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RESTORATION IMPLEMENTATION PROJECT

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OVERVIEW SUMMARY

This study is focused on identification of sites for restoration of existing salmon spawning habitat, creation of new spawning habitat, and rehabilitation of salmon stocks. The feasibility and cost effectiveness of various salmon stock rehabilitation and enhancement techniques is being evaluated for sites and stocks known to be damaged by the Exxon Valdez oil spill (EVOS). Options for enhancement of undamaged stocks as replacement for damaged stocks are also being considered. Appropriate restoration or enhancement techniques may include spawning channels and improvement of fish passage through fish ladders or step-pool structures to overcome physical or hydrological barriers. The results from this project will be used to develop proposals for restoration projects at specific sites. The study area includes Prince William Sound (PWS), Lower Cook Inlet (LCI), and Kodiak Island. The study is being conducted cooperatively by the Alaska Department of Fish and Game and the U.S. Forest Service, Glacier Ranger District.

A preliminary analysis has been conducted to determine the cost effectiveness of various instream habitat and stock rehabilitation techniques for wild salmon stocks in general (Willette et al. 1991). Results from this analysis indicated that spawning channels, fish passes, and remote fry rearing are likely the most cost-effective techniques for enhancement or restoration of wild pink and chum salmon stocks. The cost effectiveness of spawning channels is strongly affected by egg-to-fry survival. Among sites with well-sorted spawning substrate and adequate water depths, groundwater gradient is the principal factor affecting egg-to-fry survival in spawning channels. This study has focused on identifying potential spawning channel sites within the EVOS impact area with steep groundwater gradients and high groundwater stability. Fish passes may be cost effective at sites with low barrier falls and substantial high quality upstream spawning habitat. Suitable sites for construction of fish passes appear to be more numerous in the Kodiak Island area. Fry rearing appears to be a cost effective salmon stock rehabilitation technique if large numbers of fry are reared. Fry rearing involves capturing, holding, and feeding outmigrating wild salmon fry until conditions in the ocean are optimal for growth. This study has focused on identifying sites where fry weirs can be operated and large fry outmigrations occur. The cost effectiveness of remote eggtakes is relatively poor, but immediate and substantial increases in stock survival can be achieved.

Spawning channels may be used to create new spawning habitat to replace damaged habitat. During the 1991 season, twenty-one potential spawning channel sites were identified in the PWS area using data from previous reports, aerial photographs and aerial surveys. The 1992 field season concentrated on ground surveys and hydrology studies ~~and~~ at nine of these sites. Five sites that appear suitable for spawning channel construction were located in the Valdez area at Mineral Creek, Valdez Creek, and Lowe River. Channel construction at these road-accessible sites would be more cost effective than at remote sites. Three additional sites at Rude River, Complex Creek and Mill Creek are also being investigated. Ground and aerial surveys of each study area were conducted to locate salmon stocks that could be introduced into developed spawning channels. Standpipes equipped with electronic water temperature/level recorders were installed at specific locations that appeared most suitable for channel construction. This equipment will be in place throughout the winter to determine minimum temperatures and water levels at each site. The data collected from these studies will be used to identify suitable sites, develop project designs, estimate construction costs, and assess potential benefits.

In the LCI area, Port Dick Creek and Island Creek were initially surveyed as possible sites for spawning channel construction. Both streams are located in Port Dick on the east coast of the Kenai Peninsula. A spawning channel feasibility analysis was initiated in the fall of 1991 at Port Dick Creek. This creek is one of the most important pink and chum salmon producing streams in the LCI area, and it was moderately to heavily oiled by the EVOS. A possible site for a spawning channel was identified near the intertidal zone. Two standpipes equipped with electronic water level recorders were installed and a survey of available spawning substrate was conducted. Island Creek was protected by oil boom during the EVOS and the creek itself was not oiled. Preliminary surveys of this area indicated that no sites appeared suitable for the construction of spawning channels.

Fish passes are another restoration option that would allow access to undamaged spawning habitat as a replacement for damaged habitat. During the 1991 season, thirty-five streams were initially surveyed and evaluated for construction of fish passes in the PWS area. Fish pass construction appeared to be cost effective only at Gregorioff and Parks creeks. Initial construction costs at these two sites are estimated at $167,500 with a potential annual production of 43,518 adult pink salmon. In 1992, the U.S. Forest Service (USFS) conducted hydrological surveys and further evaluation studies at these two sites.

Seven sites were evaluated for construction of fish passes on Kodiak and Afognak Islands. Barriers to pink (and coho) salmon were assessed, as well as upstream spawning habitat to determine the feasibility of fish pass construction. These systems are located in areas contaminated by the EVOS. Production benefits would exceed construction costs at Cold Creek and Little Waterfall creeks after five and eight years, respectively. Initial construction cost at Cold Creek is estimated to be $125,000 with a potential annual adult production of 26,028 pink salmon. Coho production at Cold Creek would also increase providing additional benefits. At Little Waterfall Creek, construction costs are estimated to be $70,000 with a potential annual production of 47,233 adult pink salmon and a benefit-cost ratio of 4.7. Combining bypass construction projects at Pink Creek with Cold Creek would provide for an additional annual production of 8,058 adult pink salmon at a benefit-cost ratio of 3.1. Fish pass construction is not considered cost effective at the other four systems studied in the Kodiak area.

Fry rearing is a stock rehabilitation technique that would increase fry-to-adult survival. The sixteen largest pink salmon producing streams in PWS have been identified as sites where fry rearing would likely be cost effective. Fry weirs appear to be feasible in the intertidal zone at four of these streams. In the other twelve streams, fry weirs may be feasible above the intertidal zone. Escapement and pre-emergent fry index data will be used to assess the potential magnitude of fry outmigrations from upstream habitats. Fry rearing may also be appropriate as a rehabilitation technique for pink and chum salmon stocks spawning in oil-contaminated intertidal habitats. However, the benefit-cost ratio for projects at these sites will be substantially lower than on larger streams.

Remote eggtakes may also be an appropriate rehabilitation technique for salmon stocks spawning in oil-contaminated intertidal habitats. This technique involves taking eggs from females, rearing eggs in hatcheries, and releasing fry back on site after a short period of feeding in net pens. An immediate and substantial increase in stock survival can be achieved, but cost effectiveness is generally poor. Thirty-seven oiled anadromous streams were identified in PWS and LCI as potential sites for remote eggtakes. Remote eggtakes appear feasible at most of these streams depending on the number of available spawners.

INTRODUCTION

The Exxon Valdez Oil Spill (EVOS) deposited various amounts of oil in intertidal habitats utilized by spawning pink and chum salmon. Up to seventy-five percent of the pink and chum salmon returning to Prince William Sound (PWS) spawn in intertidal habitats. Salmon eggs from 1988 and all subsequent brood years that were deposited in oiled intertidal spawning areas have been contaminated and adversely affected by oil from the EVOS. Injuries from spawning ground contamination include increased mortality of eggs and higher incidence of somatic, cellular, and genetic abnormalities in alevins and fry. The observed injuries have lead to declines in numbers, health, and overall fitness of salmon populations in PWS. During the early marine period, oil contamination caused reduced growth and fry-to-adult survival, disruption of normal migration patterns and distribution, and changes in prey selection. Contamination appeared to result from uptake through the gills and ingestion of oil-contaminated prey. Salmon populations that spawn far from oil-contaminated areas may have also incurred genetic damages when juveniles migrated through oil-contaminated nearshore areas in southwest PWS. These effects may diminish the fitness and productivity of salmon populations for many years.

As a first phase of restoration of pink and chum salmon populations, this study focused on identification of sites for enhancement of existing spawning habitats, creation of new spawning habitat, and rehabilitation of stocks. Appropriate restoration or enhancement techniques may include spawning channels and improvement of fish passage through fish ladders, or step-pool structures to overcome physical or hydrological barriers. These measures will provide oil-free spawning habitat to replace oil-impacted spawning areas.

OBJECTIVES

1. Review existing literature and databases, determine preliminary restoration techniques for specific sites, and identify sites where field studies are needed.

2. Conduct field studies at specific sites to collect additional data needed to evaluate restoration techniques.

3. Compile available data and select the most appropriate fish restoration projects.

4. Collect additional field data if necessary to develop project design and cost estimates, and write proposals for specific projects.

