials could be presented through local newspapers, radio and T.V. stations, ADF&G announcements, and by the placing of signs along the footpaths. Public use of footpaths would significantly reduce the amount of damage to riparian lands.

7.3.3 Bank and Instream Restoration

The riverbanks and the riverbed are the incubation ground and nursery for all species of the river's fish; most construction activities on the banks or instream cause damage to these areas. Construction should only be permitted where the project is necessary for the needs of the public, e.g., bridge abutments or construction associated with a crossing of a public utility. Even then, the construction should be scheduled to coincide with the seasons that will minimize damage to the fish resource, i.e., give due regards to timing of fish spawning and migration.

Currently, there are many groins and instream structures that have been constructed in the river that serve no useful purpose other than, perhaps, to provide some measure of convenience to the person(s) who constructed them. Many of the structures have been built without the permits required by the COE. Some structures have not been adequately designed, constructed, or maintained. In many instances, the structures are becoming aesthetically unattractive, and their presence is altering river flow patterns as well as inducing erosion at other points in the river. It is recommended that private instream structures not be permitted, that unauthorized structures (structures not having COE permits) be removed, and that existing permitted instream structures be removed once their permit has expired. Permits for bankside structures, similar to the one shown in Figure 20, and structures needed to prevent bank erosion would only be issued after review and approval by the COE or the designated controlling authority/commission.

As the best form of bank stabilization is a heavy cover of natural vegetation and because the natural vegetation and associated riverbank habitat is a vital part of the rearing habitat for fish, it is important that damaged bank vegetation be restored. Therefore, when removing instream structures it will be necessary to initiate a revegetation program that will restore the damaged banks to their original conditions. Revegetation can be a difficult task, and technical assistance will be needed. Technical advice on reseeding, types of vegetation, fertilizers, and other considerations can be obtained from ADF&G's Habitat Protection Division, DNR's Division of Parks, the U.S. Soil Conservation Service, or from private sources in the plant nursery business.

7.3.4 Engineered Solutions

The banks of the Kenai River need to be maintained in a natural state consisting of heavy vegetation. Heavy vegetation promotes bank stability and provides the habitat necessary for the survival of juvenile fish. Maintenance of bank vegetation is prioritized as follows: (1) regulatory protective measures, (2) restoration of damaged vegetation, and (3) engineering solutions.

Engineering solutions receive the lowest emphasis because their implementation usually replaces the fish-producing bank vegetation with sterile, non-fish producing habitat. These solutions are aesthetically less attractive, are costly to construct, and require continual maintenance.

However, there are places in the river where bank stability has been destroyed, and the only remaining solution to retarding the advances of erosion is to implement an engineered solution. There is a wide variety of engineered erosion control measures that can be adapted for use on the Kenai River. There are, however, many more methods in use, other than the ones described in this report, and a single erosion control measure will not be appropriate for all sites and conditions. The COE is the foremost authority on erosion control, and their Flood Plain Management Services pamphlet Help Yourself (n.d.) illustrates many erosion control measures that are in common use. The California Department of Highway's manual Bank and Shore Protection (1979) is another excellent reference source. Locally, there are many competent, private engineering firms that are capable of designing erosion control structures that will be suitable for use in the Kenai River. As the COE is responsible for issuing permits for the construction of instream structures, interested parties are advised to seek advice from that source.

8. SUMMARY

Because of the large variation of factors contributing to bank erosion and habitat destruction along the Kenai River, this report does not attempt to list recommendations for the entire 50-mile river corridor from Skilak Lake to Cook Inlet. Instead, this report identifies the major contributors to bank erosion and provides general management guidelines to mitigate the resulting problems. Moreover, it points out that a single solution, i.e., engineered erosion control measure, will not be able to solve all problems, and that a series of site specific designs and regulations will have to be employed. The data needed to form the basis for all management decisions will have to be collected for individual segments of the river. The data collection segments may even have to be reduced to lot-by-lot surveys.

