Prepared in cooperation with the
Alaska Department of Environmental Conservation and
Alaska Department of Fish and Game

Effectiveness of Streambank-Stabilization Techniques Along the Kenai River, Alaska

Water-Resources Investigations Report 99-4156

U.S. Department of the Interior
U.S. Geological Survey

Cover: View of site near river mile 21, Kenai River, Alaska

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U.S. GEOLOGICAL SURVEY

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CONVERSION FACTORS

Multiply	by	To obtain
inch	25.4	millimeter
foot	0.3048	meter
mile	1.609	kilometer
square foot	0.09290	square meter
cubic foot	0.02832	cubic meter
foot per second	0.3048	meter per second
mile per hour	1.609	kilometer per hour
cubic foot per second	0.02832	cubic meter per second
pound per foot	1.488	meter per foot

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ABSTRACT

The Kenai River in southcentral Alaska is the State's most popular sport fishery and an economically important salmon river that generates as much as $70 million annually. Boatwake-induced streambank erosion and the associated damage to riparian and riverine habitat present a potential threat to this fishery. Bank-stabilization techniques commonly in use along the Kenai River were selected for evaluation of their effectiveness at attenuating boatwakes and retarding streambank erosion. Spruce trees cabled to the bank and biodegradable man-made logs (called "bio-logs") pinned to the bank were tested because they are commonly used techniques along the river. These two techniques were compared for their ability to reduce wake heights that strike the bank and to reduce erosion of bank material, as well as for the amount and quality of habitat they provide for juvenile chinook salmon. Additionally, an engineered bank-stabilization project was evaluated because this method of bank protection is being encouraged by managers of the river. During a test that included 20 controlled boat passes, the spruce trees and the bio-log provided a similar reduction in boatwake height and bank erosion; however, the spruce trees provided a greater amount of protective habitat than the bio-log. The engineered bank-stabilization project eroded less during nine boat passes and provided more protective cover than the adjacent unprotected natural bank. Features of the bank-stabilization techniques, such as tree limbs and willow plantings that extended into the water from the bank, attenuated the boatwakes, which helped reduce erosion. These features also provided protective cover to juvenile salmon.

INTRODUCTION

Background

Streambank erosion and sedimentation have been recognized as substantial non-point sources of pollution throughout the nation (Duijsings, 1986; Lietman and others, 1984; Odgaard, 1984; U.S. Army Corps of Engineers, 1981; von Guerard, 1989). Furthermore, these geomorphic processes are contributing causes for significant salmon population declines in anadromous river systems (American Society of Civil Engineers, 1992; Beschta, 1989; Bjorn, 1969; Hansen, 1971; Klingeman and others, 1990; Meehan, 1974; Meehan and Swanston, 1977). Riparian areas that provide cover and food sources for juvenile salmon are destroyed by streambank erosion, which subsequently increases the transport and deposition of sediment. Spawning gravels thereby become clogged with deposits of fine sediment. The effect is a reduction of salmon numbers because of habitat loss (Beschta, 1989). In addition, many bank-protection, stabilization, or restoration techniques currently in use provide poor fish habitat. For example, concrete block retaining walls can very effectively protect a bank from eroding; however, the smooth flat face of the wall provides little habitat suitable for fish.

Boatwakes cause bank erosion and resuspend streambed sediments, which can degrade water quality (Byrd and Perona, 1980; Dezman, 1990; Dorava and Moore, 1997; Garrad and Hey, 1987 and 1988; Jackivicz and Kuzminski, 1973a, 1973b; Nanson and others, 1994; Schoellhamer, 1990; Smart and others, 1985; von Krusenstierna, 1990; Yousef and others, 1978). Boatwake-induced erosion and habitat loss in important salmon-rearing areas can reduce the number of salmon ultimately available to fishermen and threaten the fishery. Bank-stabilization techniques and erosion control measures are commonly used to protect water quality and fisheries, but have had varied success (Dezman, 1990; Garcia, 1988; Nelson,1986; Trimble, 1997).

The fisheries in the Kenai River in southcentral Alaska (fig. 1) generate as much as $70 million annually (Liepitz, 1994). Because of the economic importance of these fisheries, managers of the river are concerned about anything that may threaten the fishery. Paramount among their concerns are those activities such as accelerated bank erosion from boatwakes and streamside development that are directly related to fish and fish habitat. Chinook salmon are the primary target species for sport fishermen on the Kenai River. Rearing habitat for juvenile chinook salmon is one of the principal factors limiting production of this fishery. Juvenile chinook salmon in the Kenai River commonly rear in areas within about 6 feet of the streambank, where water velocities are less than 1 foot per second, stream substrate is greater than 1.5 inches in diameter, and abundant cover can protect them from predators (Bendock and Bingham, 1988; Burger and others, 1982; Estes and Kuntz, 1986; Liepitz, 1994; Raleigh and others, 1986). These rearing habitat features are easily altered by boatwake-induced streambank erosion and streamside development. In particular, the cover provided by streamside vegetation is commonly removed by development or destroyed by streambank erosion.

The Kenai River salmon fisheries may be threatened by streambank erosion generated by boatwakes (Dorava and Moore, 1997; Reckendorf, 1991; Scott, 1982). As the State's population and river use increase, boatwake-induced streambank erosion and the associated riparian and riverine habitat losses most likely will also increase. Bank-stabilization techniques that are effective at reducing bank erosion by attenuating the effects of boatwakes and provide habitat for rearing juvenile chinook salmon would be valuable to the economy, to streamside property owners, and to wildlife, river, and land management agencies. Numerous streambank-stabilization techniques have been developed and deployed along the Kenai River; however, few of these have been designed specifically to provide protection from boatwakes.

The ultimate design goal of bank stabilization is not to minimize erosion, but to create a maintainable environment, because mobile natural stream channels are dynamic, not static (Thomas, 1990). During this study, three bank-stabilization techniques commonly used along the Kenai River were evaluated. These techniques were compared for their effectiveness in providing protection from boatwake-induced damage to riparian and riverine habitat important to juvenile chinook salmon. The study was supported in part by funds designated for mitigation of non-point source pollution provided by the Alaska Department of Environmental Conservation, and for habitat restoration provided by the Alaska Department of Fish and Game.

Objectives and Approach

The two primary objectives of the study were (1) to evaluate how effectively three streambank-stabilization techniques reduce the maximum height of boatwakes striking the bank and retard boatwake-induced streambank erosion and (2) to evaluate the amount and suitability of potential fish habitat provided by those techniques.

The approach used to address these objectives was to make three types of measurements:

(1) The average maximum height of boatwakes striking the bank was measured. The boat-