METHODS

Objective 1:

A preliminary cost-benefit analysis was conducted to determine the most cost effective wildstock restoration techniques. A summary of previous project costs was developed after a literature review. When no data was available preliminary project budgets were developed. Pink and chum salmon survival rates in natural streams, in the ocean, and resulting from various enhancement techniques were summarized. The information gathered from this review was used to evaluate the cost effectiveness of various enhancement techniques for wild salmon populations in general. The results from this analysis were used to focus restoration survey efforts on the most effective and beneficial techniques.

Potential wild salmon stock restoration sites were selected after a thorough review of all previous fisheries rehabilitation and enhancement work conducted in the EVOS impact area (Sheridan 1965; Sweet 1975; Doyle 1978; Blanchet 1979; Sanner 1982a; Sanner 1982b; P.W.S.A.C. 1982, 1983, 1984, 1985; Quimby and Dudiak 1986). In addition, relevant NRDA studies, Alaska Department of Fish and Game (ADFG) fishery production data, anadromous stream catalogs (ADFG), and U.S. Forest Service (USFS) aerial photographs were reviewed.

Streams identified as potential fish pass sites from the literature review were further evaluated using aerial photographs. Barrier falls height and quantity and quality of spawning habitat above the falls were the principal criteria used to evaluate potential fish pass sites. The USFS stream habitat classification system was used to estimate the area of suitable spawning habitat above barriers (Olsen and Wenger 1991).

Spawning channel sites described in the literature were evaluated on the seasonal stability of groundwater height, groundwater temperature, groundwater gradient, groundwater chemistry, flooding risk, availability of substrate, and availability of broodstock (Sanner 1982b). Streams identified as potential spawning channel sites from the literature review were further evaluated using aerial photographs and topographic maps. Data from topographic maps was used to estimate surface gradient and stream length. These variables are likely correlated with groundwater gradient and stability.

The feasibility of fry rearing at various streams was evaluated using aerial photgraphs, historical spawning escapement and pre-emergent fry index data collected by the ADFG, and shoreline oil-contamination maps constructed by the Alaska Department of Natural Resources (ADNR) and Alaska Department of Environmental Conservation (ADEC). Criteria used to evaluate potential fry rearing sites included the degree of oil contamination in intertidal spawning habitats, probable magnitude of fry outmigrations, availability of mooring sites for net pens, feasibility of operating fry weirs, and proximity of weir sites to net pen sites.

Salmon stocks that might be best restored by remote eggtakes were identified using historical salmon spawning escapement data, anadromous stream catalogs, and shoreline oil-contamination maps. Criteria used to evaluate remote eggtakes at these sites included degree of oil contamination, probable spawner abundance, and availability of mooring sites for net pens.

Objective 2:

Potential fish pass sites were further evaluated from aerial and ground surveys. The abundance of spawning salmon, barrier falls height, stream width, stream depth, stream gradient, and substrate type were estimated from aerial surveys. The information gained from these surveys was used to eliminate some streams from further consideration. More extensive ground surveys were conducted at sites that appeared suitable from aerial surveys. The following physical measurements were made during ground surveys. Barrier falls height was estimated with a clinometer and measuring tape. U.S. Forest Service stream habitat foot survey methods were used to estimate available spawning habitat above the barrier (Olsen and Wenger 1991).

Potential spawning channel sites were evaluated from aerial and ground surveys. Spawning channel sites described in the literature were evaluated on the seasonal stability of groundwater height, groundwater temperature, groundwater gradient, flooding risk, availability of substrate, and availability of broodstock (Sanner 1982b). Data from topographic and engineering maps were used to estimate surface gradient, stream length and subsurface geology. These variables are likely correlated with groundwater gradient and stability. Ground surveys were conducted at sites that appeared suitable from aerial surveys. The criteria developed by Bonnell (1991) were used to assess the suitability of sites for development of spawning channels (Table 1). If the area appeared to be unaffected by floods, the groundwater was shallower than 2 meters, and the substrate was composed largely of gravel or cobbles, additional survey work was conducted. Standpipes were installed to a depth at least 2 m below the groundwater level, parallel to the surface gradient, along the most likely location of the spawning channel. Standpipes were constructed from 1.5m sections of 5 cm diameter galvanized well pipe, with a sandpoint, and galvanized couplers (Figure 1). Each standpipe was driven into the ground manually with a post pounder. Once the standpipe was in place it was marked with a pole and orange flagging for ease in relocation. Electronic depth (Hugrun, model MS-210SD) and temperature (Hugrun, Seamon type A) recorders were placed in several of the standpipes to monitor groundwater level fluctuations and water temperature during the winter months.

Potential fry rearing sites were aerial surveyed when the tide was around the six foot level. A video camera was used during the aerial survey of each stream for later review. A ground survey will be conducted to measure the distance across the stream channel, mean stream depth, and mid-channel current speed at the intended location of the fry weir. The estuarine area near the potential weir site will be surveyed to locate a suitable area to moor net pens. The distance between net pen mooring sites and fry weir sites will be measured with a rangefinder. If possible, potential fry weir sites will be visited at high tide immediately after a storm.

No ground surveys were required to determine the feasibility of eggtakes at remote sites. Suitable sites for net pen mooring were identified from aerial photographs and aerial surveys. Spawner abundance will also affect the feasibility of remote eggtakes. Aerial surveys conducted immediately before eggtakes will be required to estimate spawner abundance.

Objective 3:

After all necessary data has been collected, the following criteria will be applied to determine the most appropriate restoration projects:

1. oil-spill damages to spawning habitats and salmon stocks,
2. the estimated increase in fish production resulting from the proposed project,
3. the importance of the estimated increased in fish production to subsistence, sport, and commercial user groups,
4. the estimated cost/benefit ratio of the proposed project,
5. the compatibility of the proposed project with established land uses in the area, and
6. the potential for the proposed project to maintain the wild characteristics of the affected salmon population.

PRELIMINARY STUDY RESULTS

Objective 1:

Preliminary cost-benefit analysis indicated that spawning channels and remote fry rearing are likely the most cost-effective techniques for restoration of wild pink and chum salmon populations in PWS (Willette et al. 1991). Although actual cost-benefit will vary from these estimates, this analysis enables comparison of enhancement techniques given the most likely parameter values. Construction costs for fish passes were assumed to be $25,000 per meter vertical rise at the barrier. A 6:1 slope was assumed for all fish passes (White, pers. comm.). Construction costs for egg boxes were assumed to be $5,000 per 500,000 egg box (Thompson 1982). Willette et al. (1991) summarized other assumptions used in this analysis regarding project costs and survival rates.

The cost effectiveness of fish passes is strongly affected by barrier height and the quality and quantity of spawning habitat above the barrier. In PWS, fish pass projects may be cost effective if the system can sustain a 70% commercial exploitation rate. This will depend strongly on the quality of spawning habitat above the barrier which will affect mean egg-to-fry survival. Full utilization of available spawning habitat also strongly affects cost effectiveness. Habitat utilization rates considerably below estimated capacity have been reported for fish pass projects (McDaniel 1981). The present assessment was made assuming full utilization of available spawning habitat. Thirty-five streams were initially evaluated using aerial photographs, aerial surveys, and ground surveys for construction of fish passes (Table 2). Thirty-three sites were eliminated from further consideration due to steep gradient, high barrier falls, inadequate water flow, or inadequate upstream habitat (Table 3). Only Parks and Gregorioff creeks were selected for detailed ground surveys.

The cost effectiveness of spawning channels is strongly affected by egg-to-fry survival. Groundwater gradient is the principal factor affecting egg-to-fry survival in spawning channels because it affects the rate of intragravel flow. This enhancement technique is desirable only if a high groundwater gradient is present. Other characteristics such as high groundwater stability, low susceptibility to flooding, and high substrate permeability must also be present at suitable spawning channel sites (Cowan 1987). Remote fry rearing increases the cost effectiveness of spawning channels if large numbers of fry are outmigrating (Willette et al. 1991).

Twenty-one potential spawning channel sites were identified from previous reports and aerial photographs (Table 4). Gravina River (Stream No. #10500) was eliminated as a potential spawning channel site due to instability of the mainstem channel. Stream #16980 in Mallard Bay was eliminated due to insufficent water flow. Nine sites were selected for aerial and detailed ground surveys (Table 5). These sites are relatively long river valleys with substantial alluvial deposits compared to other valleys in PWS. Three sites are characterized by low valley gradient and valley lengths greater than 15 miles (Table 6). The remaining sites are relatively short, steep valleys with alluvial deposits.