8.1 Management

Possibly the single greatest factor contributing to the degradation of the Kenai River riparian ecosystem is the lack of concerted management. The ordinances, codes, and regulations that are needed to protect the ecosystem are in existence, but there is little effort being made to enforce them. The Kenai River Task Force (unpublished paper) recommended the creation of a Kenai River Commission to replace the multitude of governing agencies that are now managing the Kenai River. This recommendation should be adopted and implemented at the earliest possible date.

8.2 Development

Riparian development is a major contributor to the degradation of riverfront lands and the destruction of irreplaceable wildlife habitat. This development can, however, be accommodated without appreciable destruction of the habitat if proper control measures are employed. Management techniques that establish buffer zones, define construction setback limits, restrict the alteration of riverbanks, and restore damaged or destroyed riverbank vegetation must be initiated.

8.3 Boat Traffic (Wake Erosion)

Boat traffic on the Kenai River has increased dramatically in the last few years. Discussions with many people who are familiar with the river suggest that boat wake erosion may now be rivaling riparian development as a major source of bank erosion. Specific data, quantifying the amount of erosion caused by wake action in the Kenai River, could not be located; however, the Mississippi River research data (summarized in section 4.1.4.3) indicates that boat traffic and wake erosion are major contributors to riverbank erosion. As with erosion caused by development, wake erosion is not a uniform problem throughout the full 50-mile stretch of the river. Until baseline data are available, boat wake control measures should be aimed at reducing the conditions that contribute to wave height. Wave height reduction could be accomplished by adapting regulations that restrict speed, engine size, boat size, hull draft, volume of traffic, and areas of access (off-limit zones). The simplest regulation to impose would be the restriction of speed: speed limits could be posted throughout the river on floating buoys or on shore-placed markers. To be effective, the speed regulations would have to be rigidly enforced.

8.4 Bank Maintenance

The riverbank vegetation is critical habitat for fish and wildlife, and it constitutes the best and most lasting bank protection available. Maintaining the natural vegetative cover of the banks should be the highest priority of any management agency; it should be accomplished through regulation and enforcement as well as through the education of the river's user groups. In cases where erosion is a problem, the first effort toward reducing its rate should be by means of revegetation. If that is not successful, then consideration should be given to the relocation of threatened structures. If revegetation and relocation projects prove to be inadequate, then engineered erosion control measures should be implemented.

8.5 Critical Habitat Areas

There are certain portions of the river, e.g., prime spawning areas, that are more important than others for the propagation of fish. These areas need to be identified and classified as critical habitat areas. One area that may fall into this category is the 3- or 4-mile stretch of river that begins at the outlet of Skilak Lake. Even our experienced guide had trouble traversing this portion of the river without striking sandbars with the boat hull or propeller. The inexperienced boat operators may also have difficulties in traversing this important spawning area. Currently, the department does not have data on the effects of boat traffic on spawning fish, but studies of this kind are underway in Bristol Bay and on the Susitna River. Hopefully, they will provide answers to similar questions about the Kenai River.

8.6 Riverbed Restoration

Numerous groins, embankments, docks, and other structures have been built in the river without COE authorization. Many of these structures do not appear to serve any useful public function. Several of the structures divert the erosive force of the river to other locations or, in some cases, they may cause loss of juvenile salmon rearing areas because of the buildup of silt in the slack water behind them. Figure 4 depicts an area of the river near RM 38 and shows where some of the structures are located. It is recommended that no future instream structures be permitted and that existing permits not be reissued once the permit expires. Illegal structures and structures with expired permits should be removed from the river.

8.7 Public Works Projects

It would be best if the riverbanks were maintained in their natural vegetated state; however, this condition is not possible as some alterations for essential public works projects will be required. Even so, bank alterations must be kept to a minimum, and it is recommended that projects that alter the natural state of the banks be restricted to public work projects, i.e., bridges, utility crossings, boat launching facilities, or governmentally-approved erosion control projects.