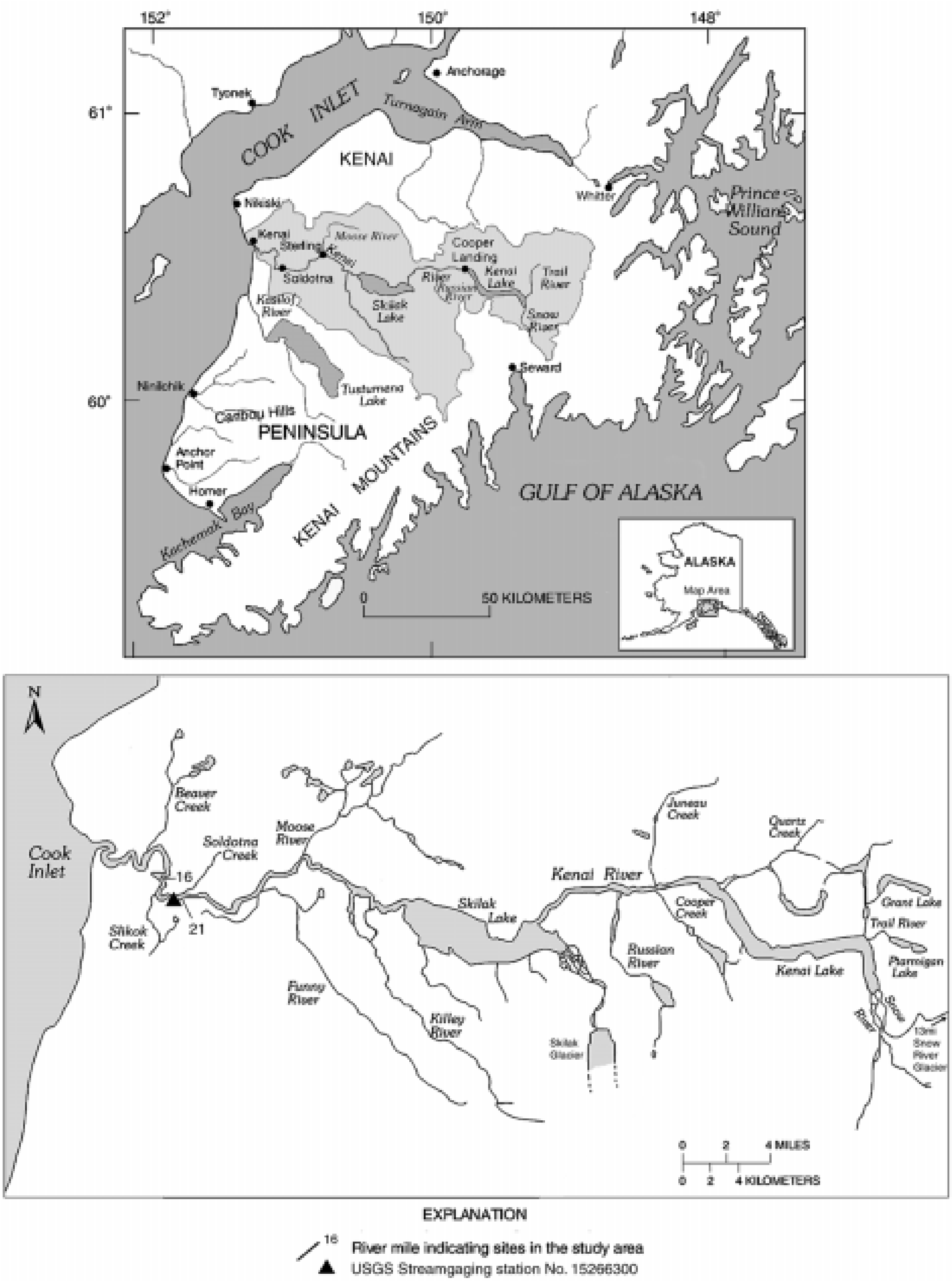

Figure 1. Location of Kenai River, Alaska, and sampling sites at river miles 16 and 21.

wakes were measured with a float encased in a screen mesh and attached to a paper chart recorder. These wake-recording instruments were also used in previous studies to evaluate the effects of boatwakes on streambank erosion and are described in greater detail by Dorava and Moore (1997).

(2) The average weight of material eroded from each foot of the streambank was measured. The material was collected in a 12- by 18- by 2-inch baking pan pinned to the stream bottom near the base of the bank with the 12-inch side parallel with the streambank. The average weight of material collected in the pan while no boatwakes were striking the bank was subtracted from the weight of material collected in the pan during each boat pass. The amount of material collected in the pan may have been less than was eroded from the bank. Some material may not have stayed in the pan because of the washing action of numerous wakes that occur with a single boat pass. This pan-collection method was also used by Dorava and Moore (1997) to evaluate the effects of boatwakes on streambank erosion.

(3) The amount of juvenile chinook salmon habitat available for protective cover was measured by determining the area of protective cover provided by each stabilization technique.

Previous Boatwake Studies

Most research that specifically addresses boatwake-induced streambank erosion is done on large rivers such as the Mississippi, Illinois, or Ohio Rivers, and generally only for large commercial vessels such as navy ships or cargo barges (Bhowmik and Demissie, 1982; Das and Johnson, 1970; Hagerty and others, 1981; Karaki and vanHoften, 1974; Sparks, 1975). Especially rare are studies of smaller rivers such as the Kenai River, whose primary traffic is 10- to 26-foot-long recreational boats (Dorava and Moore, 1997). Studies on rivers in England—where recreational and pleasure boats are a substantial component of overall boat traffic—documented that turbidity and sediment concentration increased, the river channel widened, and densities of submerged macrophytic plants declined as a result of boat traffic (Garrad and Hey, 1987, 1988; Hilton and Phillips, 1982; Murphy and Eaton, 1983). Additional studies of recreational boat traffic in Old Tampa Bay and the intra-coastal waterway of Florida (Schoellhamer, 1990; Verdon, 1999), and in Chesapeake Bay in Maryland (Zabawa and Ostrom, 1980) also report shoreline and bed-sediment disturbances associated with boatwakes. The Minnesota Department of Natural Resources (Bentley and others, 1991) has published a brochure containing design, construction, and permitting details for protecting streambanks from erosion, but noted that performance data for these techniques were sparse.

During investigations of the River Bure in England, Garrad and Hey (1987) tested various size boats (12 to 42 feet long) traveling along various sailing lines (about 0, 30, and 60 feet from the bank) and moving at different speeds (3 to 7 miles per hour). They found that suspended-sediment concentration increased rapidly following passage of a boat when it traveled at a speed greater than some minimum threshold speed. Furthermore, at speeds greater than this threshold speed, the increase in boatwake-induced suspended-sediment concentration dissipated slowly. Because of the high frequency of boat passes, the effects of increased suspended-sediment concentration from a single boat pass were not dissipated before additional boat passes occurred. The results imply that even when the boats are operated within prescribed speed limits, potentially detrimental increases in suspended-sediment concentrations can occur.

There may be a direct application of this English study to the Kenai River. Although the Kenai River does not currently have boat-operating speed limits, the existing 35-horsepower limit on outboard motors can be considered, at least conceptually, in a similar manner. It illustrates that significant streambank erosion and subsequent habitat losses can occur even when boats are operated within the current regulatory framework.

STREAMBANK-STABILIZATION TECHNIQUES

Three popular streambank-stabilization materials and techniques in use along the Kenai River were selected for this study. These included (1) man-made bio-degradable logs made of coconut husks and woven into a round cylinder (bio-logs); (2) freshly cut spruce trees cabled together in a bunch; and (3) an engineered combination of bio-logs and cabled spruce trees installed together with willow plantings. A database of restoration projects maintained by the Kenai River Center in Soldotna indicates that in 1998, about 6,615 feet of the Kenai River streambank was stabilized with spruce trees cabled to the bank, about 6,730 feet of the bank was stabilized with bio-logs, and about 1,700 feet of the bank was stabilized with an engineered combination of materials including spruce trees, bio-logs, and willow plantings (Dean Hughes, Alaska Department of Fish and Game, written commun., 1998). The three bank-stabilization materials and techniques were evaluated for their effectiveness at attenuating boatwakes and protecting the bank from erosion, and compared for the amount and quality of habitat they provided to juvenile chinook salmon, primarily as protective cover. At one site along the river, both bio-logs and spruce trees were installed in front of the bank and a boatwake-recording instrument. These techniques were compared for their ability to reduce the maximum height of boatwakes striking the bank and for their ability to retard streambank erosion. At another site about 5 miles upstream, the engineered combination of bio-logs, cabled spruce trees, and willow plantings was evaluated primarily for its ability to retard streambank erosion and provide protective cover to juvenile chinook salmon. It was impossible to quantify the ability of this engineered site to attenuate boatwakes because its previous installation into the streambank prevented measurement of wake characteristics.

SITE SELECTION AND DESCRIPTION

River Mile 16

A site in the lower river near river mile 16, downstream from the city of Soldotna, was selected for study (figs. 1 and 2). Boatwake and erosion recording instruments have been deployed at this site since 1995, and substantial boatwake-induced streambank erosion has occurred here (Dorava and Moore, 1997). This site is on the inside of a meander bend and is heavily vegetated with alder, willow, and mature spruce trees. The low banks at this instrumented site provided an opportunity to test bank response to boatwakes under the following conditions: (1) no protection, (2) a temporarily installed bio-log, and (3) temporarily installed spruce trees.