The cost effectiveness of remote fry rearing is strongly affected by the number of fry that are outmigrating. Streams with salmon escapements exceeding 20,000 fish are most desirable. The success of this technique depends on the feasibility of operating fry weirs on relatively large streams. Sixteen fry rearing study sites were identified in PWS (Table 7). These streams are the largest pink salmon producing streams in the Sound (ADFG data reports). Intertidal fry weirs appear to be feasible in four of these streams. In the other twelve streams, fry weirs may be feasible above the intertidal zone. Data from egg and fry digs will be used to assess the potential magnitude of fry outmigrations from upstream habitats. This information will be used to estimate the cost-benefit ratios for fry rearing projects at each site.

The cost effectiveness of remote eggtakes is generally poor, but significant increases in production can be achieved. Cost effectiveness is improved slightly if a large number of eggs are taken. Thirty-seven oiled anadromous streams were identified in the PWS area from shoreline oil-contamination maps, aerial survey data, and anadromous stream catalogs (Table 8). Remote eggtakes appear feasible at most of these streams depending on the number of available spawners. Aerial surveys must be conducted immediately before eggtakes to estimate spawner abundance.

Egg boxes appear to be the least cost effective technique for wildstock enhancement. Cost effectiveness is improved if fry are reared on site before release. This conclusion is based on an egg-to-fry survival rate of 80% and a mean box life of five years. More information is required to fully assess the cost-effectiveness of this technique. No egg-box study sites have yet been identified.

Objective 2:

Gregorioff and Parks Creeks appear to be the most promising sites for construction of fish passes in the PWS area (Figure 2). Stream habitat surveys were conducted at Gregorioff and Parks creeks in 1991. At Gregorioff Creek, a 3.6 m barrier falls is located 300 m above tidewater. Approximately 10,500 m^2 of suitable spawning habitat exists above the barrier. Most of this habitat is low gradient well sorted gravels (Figure 3). A 3.1 m barrier falls blocks fish passage at Parks Creek. Approximately, 16,000 m^2 of well sorted low gradient spawning habitat exists above the barrier (Figure 4). Construction of fish passes at these two sites would allow access to spawning habitat with a capacity for 26,000 spawners. The benefit-cost ratios for Gregorioff and Parks creeks are 2.1 and 3.6, respectively (Table 9). Both of these sites were evaluated by the U.S. Forest service during the 1992 field season and preliminary engineering surveys were conducted.

During the 1992 field season data was collected during detailed ground surveys at nine potential spawning channel sites. Upon completion of each ground survey, standpipes were installed to monitor overwinter groundwater level and temperature if the site appeared suitable for a spawning channel. Overwinter groundwater conditions are being monitoring in four areas around northern and eastern PWS (Figure 5). Within the Valdez area, five spawning channel study sites have been identified. Two spawning channel study sites in northern PWS have gradients greater than one percent (Table 10). Groundwater gradient is the principal factor affecting egg-to-fry survival in spawning channels, because it affects the rate of intragravel flow. Wells and McNeil (1970) attributed high intragravel oxygen in pink salmon spawning beds to high permeability of the substrate and stream gradient. After initial ground surveys, four potential spawning channel sites were not chosen for overwinter groundwater monitoring (Appendix I). A description follows of each spawning channel study site selected for overwinter groundwater monitoring.

The Rude River (Stream #10160) is a large braided glacial river that flows into Nelson Bay. One possible site for a spawning channel was located during an aerial survey of the area in 1991. During several ground surveys of the area, this upstream site was determined to be at a high risk of flooding due to the instability of river channels. Two additional areas were located in a large grassy meadow on the east side of the Rude River. Three clear water sloughs originating from several beaver dams flow through the grassy meadow into the intertidal zone. Three standpipes were placed in this area identified as West #1, East #2 and North #3. The surface gradient in this area is 0.33%. Standpipes West #1 and East #2 were installed at the upper reaches of the high tide line and receive some tidal influence. The standpipe North #3 was placed further upstream away from any tidal fluctuation. The substrate appears to be ideal for spawning in both channels (1-4 cm gravel), but only two pink salmon were observed in the area. Insufficient water flows during the winter may limit salmon production in these channels. Water levels will be monitored throughout the winter at this site.

Mill Creek (Stream #14210) was listed in the Prince William Sound phase II comprehensive salmon plan as a possible site for a spawning channel. Mill Creek is a clear water side stream flowing into the Bettles River valley from the west. There is limited spawning habitat in some intertidal channels in the lower reaches of the valley. The area was a significant pink and chum salmon producer, until the 1964 earthquake dropped the spawning grounds about 6 feet underwater. Pink salmon escapements averaged about 100,000 prior to the earthquake, while present escapement ranges from 3,000 to 15,000 fish. The area most suited for a spawning channel is located opposite Mill Creek on the east side of the valley. This area is covered with alders and several spruce trees indicating good drainage. The Bettles River seems to be slowly moving away from this area reducing flooding risk. A standpipe was installed approximately 350 meters upstream from the high tide line and 100 meters to the east of the Bettles River. The surface gradient at this site is 1.58%. The area is readily accessible during periods of low stream flow. Electronic water temperature and depth recorders were installed to monitor overwinter conditions at this site.

Complex Creek (Stream #12570) located in Jonah Bay is a braided glacial stream with several clear water tributaries. A standpipe was installed approximately 75 meters to the east of a tributary fork. The surface gradient is 1.89% in this area. The area is covered by willows and alders with spruce trees lining the valley edges. Many small clear water streams with good spawning habitat pass through the area. Even year escapement of pink salmon averages 2,315 fish, while odd year escapement averages 594. Jonah Bay appears to be a favorable rearing area for chum salmon fry (Cooney, pers. comm.). The standpipe was equipped with electronic water temperature and depth recorders to monitor overwinter conditions at this site.

Extensive groundwater aquifers exist in the Lowe River and Valdez Creek valleys near the City of Valdez. These aquifers are composed of highly permeable sand and gravel deposits left by retreating glaciers. Hydrological studies conducted near the Valdez Glacier Stream discovered two aquifers (DOWL engineers in 1979). The upper aquifer is composed of highly permeable material with the water table sloping towards Port Valdez but at a lesser angle than the ground slope. The lower aquifer is confined by an extensive silt layer that completely separates the two aquifers in the area studied. Water quality samples collected from the aquifers indicated that both were well within EPA and State of Alaska water quality standards. Water in both aquifers was also moderately hard. There are many streams in the Valdez area with sufficient populations of pink salmon that could be used as possible broodstock sources if a spawning channel is built. Five spawning channel study sites were identified in the Valdez area (Figure 6).

Two groundwater seeps were located across the Blueberry Hill Road bed adjacent to Mineral Creek. The seeps flow into a small clear water stream (Stream #11470-2006) that enters Mineral Creek approximately 100 meters downstream from where it passes through a single culvert under Blueberry Hill Road. All of the flow in the creek appears to be provided by groundwater, and the area is protected from flooding by Blueberry Hill Road. The total length of the stream is approximately 250 meters averaging 2.5 meters wide. The stream runs along the face of a 3.0-4.5 meter rock cliff on the SE side with willows and alders covering the opposite bank. The subsurface geology of the area is composed of alluvial fan deposits (Combellick 1987). The area is owned by the University of Alaska which is planning on donating the parcel to the City of Valdez. Two standpipes were installed at the Mineral Creek study site identified as Mineral Creek #1 and Mineral Creek #2 (Figure 7). The surface gradient at this site is 0.80%. Electronic water temperature and depth recorders were installed at the Mineral Creek #2 study site to monitor overwinter conditions.

In the fall of 1974 an interceptor trench (Stream #11390) was built around the Valdez sewage treatment plant to prevent surface flows from entering into the area. During excavation the groundwater table was penetrated producing water flows of 5 to 10 cfs in the trench (Blanchet and Saari 1981). The trench forms two L-shaped channels that connect to one another. Even though the substrate is relatively poor, several thousand pink salmon spawned in the trench in 1992 while nearby natural streams exhibited relatively poor escapements. A standpipe was installed in the interceptor trench to monitor changes in water level during the winter (Figure 8). The behavior of groundwater flows in the trench during winter will be used to evaluate various channel designs in this area.