9. ACKNOWLEDGMENTS

This report is, in large measure, one result of the work conducted by the Kenai River Task Force, which performed its functions during the later months of 1982 and the early months of 1983. It was the actions of the Kenai River Task Force that emphasized the need for a concerted study effort and initiated efforts to secure the funds needed for this study.

Thanks go to Steve Hammarstrom, Jay Carlin, Larry Marsh, and Pat Rice of the Sport Fish Division in Soldotna for providing the boats, equipment, and guide service during the river inspection trip in August. Gary Liepitz of the Habitat Protection Division in Anchorage participated in the field trip and provided valuable information for the report in the form of aerial photographs. George Cunningham, Carol Downing, Cindy Smith, Teresa Leaf, Bob Burkett, Sid Morgan, and Ken Leon of the FRED Division provided excellent help during the field trip, drafting of figures, typing, and editing of the report.

Also, thanks go to the unnamed personnel in the Habitat, Commercial Fisheries, and Sport Fish Divisions who edited the draft report and who provided a large amount of the data which went into this completed report.

10. REFERENCES

Alaska Department of Fish and Game. 1982. Aquatic habitat and instream flow studies. Susitna Hydro Aquatic Studies. Phase II: Basic Data Reports. Vol. 4, Part II. Anchorage, Alaska.

Alaska Department of Natural Resources. Kenai River State Park Units Master Plan. March 1983.

Barnes, R. C. Jr. 1973. In Clark, J. R. 1977. Coastal Ecosystem management: a Technical Manual for the Conservation of Coastal Zone Resources. John Wiley and Sons. New York. 928 pp.

Bhowmik, N. G. 1975. Development of criteria for shore protection against wind-generated waves for lakes and ponds in Illinois. Illinois University at Urbana-Champaign. Contract No. DI-14-31-0001-5013. Prepared for Water Resources Center, Office of Water Research and Technology, Washington, D.C. Report No. UILU-WRC-76-0107. 50 pp.

Bhowmik, N. G., M. Demissie, and S. Osakada. 1981. Waves and drawdown generated by river traffic on the Illinois and Mississippi Rivers. Illinois State Water Survey Division, SWS Contract Report No. 271 for Environmental Work Team, Upper Mississippi River Basin Commission Master Plan Task Force, Minneapolis, Minnesota. September 1, 1981. 98 pp.

Bhowmik, N. G., R. L. Evans, J. R. Adams, and M. Demissie. 1980. Identification and prioritization of study needs on the physical and chemical impacts of navigation. Draft Report. Illinois Institute of Natural Resources, State Water Survey Division, Champaign. 26 pp.

Bhowmik, N. G., and R. J. Schicht. 1980. Bank erosion of the Illinois River. Illinois State Water Survey, Champaign. Report of Investigation 92. 52 pp.

Bumm, H., F. Jambor, H. Kohler, K. Pichl, and A. Rohnisch. 1973. New materials and new methods for protecting the banks and bottoms of canals, rivers, and ports. Their cost and respective advantages. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi. Translation No. 73-4. 37 pp.

Burger, C. V., D. B. Wangaard, R. L. Wilmot, and A. N. Palmisano. 1982. Salmon investigations in the Kenai River, Alaska, 1979-1981. U.S. Fish and Wildlife Service, Anchorage, Alaska. 178 pp.

Camfield, F. E., R. E. L. Ray, and J. W. Eckert. 1980. The possible impact of vessel wakes on bank erosion. Prepared by U.S. Army Corps of Engineers, Fort Belvoir, Virginia, for U.S. Department of Transportation and U.S. Coast Guard, Washington, D.C. Report No. USCG-W-1-80. 114 pp. NTIS No. ADA-083 896.

Das, M. M., and J. W. Johnson. 1970. Waves generated by large ships and small boats. Proceedings of Conference on Coastal Engineering (Washington, D.C.) 13:2281-2286.