A bio-log and cabled spruce trees were installed near river mile 16 on August 4, 1998. During the wake testing, stream discharge at the site was about 13,800 cubic feet per second based on records at the nearby USGS streamgaging station Kenai River at Soldotna (No. 15266300; fig. 1) (Bertrand and others, 1999). This discharge is within 5 percent of the long-term mean discharge for August (14,470 cubic feet per second), which has typically been the month of maximum mean discharge. This 5 percent discharge difference translates into a water depth difference of about 0.15 foot, indicating that the river flow during the August test

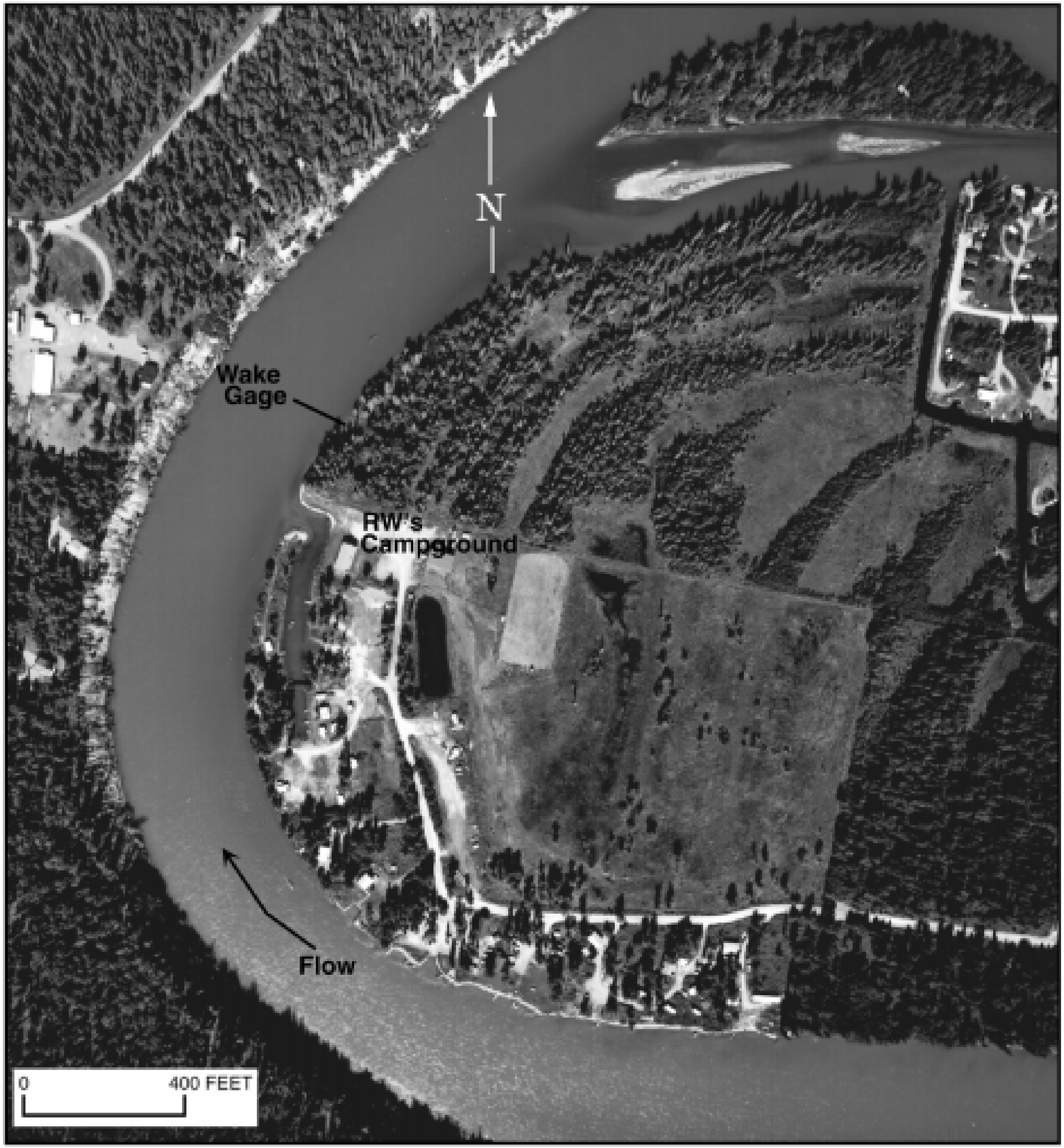

Figure 2. Aerial view of river mile 16, Kenai River, Alaska.

period was close to mean annual high-water conditions. The bio-log, about 20 feet long and 12 inches in diameter, was installed in front of the bank by pinning it to the stream bottom with metal stakes (fig. 3). The bio-log protruded about 3 inches above the waterline. Two freshly cut spruce trees about 20 feet long were cabled together and attached to the streambank with short cables (fig. 4). The spruce trees extended above the water line and into the river considerably more than the bio-log.

Figure 3. Bio-log installed near river mile 16, Kenai River, Alaska.

Figure 4. Spruce trees cabled to streambank near river mile 16, Kenai River, Alaska.

River Mile 21

Another site near river mile 21, upstream from the Sterling Highway Bridge in Soldotna, was also selected for study (figs. 1 and 5). Boatwake recording instruments have been installed at this location since 1995. Measurements indicate that boatwake-induced erosion has been less here than at river mile 16 (Dorava and Moore, 1997). The banks near river mile 21 are covered with grass and some short willow brush, but the vegetation cover is less dense here than at the downstream site. This site provided an opportunity to test the effects of boatwakes on a natural unprotected bank and on a bank stabilized with an engineered combination of materials.

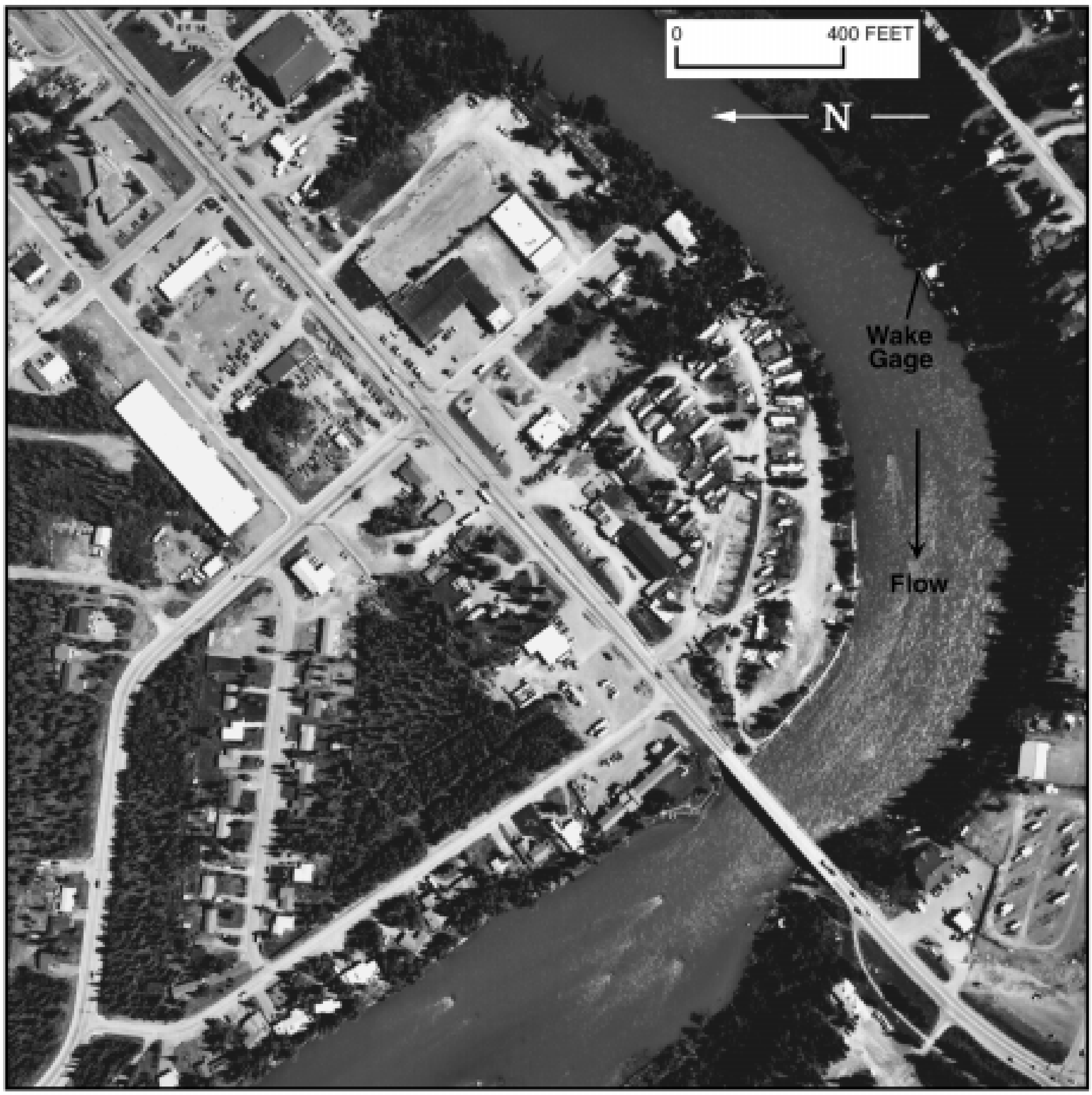

Figure 5. Aerial view of river mile 21, Kenai River, Alaska.