The area just south of the old Valdez pipeyard likely exhibits groundwater flows similar to that observed in the interceptor trench. This area is owned by the City of Valdez and is not currently being used, but it is protected from flooding by a roadbed to the south. The subsurface geology of the area is made up of glacial outwash material. A standpipe was installed at the southwest corner of the old Valdez pipeyard (Figure 8). The surface gradient at this site is 0.60%. Groundwater was located approximately two feet below the surface. Electronic water temperature and depth recorders were installed to monitor overwinter conditions.

The area between the Valdez and Robe rivers also appears to be suitable for construction of a spawning channel. A groundwater filled pond and a small stream were located in the area near the softball fields along the Richardson Highway (Figure 8). The surface gradient in this area is 0.60%. Standpipes were installed in the pond next to the softball fields and approximately 1 km below the softball fields in a small stream that flows into the Lowe River. This stream starts close to the pond and appears to be mainly groundwater fed. Five spawned-out pink salmon were seen in the stream. The subsurface geology of this area is glacial outwash material. An electronic water temperature and depth recorder was installed to monitor overwinter conditions at this site.

Several gravel pits along the Lowe River were evaluated as potential spawning channel sites. These pits were excavated to provide gravel for road construction after the 1964 earthquake. All of the gravel pits except one had been filled with sediment-laden water originating from migrating side channels of the Lowe River. Because it appeared that the channels of the Lowe River are very unstable, further efforts to locate spawning channel sites focused on areas protected by road beds from the Lowe River.

A spawning channel study site was identified at 7 mile on the Richardson Highway in a small clear water creek located approximately 50 meters off the road away from the Lowe River (Figure 9). The creek appears to be filled by both groundwater and runoff from the surrounding hills. Approximately 350 meters downstream the creek passes through a culvert under the highway. Pink salmon were seen spawning in a large pool just upstream of the culvert. The creek itself is surrounded with dense vegetation. The surface gradient is 0.30% in this area. A standpipe equipped with electronic water temperature and depth recorders was installed to monitor overwinter conditions. During the installation of the recorders in mid-November coho salmon were observed spawning in the area.

A potential spawning channel site was also identified at 9 mile of the Richardson Highway near a shallow clear water pond (Figure 9). The area is located approximately 20 meters off the road away from the Lowe River. Stream flows appear to be mainly fed by groundwater that bubbles up through the gravel over much of the area. Five sockeye salmon were seen spawning in a small pond just above the culvert that passes under the Richardson Highway. The surface gradient is 0.40% in this area. A standpipe equipped with electronic water temperature and depth recorders was installed to monitor overwinter conditions.

Five possible spawning channel sites were eliminated from further consideration because they did not appear suitable for channel development. Simpson River (Stream #10260) was eliminated as a study site after a ground survey of the area. What appeared to be an old channel from the air floods during high tide. No additional side streams or old channels were found that could possibly be used for a spawning channel. Both the Gravina River (Stream #10500) and Billings Creek (Stream #14370) were eliminated due to instability of the stream channel and the high risk of flooding. The Tebenkof River (Stream #14510) was eliminated, because it is a very short glacial system with high flows and flooding risk. Suitable spawning channel sites may exist in the upstream portions of the Jack River (Stream #11270) valley. However, this site was eliminated from further consideration at this time due to the cost and difficulty of accessing this area.

Data obtained from the electronic depth recording devices will be analyzed to evaluate groundwater stability and the probable rate of intragravel flow at potential spawning channel sites. This information will be useful to evaluate and identify other suitable spawning channel sites in the PWS area. Additional field work may be required to collect engineering data needed for development of detailed project designs. Construction of spawning channels in the Valdez area would be the most cost effective since all the sites are accessible by road reducing the costs of moving in heavy equipment for channel construction.

Objective 3:

Appropriate and cost-effective instream habitat and stock restoration projects cannot be identified until all field data is compiled and reviewed. Project selections will be made in 1993 after overwinter groundwater studies at spawning channel study sites are completed.

Objective 4:

Detailed project proposals will not be developed until objective 3 is completed.

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Appendix I: Description of streams with potential for fish passes and spawning channels in Prince William Sound, Lower Cook Inlet, and Kodiak Island.

Fish Pass Sites

Gregorioff Creek #11230 (Jack Bay): A ground survey of the was conducted on this stream on September 11, 1991. A series of small waterfalls block fish passage near tidewater. Gabion steps or a short fish pass would make the falls passable. Several thousand pink salmon carcasses were observed in the intertidal area and lower sections of the stream. The stream is approximately 1.8 miles in length with a gradient of 2.0%. The amount of available spawning area above the falls is approximately 10,563 square meters.

Parks Creek #14580 (Cochrane Bay): A ground survey was conducted on this stream on September 6, 1991. A 3.1 meter high waterfall near tidewater blocks fish passage. The stream is approximately 1.4 miles in length with a gradient of 1.8%. About 15,792 square meters of excellent spawning habitat exists above the barrier. Two thousand five hundred pink salmon and three sockeye were seen spawning below the falls.

Spawning Channel Sites

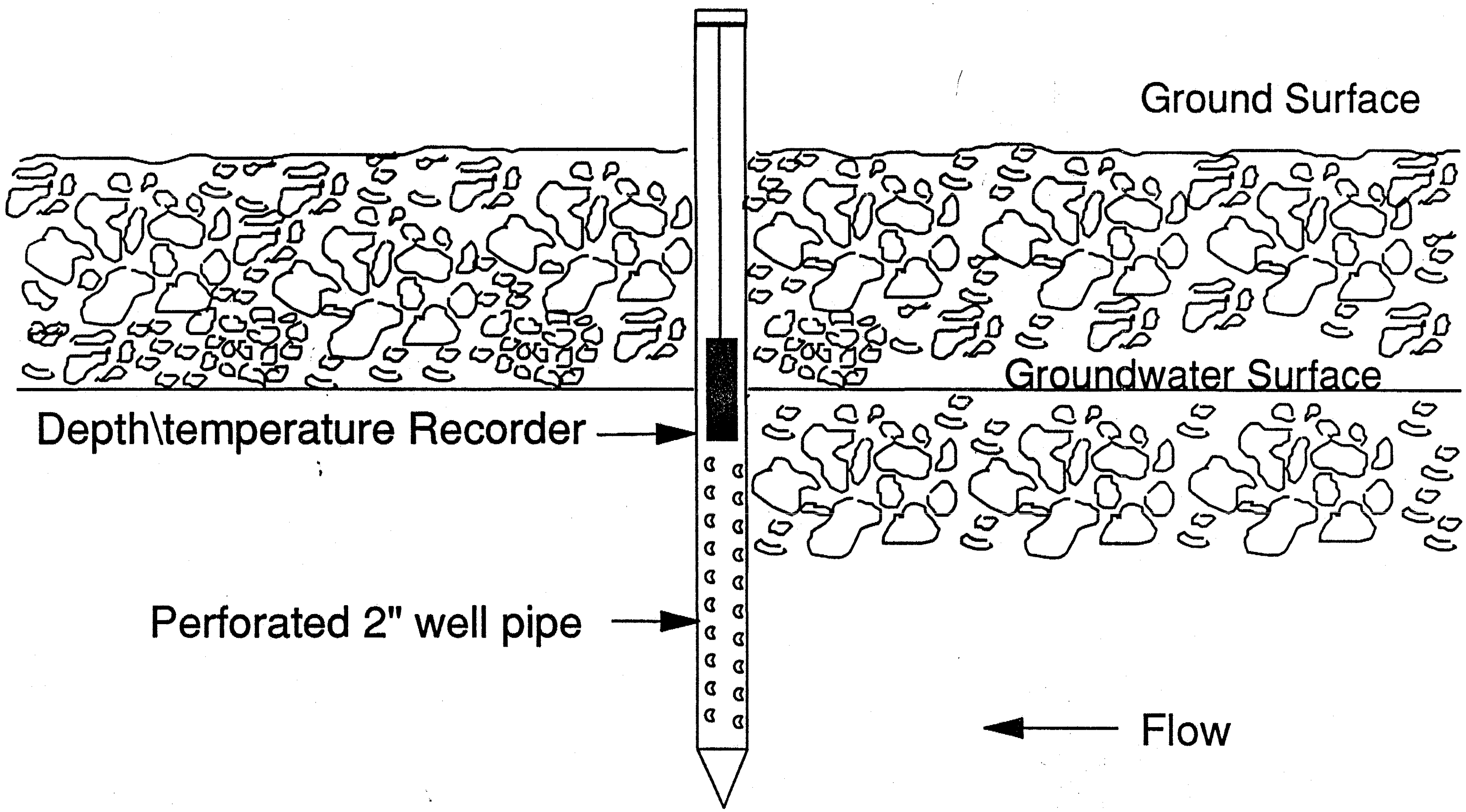
Old Creek #14240 (Hummer Bay): This is a small steep gradient creek that has several branches. Aerial and ground surveys were conducted in September 1991 and a dry channel running through thick alders was located. The channel appeared to carry water during periods of high flow. Another ground survey of this site is needed to locate other potential sites in the valley. This site will be evaluated in relation to other sites before deciding on further action.