Duff, D. (Chairman). 1980. Position paper on management and protection of western riparian stream ecosystems. Western Division American Fisheries Society. Tualatin, Oregon. 24 pp.

Hay, D. 1969. Ship waves in navigable waterways. Proceedings of Conference on Coastal Engineering, American Society of Civil Engineers 11(vol. 2):1472-1487.

Hynes, H. B. N. 1970. The ecology of running waters. University of Toronto Press, Toronto, Canada. 555 pp.

Johnson, J. W. 1969. Ship waves in shoaling waters. Proceedings of Conference on Coastal Engineering, American Society of Civil Engineers 11(vol 2):1488-1498.

Karaki, S., and J. Van Hoften. 1974. Resuspension of bed material and wave effects on the Illinois and Upper Mississippi Rivers caused by boat traffic. Colorado State University, Fort Collins. Contract No. LMSSD 75-881. Prepared for U.S. Army Corps of Engineers, St. Louis District. 30 pp.

Lubinski, K. S., H. H. Seagle, Jr., N. G. Bhowmik, J. R. Adams, M. A. Sexton, J. Buhnerkempe, R. L. Allgire, D. K. Davie, and W. Fitzpatrick. 1981. Information summary of the physical, chemical, and biological effects of navigation. Illinois Natural History Survey and Illinois State Water Survey. Submitted to Environmental Work Team, Upper Mississippi River Basin Commission, Minneapolis, Minnesota. 132 pp.

Meehan, W. R., F. J. Swanson, and J. R. Sedell. 1977. Influences of riparian vegetation on aquatic ecosystems with particular reference to salmonid fishes and their food supply. Pages 137-145 in R. R. Johnson and D. A. Jones (Tech. Coord.), importance, preservation and management of riparian habitat: a symposium. United States Department of Agriculture, Forest Service General Technical Report RM-43. Washington, D.C.

Merritt, R. W., and D. L. Lawson. 1978. Leaf litter processing in floodplain and stream communities. Pages 93-105 in R. R. Johnson and J. F. McCormick (Tech. Coord.), strategies for protection and management in floodplain wetlands and other riparian ecosystems. United States Department of Agriculture, Forest Service Technical Report WO-12. Washington, D.C.

Platts, W. S. 1982. Vegetation requirements for fisheries habitats. United States Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. Boise, Idaho. 4 pp.

Rummel, B. W. 1982. Agricultural practices and water quality effects. Alaska Department of Environmental Conservation. Anchorage, Alaska. 82 pp.

Schulz, R. M. 1978. River tow behavior in waterways. Report 1, Exxon Test Program. Schulz Associates, Lafayette, California. Prepared for U.S. Army Engineer Waterways Experiment Station, Hydraulics Laboratory, Vicksburg, Mississippi. Technical Report H-78-17. 142 pp.

Simons, D. B., R-M. Li, M. A. Alawady, and J. W. Andrew. 1979. Report on: Connecticut River streambank erosion study, Massachusetts, New Hampshire, and Vermont. Colorado State University Research Institute, Fort Collins. Prepared in cooperation with Water and Environmental Consultants, Inc., Fort Collins, Colorado for U.S. Army Corps of Engineers, New England Division, Waltham, Massachusetts. Report No. CSU-213. 256 pp.

Sorenson, R. M. 1973. Ship-generated waves. Pages 49-83 in V. T. Chow ed. Advances in hydroscience, Vol 9. Academic Press, New York.

Sparks, R. E. 1975. Possible biological impacts of wave wash and resuspension of sediments caused by boat traffic in the Illinois River. Illinois Natural History Survey, River Research Laboratory, Havana. Prepared for U.S. Army Engineer District, St. Louis, Missouri. 23 pp.

State of California - Department of Public Works - Division of Highways. Bank and Shore Protection in California Highway Practice. 1970.