A previously installed, engineered bank-stabilization technique near river mile 21 was tested on September 25, 1998. During the September boatwake testing, stream discharge at the site was about 8,750 cubic feet per second, also based on records at the USGS stream-gaging station Kenai River at Soldotna (fig. 1) (Bertrand and others, 1999). This discharge is about 40 percent less than the long-term mean discharge for August, typically the month of maximum mean discharge. This 40 percent discharge difference translates into a water depth difference of about 1.24 feet, indicating that the river flow during the September test period was well below mean annual high-water conditions. A segment of bank downstream from the wake-recording instruments had been stabilized with a combination of cabled spruce trees, bio-logs, rocks, and willow plantings (fig. 6) about 2 years before the current study. This type of engineered stabilization is encouraged by river managers as a preferred technique because it is thought to both protect the bank and provide fish habitat (Gary Liepitz, Alaska Department of Fish and Game, oral commun., 1999). Just upstream from the wake-recording instruments, the bank is covered with grass and short willows and is in its natural unprotected state.

WAKE HEIGHTS

At the site near river mile 16, a sailing line about 75 feet from the streambank was established with floating buoys. A 20-foot-long, flat-bottom boat, powered by a 28-horsepower outboard, made 20 passes (10 upstream and 10 downstream) during each of the three test conditions. The boat was operated at top speed traveling along the established sailing line with the equivalent weight of three passengers on board. A wake gage installed near the bank at this site recorded the maximum wake height striking the bank from each boat pass as an ink trace on a paper chart. Initially, data were collected from the unprotected natural bank, including the maximum wake heights striking and the weight of sediment eroded from it during 20 boat passes.

Following the test on the natural bank, the bio-log was installed in front of the bank (fig. 3). This bio-log was not a typical bio-log installation, but rather was intended to simulate the effect the bio-log would have on boatwakes. Boatwakes approaching the bank struck the bio-log prior to striking the bank or being recorded by the wake gage. After this test, the bio-log was replaced by the cabled spruce trees (fig. 4). Boatwakes struck the spruce trees prior to the wake-gage or the streambank. The average of the 20 recorded maximum wake heights was calculated and used to compare the natural bank with the same bank after installing the bio-log and the cabled spruce trees (fig. 7, table 1).

Table 1. Wake heights measured near river mile 16, Kenai River, Alaska

Bank-stabilization technique	Wake height (foot)		
	Average maximum	Range	Standard deviation
None; natural	0.58	0.35—0.83	0.14
Bio-log	0.48	0.25—0.73	0.15
Spruce trees	0.46	0.27—0.76	0.16

BANK EROSION

During the wake tests near river mile 16, the average weight of eroded bank material was measured at the natural bank and with each bank-stabilization technique in place. The material eroded from the streambank during each boat pass was collected in a a 12- by 18- by 2-inch baking pan pinned to the river bottom with the 12-inch side of the edge adjacent to the streambank. The average weight of eroded bank material retained in the pan during the test was measured. This measurement was used as

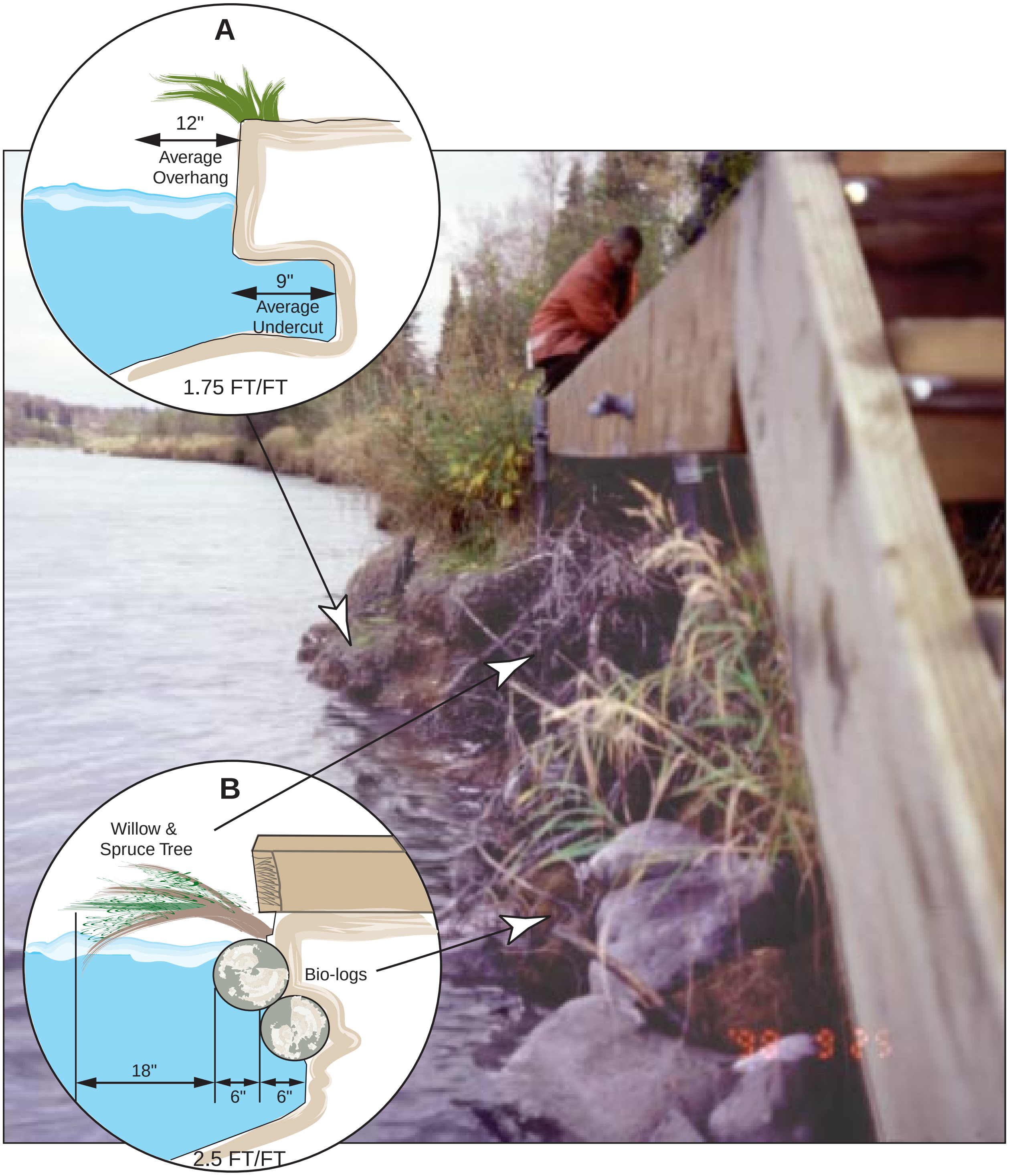

Figure 6. View of site near river mile 21, Kenai River, Alaska: (A) natural streambank and (B) engineered bank stabilization technique.