Siwash River #12640 (Unakwik Inlet): A ground survey was conducted at this site in September 1991. The intertidal zone is a grassy outwash plain which is underwater during high tide. Thick stands of alder and spruce and extensive areas covered with standing water occur above the intertidal zone. This site will be evaluated in relation to other sites before deciding on further action.

Lafayette River #13210 (Port Wells): This is a braided glacial stream providing runoff from the Lafayette glacier. The U.S. Forest Service investigated this area for a proposed spawning channel. The best site lies in an old channel of the Lafayette River that connects with the Coghill River. The area is presently covered with willows and alders. A spawning channel at this site may be at risk of flooding from the Lafayette River, but it would provide approximately twelve miles of spawning habitat if the channel was built in a zig zag pattern.

Halferty Creek #14540 (Cochrane Bay): This is a semi-glacial stream with several clear water tributaries. The creek flows along several braided gravel channels and appears to be relatively stable. One possible site for a spawning channel was located during an aerial survey. The site is located along a hillside and surrounded by willows and alders with a small clear water stream flowing just above it. The area appeared to have good drainage and a possibility of good groundwater flow. At the time of the survey in October the water level in Halferty Creek was low. A standpipe was not installed because the ground was partial frozen. This site will be evaluated in relation to other sites before deciding on further action.

Figure 1
Groundwater standpipe for watertable fluctuation measurements



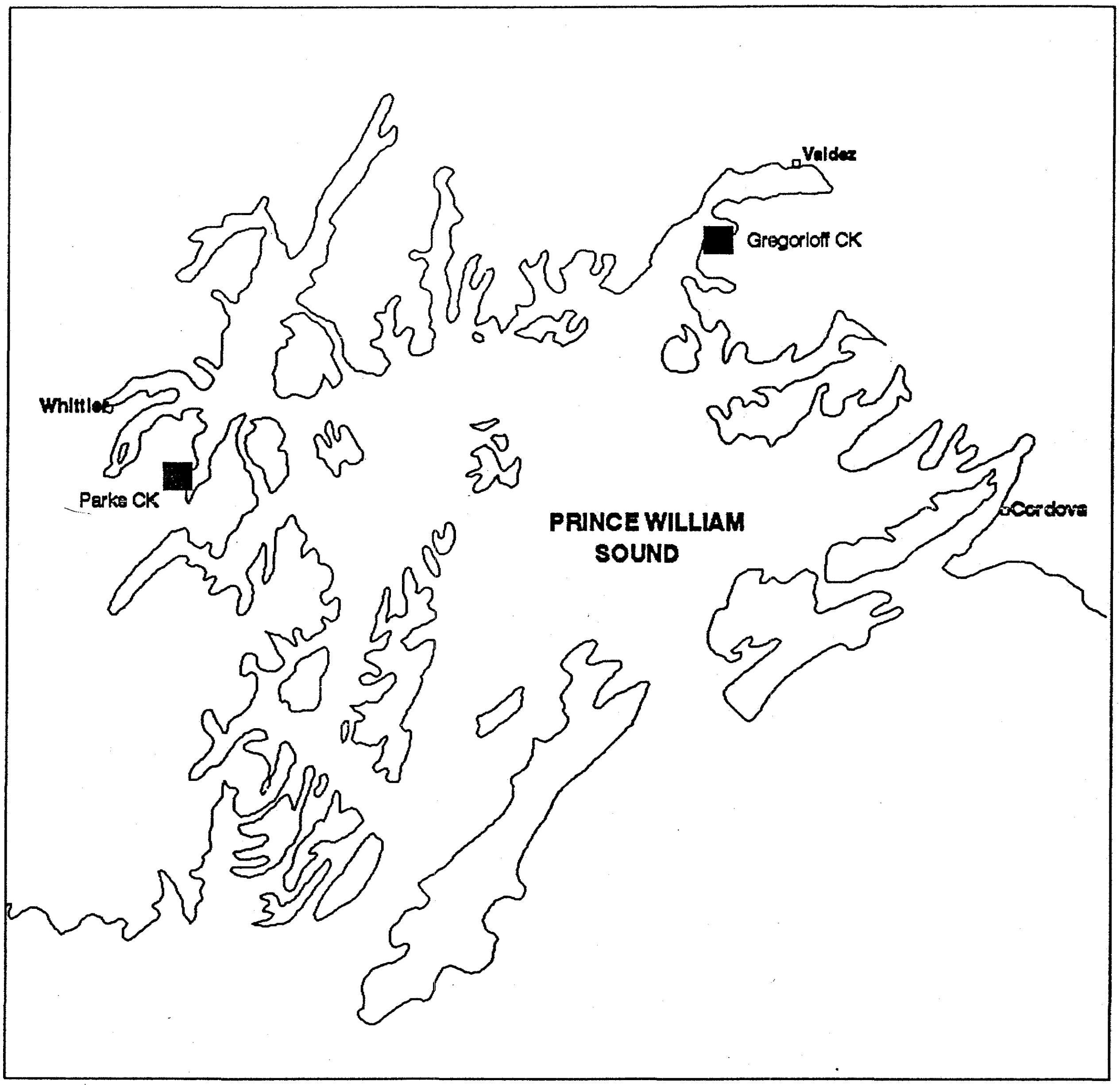


Figure 2. Fish pass study sites in Prince William Sound.