U.S. Department of Agriculture - Soil Conservation Service. Engineering Field Manual for Conservation Practices. April 1975.

U.S. Department of the Army, Alaska District, Corps of Engineers. Kenai River Review-Final. April 1978.

_____. Flood Plain Management Services. "Help Yourself", a discussion of the critical erosion problems and alternative methods of shore protection.

_____. Rock Island District, Corps of Engineers. Streambank Erosion Control Methods. U.S. Government Printing Office: 1980-652.712.

U.S. Geological Survey. Erosion and Sedimentation in the Kenai River, Alaska. Geological Survey Professional Paper 1235.

U.S. Fish and Wildlife Service. Salmon Investigations in the Kenai River, Alaska. 1979-1981.

_____. Manual of Stream Channelization Impacts on Fish and Wildlife. FWS/OBS-82/24. July 1982.

_____. Resource Publication 149. Mitigation and Enhancement Techniques for the Upper Mississippi River System and Other Large River Systems.

APPENDIX A

LIST OF TERMS

Anabranching: The separation of a river into a number of entwined channels.

Armor: Artificial surfacing placed on the banks of a stream to resist erosion or scour.

Bank Protection: Placement of revetment of other armor to stabilize a streambank against erosion or use of a river training structure designed to deflect the hydraulic erosive forces away from a streambank.

Biochemical Oxygen Demand (BOD): The quantity of dissolved oxygen taken up by nonliving organic matter in the water.

Bridge Abutment: The part of a bridge that supports the end of the span and prevents the bank from sliding under it.

Bulkhead: A vertical or nearly vertical structure supporting a natural or artificial embankment.

Buoy: A floating object attached to the bottom of a waterway, used for marking moorage.

Canal: In this report, canal refers to the man-made channels excavated inland from the river. Purpose of the canal(s) is to provide river access and moorage for boat owners.

Channel: Refers to the bed of the Kenai River.

Crib: An open-frame structure filled with earth or rock ballast designed to absorb energy and to deflect hydraulic currents away from a streambank.

Cross Section: A vertical section (profile) of the surface, the ground, and/or underlying material, which provides a side view of the structure.

Cut Bank: The concave wall of a meandering stream that is maintained as a steep or overhanging cliff by the impinging streamflow against its base.

Dike (sill, groin, spur, jetty): A river training aid constructed of earth, wood, or rock, designed to deflect erosive currents away from a bank and to control movement of bed material.

Dock: A place for the loading/unloading of people/goods from boats. Docks observed on the Kenai River included artificial basins (cutouts in the riverbank), floating wharfs, piled platforms, and cribbed structures.

Dredging: Dredge means to dig under water. In the Kenai River dredging, for docks or boat canals, disturbs the stream substrate which is detrimental to salmon spawning and which may alter stream flow and current patterns.

Embankment (levee): A fill, usually earth or rock, whose top is higher than the adjoining surface. When used in or near water, an embankment is called a levee.

Erosion: The wearing away of land by the action of nature or man.

Fence: A river training structure normally consisting of mesh attached to a series of posts often in double rows; the interstitial space between the rows may be filled with rock, brush, or other locally available materials.

Fill: An earth or rock structure or embankment used to raise a grade and/or extend property limits. Fill was observed along the Kenai River being used to extend property limits into the river or wetlands.

Filter: Layer of sand, evenly graded rock, or cloth, placed between the bank armor and soil for one or more of three purposes: to prevent the soil from coming through the armor by extrusion or erosion, to prevent the armor from sinking into the soil, and to permit natural seepage from the streambank to occur and thus prevent buildup of excessive hydrostatic pressure.

Floodplain: The flood-prone lowlands and relatively flat areas adjoining inland and coastal waters, including contiguous wetlands and floodplain areas offshore islands; this will include, at a minimum, that area subject to a 1% or greater chance of flooding in any given year (100-year floodplain).