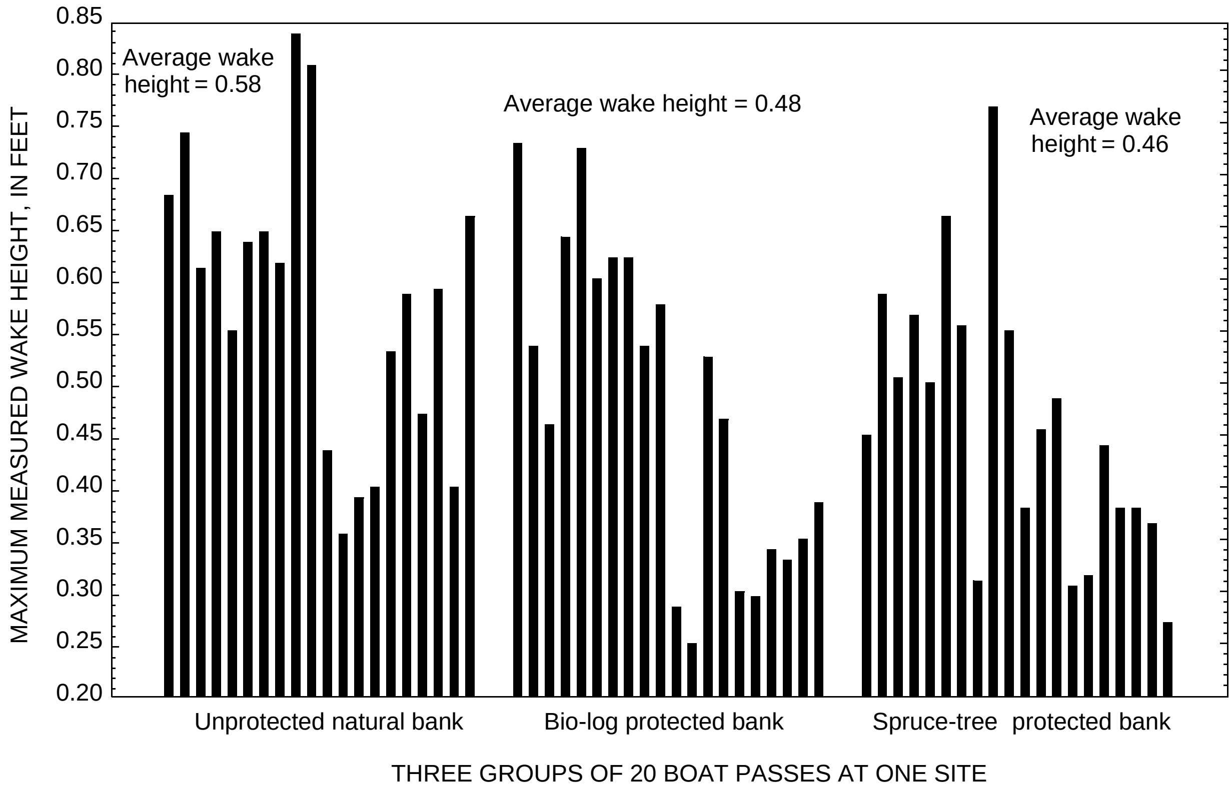

Figure 7. Height of wakes striking the bank near river mile 16 of the Kenai River, Alaska.

the primary measure of the effectiveness of each bank-stabilization technique to retard boatwake-induced streambank erosion. At river mile 16, the material eroded from the bank was collected during each of the 20 boat passes (fig. 8; table 2). A test of bank erosion was also done at the site near river mile 21. At this site, the weight of material eroded from the unprotected natural bank was compared with material eroded from the front of the adjacent engineered bank (fig. 6). This material was collected during each of nine boat passes (fig. 9; table 2).

Table 2. Weight of eroded bank material retained in collection pan near river miles 16 and 21, Kenai River, Alaska

Bank-stabilization technique	Average weight (pound per foot of bank)
River mile 16	
None; natural	0.00048
Bio-log	0.00014
Spruce trees	0.00010
River mile 21	
None; natural	0.163
Engineered restoration	0.044

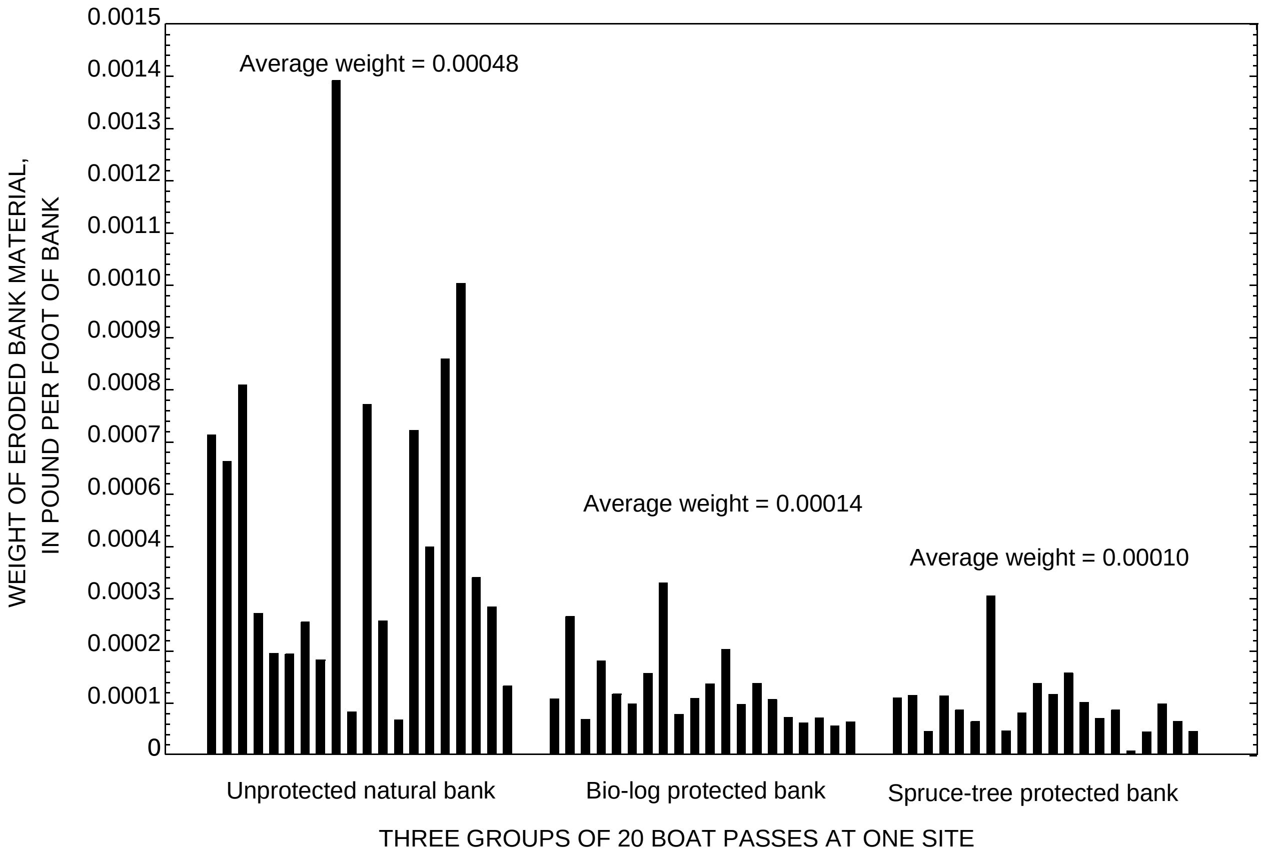

Figure 8. Weight of material eroded from the bank near river mile 16 of the Kenai River, Alaska.

To help understand the accuracy, variability, and reliability of the weight-measurement method, several quality-control and quality-assurance measures were employed. For example, because the bank-erosion comparisons were intended to evaluate only boatwake-induced erosion, a sample of bank erosion was also taken when no wakes were striking the bank. This type of sample was collected twice during each test: before running the boat passes and after all 20 boat passes. The average weight of these bank-erosion samples taken before and after the boatwake test was then subtracted from the average weight of material eroded from the banks during each test to determine the wake-induced erosion. The average weight of material collected at the base of the bank when no wakes were striking the bank ranged from 5.2 to 41 percent of the average weight of material eroded during the tests (table 3).

In addition, laboratory procedures included duplicate measurements for 25 percent of the samples, to assess for instrument and human errors in the sample weights. The error in laboratory duplicate weights averaged less than 6 percent of the average test sample weights.