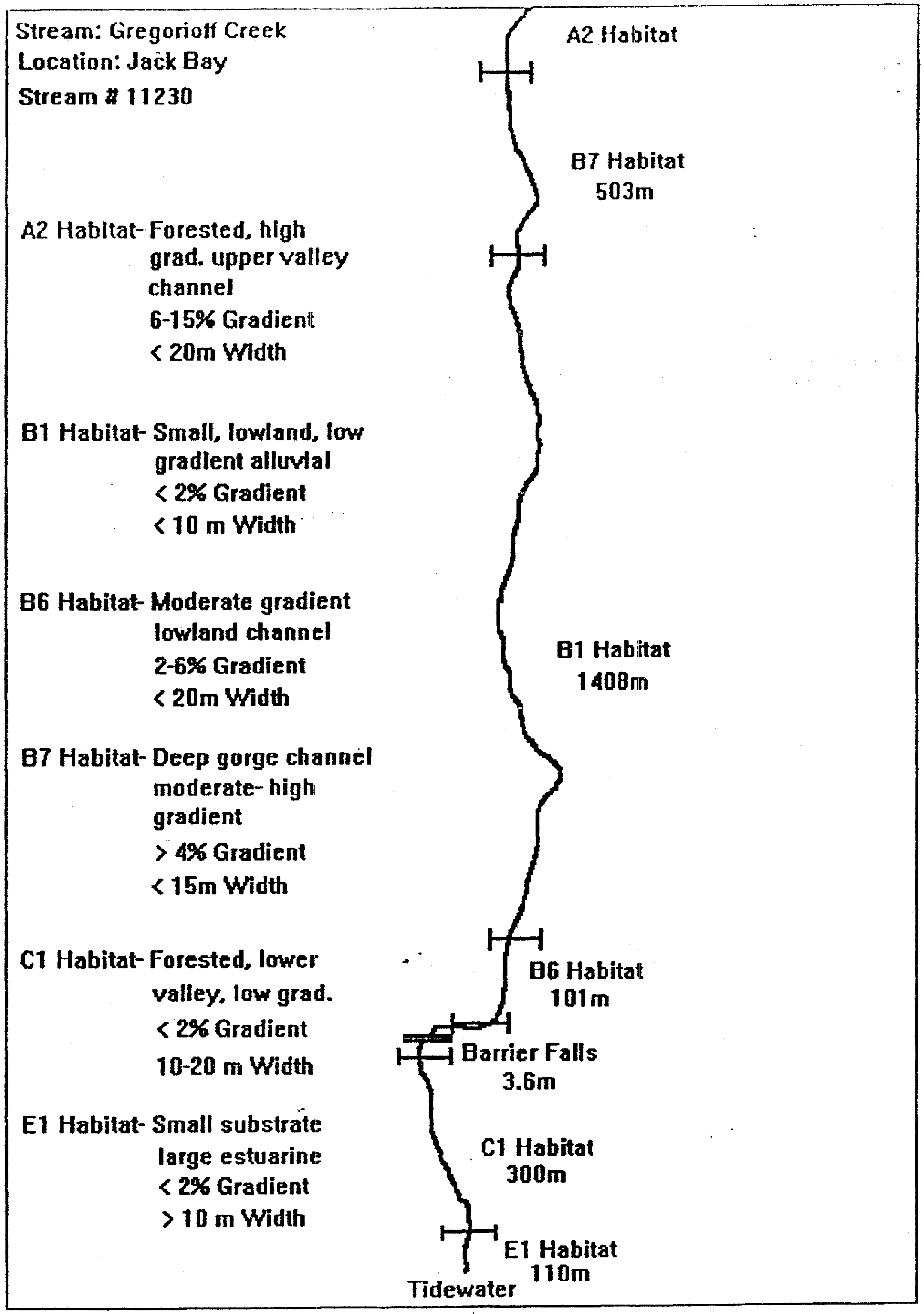


Figure 3: Instream habitat map of Gregorioff Creek

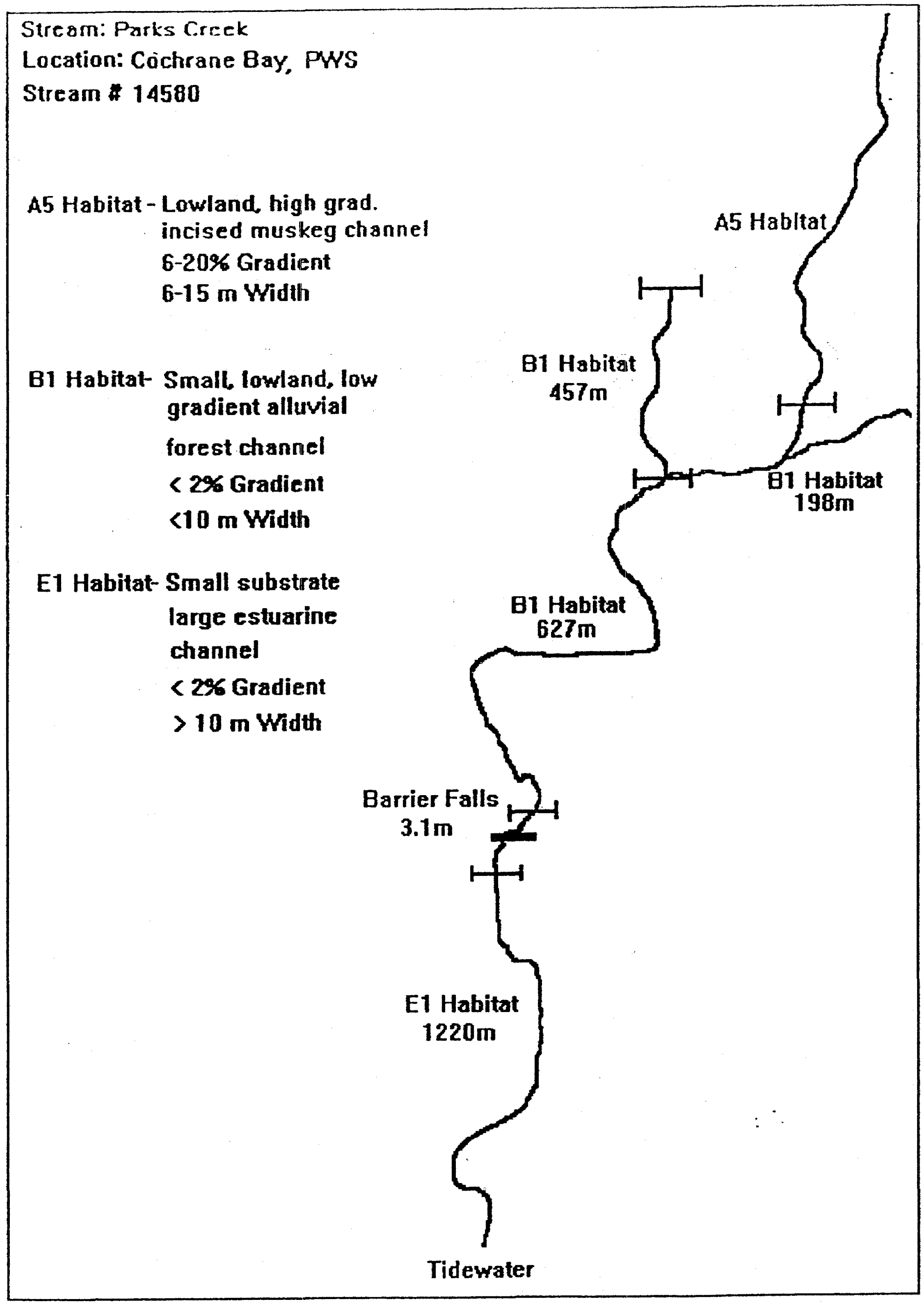


Figure 4: Instream habitat map of Parks Creek

COMPONENT 2

Lower Cook Inlet

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The area of Lower Cook Inlet (LCI) along the southern Kenai Peninsula has a significant number of estuarine and intertidal nursery areas important to pink and chum salmon production. The harvest of pink and chum salmon returns to the area provide a significant contribution to the southern Kenai Peninsula economy. The goal of this oil spill restoration survey involved the identification of impacted areas from the Exxon Valdez oil spill (EVOS) and the determination of the optimal methods of restoration in terms of habitat rehabilitation and fish enhancement methods.

The restoration surveys were initiated in FY/91 and FY/92, resulting in the final selection of Port Dick Head End Creek, on the Outer Gulf Coastal area of the Kenai Peninsula (Figure 1). This system was chosen because it is considered one of the most important pink and chum salmon production streams in the LCI area and it was moderately to heavily oiled by the EVOS. A potential spawning channel feasibility analysis at this site was initiated in FY/91 and will continue through to the spring of 1993.

The selected intermittent tributary or channel has historically supported a run of pink and chum salmon. However, since 1964 the channel site has filled in, apparently the result of the combined effects of the earthquake and periodic high surface runoff. The proposed channel site selected merges with the main stem of Port Dick Creek, before flowing into the estuarine area of the West Arm of Port Dick Bay (Figure 2). The lower 150 m of channel has been selected for this restoration survey. The existing channel currently has a major water source including a small lake at the 300 m. elevation (Figure 2). In some years during the summer months the channel is watered enough to attract spawning salmon, however as the season progresses the water level is drawn down below the 60-90 cm of deposited gravel. Further up the channel the water level remains above ground throughout the year.

OBJECTIVES

The original objectives of this restoration site survey include:

1) Field survey of documented oil impacted pink salmon streams and nursery areas in the Lower Cook Inlet area.

2) Based on results of these surveys, determine the best technique to restore the potentially damaged pink salmon stocks and or habitats required for spawning and nursery functions.

These objectives subsequently developed into the final selection of Port Dick Creek for feasibility surveys as a pink and chum salmon spawning channel to determine if adequate water quantities exist throughout the low water periods. Other parameters that continue to be evaluated are the availability and proximity of suitable spawning substrate, availability of existing donor broodstock and adequate water quality. Additional factors that will be evaluated are the protection from surface runoff and the vulnerability to floods, access for construction and subsequent maintenance and monitoring. Consideration of mixed stock salmon management will also be addressed. The surface gradient along the proposed channel site will be measured along with the available spawning area after the project is completed.

METHODS

Aerial and ground surveys were conducted to determine the best restoration site and technique. Several sites were initially investigated but not selected due to unsuitability of restoration methods. Island Creek in Port Dick Bay was investigated as a potential pink and chum salmon spawning channel site. However, no potentially stable channel site was identified.

Windy Bay was also considered as a potential short-term rearing site for pink salmon. Further investigation of this area indicated that Windy Bay in proximity to the important pink salmon spawning streams, is exposed to strong winds and subsequent rough sea conditions. This would impact the ability to successfully conduct saltwater short-term rearing operations using floating net pen systems. Other sites in the Outer Gulf Coastal area were also considered but not selected for similar reasons.