Groin: A structure built from shore into water for protection against erosion, to direct the axis of flow, to promote scour and sediment deposition, and to trap bedload to build up new banks. Kenai River groins are being used for property extension, fishing piers, boat mooring, and other purposes.

Habitat: The specific place where a particular plant or animal lives--where interacting physical and biological factors provide at least the minimum life requirements for one organism or for a group of organisms occurring together.

Impermeable: Not permitting passage of water.

Jack (Kellner Jack): A component of a river training structure consisting of wire or cable strung on three, mutually perpendicular metal, wooden, or concrete struts.

Jetty: (1) On open seacoasts, a structure extending into a body of water, and designed to prevent shoaling of a channel by littoral materials, and to direct and confine the stream of tidal flow. Jetties are built at the mouth of a river or tidal inlet to help deepen and stabilize a channel. (2) In British usage, jetty is synonymous with PIER or "wharf."

Levee, Natural: Low alluvial ridge adjoining the channel of a stream composed of sediment deposited by floodwater which has overflowed the banks of the channel.

Lower Bank: That portion of a streambank having an elevation less than the mean water level of the stream.

Meandering: Extremely looping or winding flow of a river over a flattish area such as on tidal flats.

Overhead Utility Crossing: Utility line (telephone/electrical) corridors where the transmission line routes have been cleared of trees and tall brush. Several overhead utility line crossings span the Kenai River between RM 0 & 50.

Permit: A document issued by the Department of the Army expressing the assent of the Federal Government, so far as concerned the public rights of navigation and the general public interest, for the accomplishment of certain works on or adjacent to navigable waters of the United States.

Pier: A structure, usually of open construction, extending out into the water from the shore, to serve as a landing place or recreational facility, rather than to afford coastal protection.

Pile: An elongated member, usually made of timber, concrete, or steel, that serves as a structural component of a river training structure.

Ramps: An inclined driveway used for launching boats.

Revetment: A reinforced facing (concrete, rock, steel) used on a bank to retain a desired slope.

Riparian Ecosystem: Riparian ecosystems consist of a water body (river, stream, lake, etc.) and adjacent plant communities that are influenced by the presence of the water. Along rivers and streams, riparian ecosystems, which include vegetation communities, streambanks, and the stream channel, are located within the riverine floodplain.

Riparian Land: The land situated along the banks of the river.

Riprap: Broken rock, in pieces usually weighing from about 15 to 150 pounds each, placed on earth surfaces for protection against erosion.

River Training Structure: Any configuration constructed in a stream or placed on, adjacent to, or in the vicinity of a streambank which is intended to deflect currents, induce sediment deposition, induce scour, or in some other way alter the velocity regiment of the stream.

Scour: Erosive action--particularly, pronounced local erosion--of water in a stream, in excavating and carrying away materials from the bed and banks.

Sediment: Fragmental material that originates from weathering of rock and is transported by, suspended in, or deposited by water or air.

Silt: Sediment particles with diameters of 0.004 to 0.062 mm.

Sinuous: Bending or winding river flow, but not as circuitous as meandering flow.

Slips: A pier, platform or sloping ramp extending to the water's edge and used for the purpose of loading/unloading boats/float planes.

Spawning: Deposition of fertilized eggs, by fish and certain other aquatic animals.

Stream Piracy: The natural diversion of one stream into the channel of another.

Toe: That portion of a stream cross-section where the lower bank terminates and the channel bottom or the opposite lower bank begins. The base of a structure, the lowest part.

Trench-Fill Revetment: Rock, concrete, or ceramic material placed in a trench dug behind and parallel to an eroding streambank. When the erosive action of the stream reaches the trench, the material placed in the trench retards further erosion.

Underfit: Greatly reduced in volume and, therefore, in ability to erode or transport as a consequence of stream piracy.

Upper Bank: That portion of a streambank having an elevation greater than the mean water level of the stream.

Vegetation: Woody or nonwoody plants used to stabilize a streambank and retard erosion.