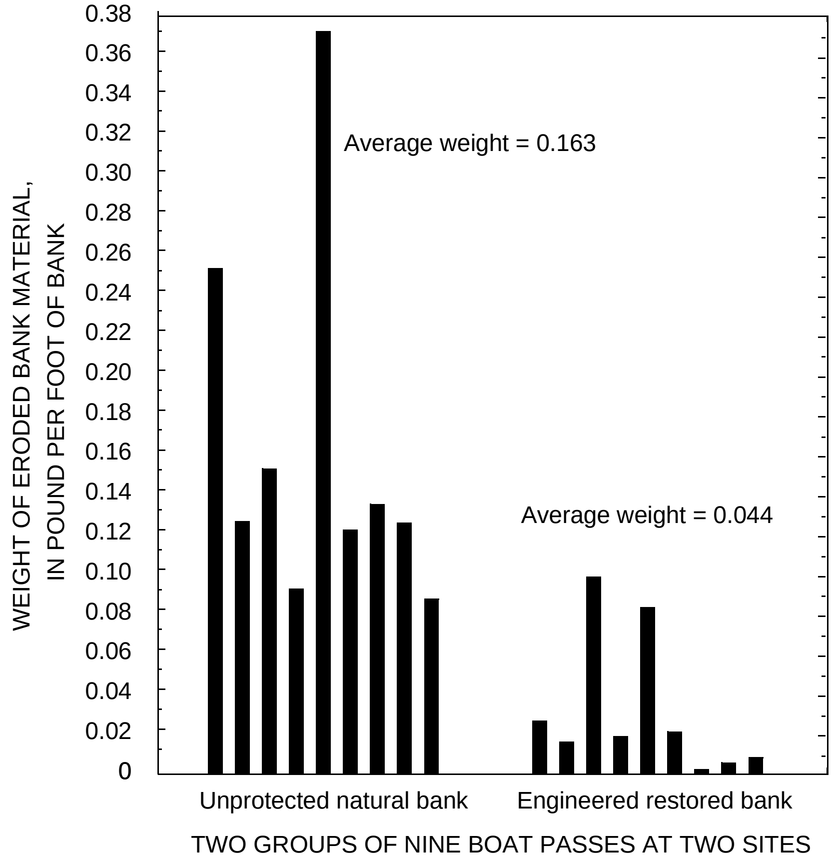

Figure 9. Weight of material eroded from the bank near river mile 21 of the Kenai River, Alaska (see fig. 6A and 6B).

Table 3. Weight of eroded bank material retained in collection pan during, before, and after boatwake tests near river miles 16 and 21, Kenai River, Alaska

Bank-stabilization technique	Average weight (pound per foot of bank)		Percentage of pre- and post-test average weight eroded during test
	During boatwake test	Pre- and post-test	
River mile 16			
None; natural	0.00048	0.000087	18
Bio-log	0.00014	0.000050	37
Spruce trees	0.00010	0.000041	41
River mile 21			
None; natural	0.163	--	--
Engineered restoration	0.044	0.0023	5.2

HABITAT VALUE

The habitat for juvenile chinook salmon that is provided by each mitigation technique was compared, using the amount (area) and the quality (suitability) of habitat at each installation. The amount of habitat provided was determined using standard evaluation procedures (Stiehl, 1994), and habitat quality was evaluated using published information on habitat suitability for juvenile chinook salmon (Bendock and Bingham, 1988; Burger and others, 1982; Estes and Kuntz, 1986; Liepitz, 1994; and Raleigh and others, 1986).

The most important habitat features for rearing juvenile chinook salmon in the Kenai River are generally found along the margin of the river. These features are found primarily in areas within about 6 feet of the streambank, where water velocities are less than 1 foot per second, stream substrate is greater than 1.5 inches in diameter, and abundant cover can protect the juvenile chinook salmon from predators. Because the streambank modifications tested did not substantially alter stream substrates—at least during the short term—substrate size was not considered as a habitat attribute for comparisons. As a result, water velocity and available protective cover were selected as the two primary attributes used to evaluate habitat.

Water Velocity

Establishing representative measurements of water velocity at the sites was difficult. A single measurement of water velocity at a site may not accurately represent the prevailing conditions. In addition, water velocity naturally varies considerably in the water column from the bed of the stream where it is a minimum to the water surface where it is a maximum. Additionally, the velocity of water along a river margin also varies substantially. Velocity may be greater near natural or man-made projections into the channel. It may also be greater where bank friction is low, and at a minimum where flow friction is greater, such as adjacent to thick vegetation. Water velocity is also further complicated by variations in channel hydraulics. Near streamside bank-stabilization projects, water velocity can be altered substantially (Dorava, 1995). When a specific stabilization project extends into the channel, changes in water velocity can be greater than when only the material composing the bank is altered (Dorava, 1995).

During this test, water velocity near the natural bank at the site near river mile 16 was measured with a Price-AA meter. A single point measurement was made about 3 feet from the bank, at a depth of 0.6 times the total water depth. In this one location, mean water velocity was about 0.7 foot per second. This velocity is within the range that results in the highest suitability for juvenile salmon. In fact, water velocity ranging from 0.4 to 0.8 foot per second is optimal for juvenile chinook salmon (Bendock and Bingham, 1988; Burger and others, 1982; Estes and Kuntz, 1986; Liepitz, 1994; and Raleigh and others, 1986). Furthermore, although difficult to verify, it is most likely that water velocity near the bio-log and the spruce trees remained within this preferred range for some distance surrounding their installation. Determining the area or volume surrounding each bank-stabilization technique where water velocity is optimal would require three-dimensional velocity measurements beyond the scope of this project. As a result, it was concluded that single measurements of mean water velocity would not provide an adequate measure of habitat value from which to compare stabilization techniques.

Another approach to using velocity as a measure of habitat value was attempted near river mile 21 at the site of the engineered bank stabilization technique. Near this stabilized bank, multiple mean water velocity measurements were made with a Price-AA meter, at a depth of 0.6 times the total water depth. These measurements were made at four points at 2-foot increments from the streambank out into the channel. These multiple velocity measurements were then repeated at the adjacent natural bank approximately 20 feet upstream. The results indicated that the four mean velocity measurements made at 2, 4, 6, and 8 feet from the bank averaged 0.889 foot per second at the stabilized bank and 0.869 foot per second at the natural bank. This small difference in velocity is essentially insignificant to juvenile chinook salmon, providing suitability indices of 91 and 93 percent of optimum values, respectively (Bendock and Bingham, 1988; Burger and others, 1982; Estes and Kuntz, 1986; Liepitz, 1994; and Raleigh and others, 1986).

This exercise indicates that even more detailed measurements of water velocity can be difficult to use for habitat value comparison. As a result, water velocity was not used in this study as an attribute to compare bank-stabilization techniques. Rather, water velocity was used only as a qualitative comparison; values were assumed to fall within the range of optimum suitability somewhere near each site, at least during the short period of testing.

Protective Cover

Protective cover has been identified as a essential component of chinook salmon rearing habitat by several researchers (Bendock and Bingham, 1988; Burger and others, 1982; Estes and Kuntz, 1986; Liepitz, 1994; Raleigh and others, 1986). The protective cover for juvenile chinook salmon provided by natural and restored banks was evaluated at both study sites. Near river mile 16, the amount of protective cover provided by the bio-log and by the spruce trees was compared directly. Both the bio-log and spruce trees provide protective cover to juvenile chinook salmon that can hide under them. The amount of habitat provided by the bio-log was limited to the diameter of the log, about 12 inches. The amount of habitat provided by the cabled spruce trees included both its 20-foot length and the extension of the limbs into and above the water. The bio-log provides an area coverage of about 1 foot per linear foot (table 4). In contrast, the two cabled spruce trees form a triangular-shaped protective area about 6 feet wide at the base. Because juvenile chinook salmon can find protective cover anywhere under the trees, the entire area under the trees provides cover. The area of this triangular-shaped space can be determined as one-half the width of the base of the trees, multiplied by the 20-foot length. This computation results in an average of about 3 feet of available protective cover per linear foot of tree provided by the spruce trees (table 4). This calculation indicates that the tested cabled spruce-tree stabilization technique potentially provided about three times more cover to juvenile chinook salmon than the tested bio-log.

Table 4. Amount of protective cover for juvenile salmon at river miles 16 and 21, Kenai River, Alaska

Bank-stabilization technique	Protective cover (foot per linear foot)
River mile 16	
None; natural	0 base
Bio-log	1.0
Spruce trees	3.0
River mile 21	
None; natural	1.75
Engineered restoration	2.50

Near river mile 21, the habitat provided as protective cover by the stabilized bank was compared with that provided by the adjacent natural bank. During bankfull conditions, the natural bank had about a 9-inch-deep undercut at the base of the bank and was covered primarily by grass vegetation that overhung about 12 inches over the river (fig. 6A). This bank configuration resulted in an average of about 1.75 feet of cover per linear foot of bank (table 4). About 20 feet downstream at the stabilized bank, the willow plantings and cabled spruce trees both extended into the water about 18 inches (fig. 6B). Additionally, the bio-logs at the bank base extended streamward about 6 inches in a two-layered tier. This arrangement created three layers of protective cover, resulting in about 2.5 feet of protective cover per linear foot of bank (table 4).The comparisons at this site indicate that restoration efforts created more cover than the adjacent natural bank. However, it should be noted that each restoration project is different and the cost of creating suitable juvenile chinook salmon habitat is commonly greater than property owners want to expend. In addition, because each natural bank is different and each may provide more or less potential habitat, making site-to-site comparisons is difficult.