Preliminary surveys of Port Dick Creek indicated that it was the best candidate for further detailed restoration survey work as a salmon spawning channel. Groundwater standpipes are being used at the Port Dick proposed spawning channel site to measure the groundwater fluctuation. At least two sites were chosen to install the pipes. The standpipes are constructed of 8 cm polyvinyl chloride (PVC) pipe perforated along its length. At the top of each pipe a horizontal axle is installed with a spool and line on which a weighted tennis ball is attached. This pays out as the water recedes indicating the lowest level between recordings. Two holes were excavated by hand in which to install to the standpipes.

A battery operated stream stage recorder is also used to record water level data. A Datapod digital recorder model SR-1715 along with an Enviro-Labs model PT-105v-4 pressure transducer was installed in the channel site. The Datapod is powered by a external

12 volt battery source. The pressure transducer was installed in a well point which was constructed of 3.75 cm schedule 40 iron pipe. A point was made from 3.75 cm solid round stock, welded to one end of the pipe and grounded to a point. Small slits were cut into the pipe along its length to facilitate the movement of water. The top end of the pipe was threaded and a drive cap tightly fitted. Before the well point was driven into the streambed a 3.75 cm wood dowel was inserted into the pipe to prevent material from entering the pipe. The 150 cm well point was driven flush with the streambed and a layer of styrofoam laid over the top to help prevent freeze out. The external battery pack was fitted into a plastic 5 gallon bucket with a gasketed lid and secured to a nearby tree. One hole was drilled into the bucket to accept the transducer lead and sealed with silicone sealant. This stand pipe and recording system should operate efficiently though the extreme winter conditions.

The availability and size of suitable spawning substrate was noted and measured during excavation of the standpipe holes. Ground water quality will be evaluated by periodic observations. The preliminary surface gradient will be measured with a hand held clinometer. Several points along the channel site will be chosen for detailed measurements to determine the amount of available spawning area.

PRELIMINARY STUDY RESULTS

Two standpipes were installed at the Port Dick Creek site on November 21, 1991 (Figure 2). Excavation by hand proved to be very labor intensive as the water table was very shallow, allowing the newly dug holes to slough off as the digging progressed. As Standpipe #1 was installed to a depth of 50 cm, water was first contacted at a depth of 20 cm. Pink salmon eggs were also uncovered from hole #1. The top layer of eggs were frozen, while the lower layer were eyed and appeared to be viable. Standpipe #2 was installed to a depth of 52.5 cm. Water was observed at a depth of 15 cm.

Efforts were made to visit the site every 30-40 days throughout the period of low water flow. Severe winter weather and the remoteness of this site dictated the schedule be amended at times. Water table level results and dates of on-site visits are shown in Figure 3 and 4. Water table levels were very similar at both standpipes varying from a positive 18.75 cm on January 14, 1992 to trace amounts on March 3, 1992 (Figures 3 and 4). Upon our return to the channel site on January 14, 1992 we found that the axle, spool and string apparatus had frosted and proved to be unreliable to determine the lowest water level between recording visits. Therefore all subsequent readings are dipstick type measurements.

On October 23, 1992 a digital stream stage recorder was installed to a depth of 120 cm near the site of standpipe #1 (Figure 1). The datapod was programmed to record the stream stage every 60 minutes giving the data chip a life span of 30-40 days. Results for the 1992-93 low water period will be forthcoming. Preliminary observations show that there is an abundant supply of suitable native spawning material available on site. Observations made during excavations reveal 60% of the materials were 0.62-1.88 cm in size with 20% fines (sand) and approximately 20% were 6.2-8.75 cm rock. Width measurements of the channel produced an average width of 9.7 m. This could produce an area of approximately 1,458 m^2 of suitable spawning area. Pink and chum salmon spawn extensively in Port Dick Creek. Long term average escapement includes 42,600 pink and 4,300 chum salmon. Based on this information it is assumed that the native stocks will be used to seed the spawning channel. Therefore genetic factors and mixed stock management will not be a concern. At this time water quality is not considered a concern since adjacent Port Dick Creek intercepts surface and ground water from the channel site and the channel attracts spawning salmon when sufficient surface water is available.

The spawning channel site is located within the high intertidal zone. The surface gradient was measured on 21 November 1992 at the highest tide of the year, 4.5 m. The high tide reached the upper end of the proposed channel at 150 m. The depth of the water at the lower end of the channel where it merges with Port Dick Creek measured 95.6 cm resulting in a preliminary determination of surface gradient of 0.64%

Further engineering investigations will be done to determine the optimum engineering design for the spawning channel as well as excavation and construction equipment required and estimated costs. Construction access to the spawning channel will be limited to larger landing craft modules (LCM'S) to transport construction equipment. Trip time to Port Dick from the Homer Harbor is estimated at 10-12 hrs.

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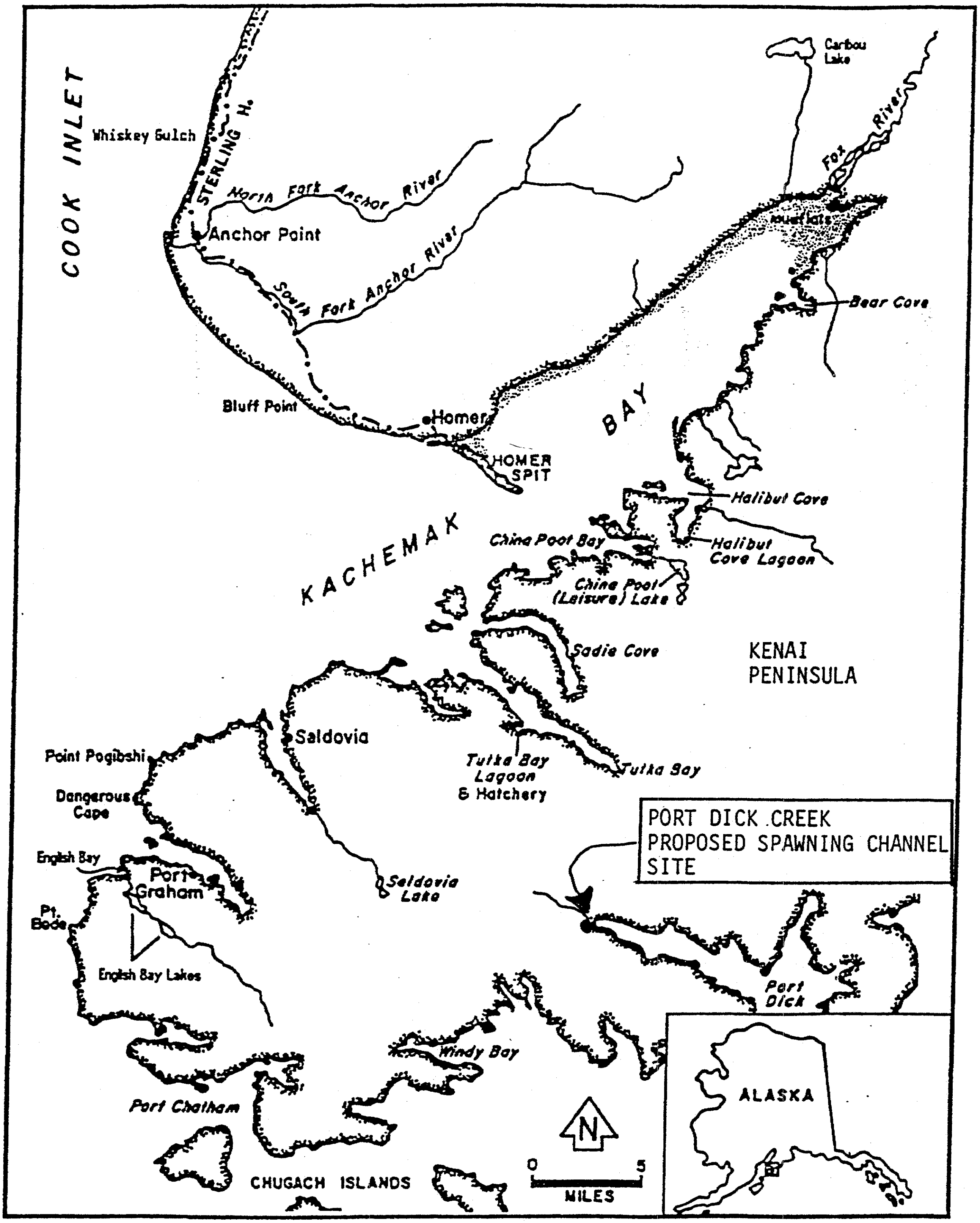

Figure 1. Location map of the Port Dick Creek Proposed Spawning Channel Site, Kenai Peninsula.