DISCUSSION

Using a two-sample t-test ($\alpha = 0.05$; Zar, 1984), the average maximum wake heights striking the unprotected natural bank were significantly greater than those striking the bank where it was protected by a bio-log or cabled spruce trees. Where the bank was protected by spruce trees, average values for maximum wake heights were not significantly different ($\alpha = 0.05$) from where the bank was protected by the bio-log. The average maximum wake heights were not significantly different between bio-log and spruce tree bank-stabilization techniques. Both techniques share characteristics that help reduce wake heights striking the banks, such as materials extended above the waterline and into the stream. These types of materials will intercept boatwakes and, consequently, attenuate boatwakes. The wake-attenuation characteristics of bio-logs and spruce trees shown by this study's data set are also supported by engineering intuition. Interference with boatwakes as they approach the bank, as provided by spruce-tree limbs that extend substantially into and above the water, will be effective at a wide range of water depths and can be adopted into other bank-stabilization techniques. For example, a bio-log could be attached to the streambed and bank with live willow stakes that later will grow into mature willows that enhance wake-attenuating characteristics. In addition, submerged vegetation that has either fallen into the water or grows below the waterline would most likely attenuate boatwakes as they approached the streambank.

Reducing the height of wakes striking the bank will most likely lead to a reduction in bank erosion, because smaller wakes have less energy to dissipate on the streambank (Anderson, 1975; Dorava and Moore, 1997; Limerinos and Smith, 1975; U.S. Army Corps of Engineers, 1984; von Krusenstierna, 1990; Yousef and others, 1978). The measured streambank erosion at banks protected by spruce tree and bio-logs was significantly reduced to at least 25 percent of what it was at the unprotected natural bank. The erosion-control effectiveness of spruce trees and bio-logs was not significantly different at an α level of 0.05 (Zar, 1984).

At river mile 21, where one segment of bank was protected by the engineered combination of materials, the boatwake-induced streambank erosion measured at the protected bank was 27 percent of that measured at the unprotected natural bank. The characteristics of this engineered bank-stabilization technique that reduce bank erosion are similar to those that were effective at the river mile 16 site. For example, the engineered stabilization site had a bio-log toe with willow shrubs growing through it, and a layer of spruce trees above that (fig. 6B). Bank-stabilization techniques that include projections into and above the water will reduce both wake height and boatwake-induced streambank erosion.

Bio-logs are a relatively new erosion control technique, whereas the low-cost erosion reduction provided by spruce trees has been recognized for some time. An illustrative example is the use of Christmas trees as erosion control along the coastline of Louisiana (Bahlinger, 1996; Dunne, 1999) (fig. 10).

The comparisons of habitat value or habitat suitability provided by each tested stabilization technique indicated that cabled spruce trees potentially provided more cover for juvenile chinook salmon than bio-logs did. The characteristics of the spruce trees that help to attenuate wakes and reduce bank erosion also provided valuable cover to juvenile chinook salmon. The habitat provided by the engineered bank-stabilization project at river mile 21 was greater than that provided by the adjacent natural bank. When selecting a type of bank stabilization, the relative contribution to fish habitat may be a valuable consideration in addition to effectiveness at reducing wake heights and bank erosion. Another consideration for selection is the durability of the stabilization technique. For example, as spruce trees age, the possible loss of needles and limbs may reduce the ability of this technique to attenuate wakes and provide fish habitat. However, determining the potential reduction in effectiveness of aging spruce trees or their anticipated life span is beyond the scope of this study.

Figure 10. Christmas trees being used as shoreline erosion control in Louisiana (photograph courtesy of Louisiana Department of Natural Resources).

Although these tests of bank-stabilization techniques indicate an enhancement of fish habitat and an effective reduction in erosion from the tested techniques, these tests were conducted during specific conditions. As a result, no information is provided about how well the bank-stabilization techniques perform over longer periods. For example, it is not clear which technique is more effective at reducing flood-induced erosion, which can occur infrequently—every 10 to 100 years. In addition, no evaluation has been made to compare the effectiveness of the bank-stabilization techniques during different climatic conditions such as following major rainfalls or extensive periods of no rainfall, when streambanks might react differently to boatwakes. With these limitations, the results of this study indicate the relative effectiveness of several popular bank-stabilization techniques in use along the Kenai River. The study also provides insight as to how to modify or adapt other streambank-stabilization techniques specifically to protect shorelines from boatwake-induced streambank erosion.

Managers of the Kenai River or other rivers subjected to boat traffic can use this information when identifying preferred streambank-stabilization techniques. Additionally, streamside property owners can use this information when selecting a method to protect their river frontage from boatwake-induced erosion.

SUMMARY

This study of the effectiveness of streambank-stabilization projects along the Kenai River was motivated by the economic importance of the Kenai River fisheries and the potential threat to these fisheries from boatwake-induced streambank erosion. The managers of the river are concerned that current streambank restoration practices may not be adequately addressing boatwake-induced streambank erosion, which generates undesirable non-point source pollution or damages important riparian and riverine fish habitat. The results of this study provide a comparison of three bank-stabilization techniques and a description of some characteristics of the stabilization techniques that are most effective at reducing boatwake-induced erosion and that provide protective cover for juvenile salmon.

Controlled in-river tests were designed to evaluate the ability of a few commonly used bank-stabilization techniques to attenuate boatwakes and retard streambank erosion. The results indicated that spruce trees cabled to the streambank and bio-logs pinned to the streambed significantly reduced both maximum wake heights and streambank erosion. In addition, spruce trees provided more protective cover for juvenile chinook salmon than bio-logs did. An engineered bank-stabilization project that used a combination of spruce trees, bio-logs, rocks, and willow plantings provided more protective cover and erosion protection than the adjacent unprotected natural bank.

REFERENCES CITED

American Society of Civil Engineers, 1992, Sediment and aquatic habitat in river systems—Task force committee on sediment transport and aquatic habitats. Sedimentation Committee: Journal of Hydraulics, v. 118, no. 5, p. 669-687.

Anderson, F. E., 1975, The short term variation in suspended sediment concentration caused by passage of a boat wave over a tidal flat environment: University of New Hampshire, Technical Report No. 2, 40 p.

Bahlinger, K.D., 1996, Effectiveness of Christmas tree projects: Louisiana Department of Natural Resources, PCWRP Information Series No. 2, variously paged.

Bendock, T., and Bingham, A., 1988, Juvenile salmon seasonal abundance and habitat preference in selected reaches of the Kenai River, Alaska, 1987-1988: Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series 70, variously paged.

Bentley, Cliff, Parke, Gary, and Leuthe, David, 1991, Streambank erosion—Gaining a greater understanding: Minnesota Department of Natural Resources, Division of Water, 33 p.

Bertrand, C.M., Hess, D.L., Meyer, D.F., Jackson. M.L., and Smith, C.W., 1999, Water resources data for Alaska—Water year 1998: U.S. Geological Survey Water-Data Report 98-1, 321 p.

Beschta, R.L., 1989, The intrusion of fine sediments into a stable gravel bed: Journal of the Fisheries Research Board of Canada, v. 36, no. 2, p. 204-210.

Bhowmik, N.G., and Demissie, M., 1982, Waves generated by river traffic: Conference on Applying Research to Hydraulics Practice, American Society of Civil Engineers Hydraulic Division, Proceedings, p. 179-187.

Bjorn, T.C., 1969, Embryo survival and emergence studies: Idaho Fish and Game Department Job Compliance Report, Project F-49-R-7, 11 p.

Burger, C.V., Wangaard, D.B., Wilmot, R.L., and Palmisano, A.N., 1982, Salmon investigations in the Kenai River, Alaska, 1979-1981: U.S. Fish and Wildlife Service National Fisheries Research Center, 139 p.

Byrd, J.E., and Perona, M.J., 1980, The temporal variations of lead concentration in a freshwater lake: Water, Air and Soil Pollution, v. 13, p. 207-220.

Das, M.M., and Johnson, J.W., 1970, Waves generated by large ships and small boats: Twelfth Coastal Engineering Conference, Proceedings, v. 3, p. 2281-2286.

Dezman, L.E., 1990, Can erosion control meet regulatory standards?: National Conference, American Society of Civil Engineers Hydraulics Division, Chang, H.H. and Hill J.C. ed., Proceedings, p. 391-396.

Dorava, J.M., 1995, Hydraulic characteristics near streamside structures along the Kenai River, Alaska: U.S. Geological Survey Water-Resources Investigations Report 95-4226, 41 p.

Dorava, J.M., and Moore, G.W., 1997, Effects of boatwakes on streambank erosion, Kenai River, Alaska: U.S. Geological Survey Water-Resources Investigations Report 97-4105, 84 p.

Duijsings, J.J.H.M., 1986, Streambank contribution to the sediment budget of a forest stream: Amsterdam, Universiteit, Fysisch-Geografisch en Bodemkundig Laboratorium, v. 40, 190 p.

Dunne, Mike, 1999, Christmas trees take on tidal-lake mission: Lafayette Louisiana, The Advocate, January 27, 1999, p. 2B.

Estes, C.C., and Kuntz, K.J., 1986, Kenai River habitat study: Alaska Department of Fish and Game Federal Aid in Fish Restoration F-10-1 and Anadromous Fish Studies, v. 27, variously paged.

Garcia, K.T., 1988, Effect of erosion-control structures on sediment and nutrient transport, Edgewood Creek drainage. Lake Tahoe basin, Nevada, 1981-83: U.S. Geological Survey Water-Resources Investigations 87-4072, 65 p.

Garrad, P.N., and Hey, R.D., 1987, Boat traffic, sediment resuspension and turbidity in a Broadland river: Journal of Hydrology, v. 95, p. 289-297.

Garrad, P.N., and Hey, R.D., 1988, The effect of boat traffic on river regime: Proceedings of the International Conference on River Regime, Paper J1, p. 395-409.

Hagerty, D.J., Spoor, M.F., and Ullrich, C.R., 1981, Bank failure and erosion on the Ohio River: Engineering Geology, v. 17, p. 141-158.

Hansen, E.A., 1971, Sediment in a Michigan trout stream—Its source, movement, and some effects on fish habitat: U.S. Department of Agriculture Forest Service Research Paper NC-59, 14 p.

Hilton J,. and Phillips, G.L., 1982, The effect of boat activity on turbidity in a shallow Broadland river: Journal of Applied Ecology, v. 19, p. 143-150.

Jackivicz, T.P., and Kuzminski, L.N., 1973a, The effects of the interaction of outboard motors with the aquatic environment—A review: Environmental Research, v. 6, p. 436-454.

Jackivicz, T.P., and Kuzminski, L.N., 1973b, A review of outboard motors effects on the aquatic environment: Journal of Water Pollution Control Federation, v. 45, no. 8, p. 1759-1770.

Karaki, S. and vanHoften J., 1974, Resuspension of bed material and wave effects on the Illinois and Upper Mississippi Rivers caused by boat traffic: Colorado State University Engineering Research Center, 31 p. [Prepared for U.S. Army Engineer District, St. Louis.]

Klingeman, P.C., Matin, Habibollah, and Huang, C.-C., 1990, Investigation of motorboat-induced streambank erosion on the Lower Deschutes River: Oregon State University, Water Resources Research Institute Report, 67 p. + appendixes.

Liepitz, G.S., 1994, An assessment of the cumulative impacts of development and human uses on fish habitat in the Kenai River: Alaska Department of Fish and Game Technical Report No. 94-6, 63 p.

Lietman, P.L., Ward, J.R., and Behrendt, T.E., 1984, Effects of specific land uses on nonpoint sources of suspended sediment, nutrients, and herbicides—Pequea Creek basin, Pennsylvania, 1979-80: U.S. Geological Survey Water-Resources Investigations 83-4113, 88 p.

Limerinos, J.T., and Smith, Winchell, 1975, Evaluation of causes of levee erosion in the Sacramento-San Joaquin Delta, California: U.S. Geological Survey Water-Resources Investigations 28-74, 53 p.

Meehan, W.R., 1974, The forest ecosystem of southeast Alaska. Part 3, Fish habitats: U.S. Forest Service General Technical Report PNW-15, 15 p.

Meehan, W.R., and Swanston, D.N., 1977, Effects of gravel morphology on fine sediment accumulation and survival of incubating salmon eggs: U.S. Forest Service Research Paper PNW-220, 16 p.

Murphy, K.J., and Eaton, J.W., 1983, Effects of pleasure-boat traffic on macrophyte growth in canals: Journal of Applied Ecology, v. 20, p. 713-729.

Nanson, G.C., Von Krusenstierna, A., Bryant, E.A., and Renilson, M.R., 1994, Experimental measurements of river-bank erosion caused by boat-generated waves on the Gordon River, Tasmania: Regulated Rivers—Research and Management, v. 9, p.1-14.

Nelson, L.M., 1986, Effect of bank protection measures, Stehekin River, Chelan County, Washington: U.S. Geological Survey Water-Resources Investigations Report 85-4316, 22 p.

Odgaard, A.J., 1984, Bank erosion contribution to stream sediment load: Iowa Institute of Hydraulic Research Report No. 280, 92 p.

Raleigh, R.F., Miller, W.J., and Nelson, P.C., 1986, Habitat suitability index models and instream flow suitability curves—Chinook salmon: U.S. Fish and Wildlife Service, Biological Report 82 (10.122), 59 p.

Reckendorf, F.F., 1991, Streambank erosion: problems, causes, and solutions, Fifth Federal Interagency Sedimentation Conference Proceedings, p. 363-370

Schoellhamer, D.H., 1990, Observation of sediment resuspension in Old Tampa Bay Florida: National Conference, American Society of Civil Engineers Hydraulics Division, Chang, H.H. and Hill J.C. eds., Proceedings, p. 51-56.

Scott, K.M., 1982, Erosion and sedimentation in the Kenai River, Alaska: U.S. Geological Survey Professional Paper 1235, 35 p.

Smart, M.M., Rada, R.G., Nielsen, D.N., and Claffin, T.O., 1985, The effect of commercial and recreational traffic on the resuspension of sediment in Navigation Pool 9 of the Upper Mississippi River: Hydrobiologia, v. 126, p. 263-274.

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, 23 p.

Stiehl, R.B., 1994, Habitat evaluation procedures workbook: Fort Collins Colo., National Biological Survey, variously paged.

Thomas, W.A., 1990, Example of the stable channel design approach: National Conference, American Society of Civil Engineers Hydraulics Division, Chang, H.H. and Hill J.C. eds., Proceedings, p. 175-180.

Trimble, S.W., 1997, Streambank fish-shelter structures help stabilize tributary streams in Wisconsin: Environmental Geology, v. 32, no. 3, p. 230-234.

U.S. Army Corps of Engineers, 1981, Streambank erosion demonstration project: Final Report to Congress, December 1981, Volume 1 of 2, variously paged.

U.S. Army Corps of Engineers, 1984, Shore protection manual (4th ed.): Coastal Engineering Research Center, Waterways Experiment Station, v. 1, chap. 1-5, and v. 2, chap. 6-8 + appendixes, variously paged.

Verdon, Michael, 1999, Can the ICW (IntraCoastal Waterway) be saved?: Boating World, March 1999, p. 47-51.

von Guerard, P., 1989, Suspended sediment and sediment-source areas in the Fountain Creek Drainage Basin upstream from Widefield, southeastern Colorado: U.S. Geological Survey Water-Resources Investigations Report 88-4136, 36 p.

Von Krusenstierna, Axel, 1990, River bank erosion by boat-generated waves on the lower Gordon River, Tasmania: The University of Wollongong, Australia, M.S. thesis, 136 p.

Yousef, Y.A., McLellon, W.M., Fagan, R.H., Zebuth, H.H., and Larrabee, C.R., 1978, Mixing effects due to boating activities in shallow lakes: Florida Technological University, Technical Report ESEI No. 78-10, 352 p.

Zabawa Chris, and Ostrom Chris, 1980, Final report on the role of boat wakes in shore erosion in Anne Arundel County, Maryland: Maryland Department of Natural Resources, variously paged

Zar, J.H., 1984, Biostatistical analysis (2d ed.): New Jersey, Prentice Hall, 718 p.