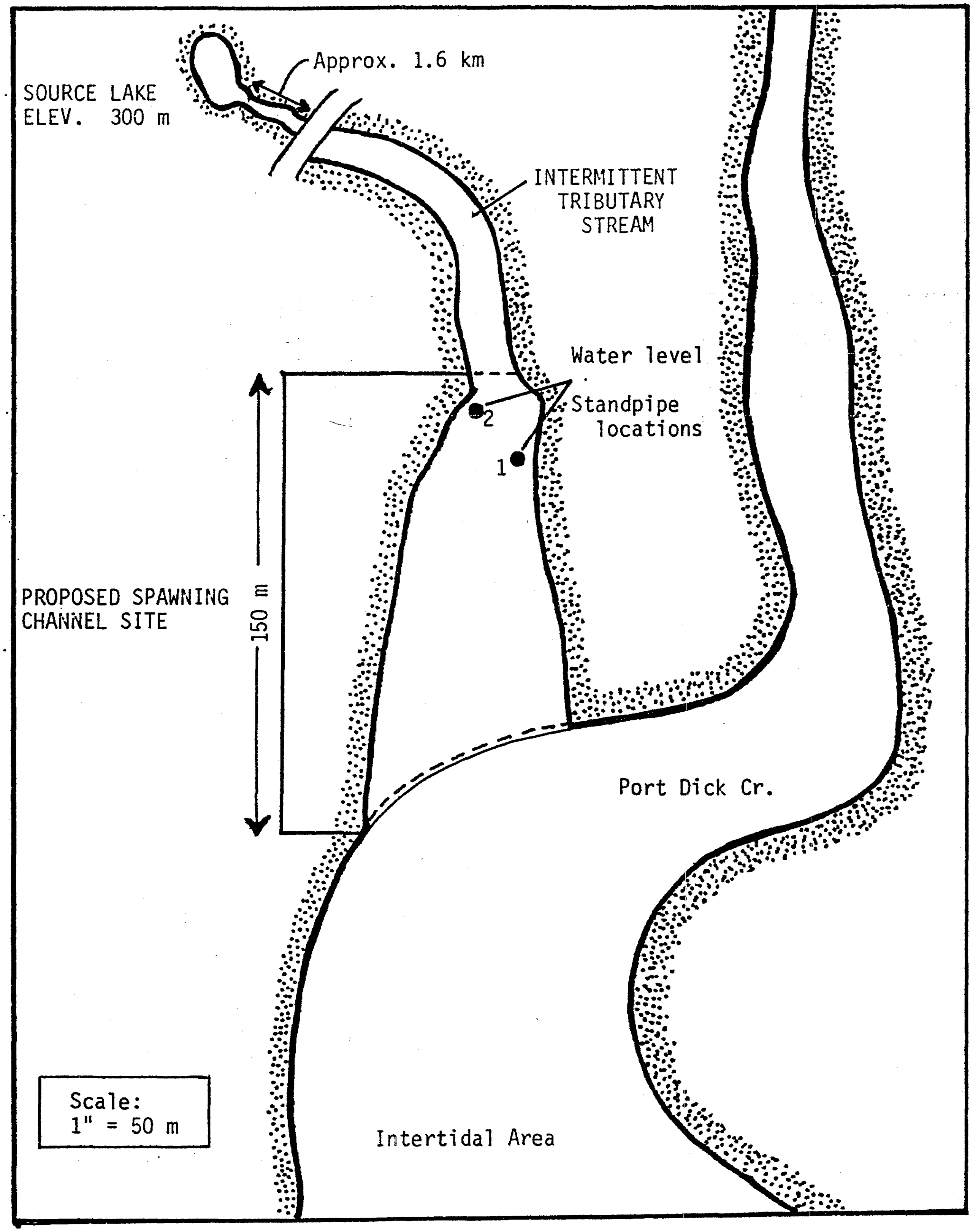

Figure 2. Port Dick Creek, adjacent proposed spawning channel site, and water level standpipe locations.

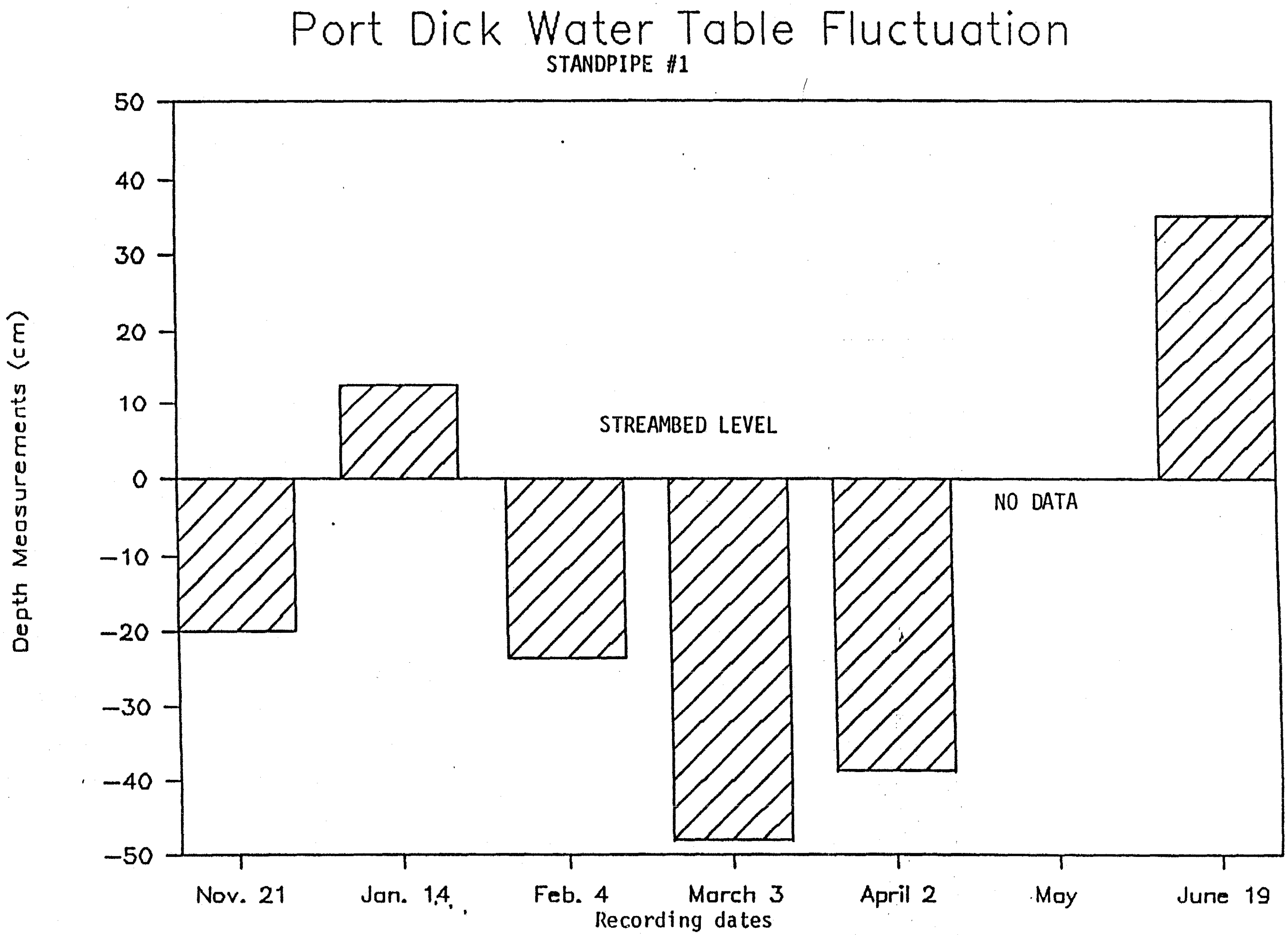

Figure 3. Standpipe #1 Water Table measurements, Port Dick Creek, November 1991 - June 19, 1992.

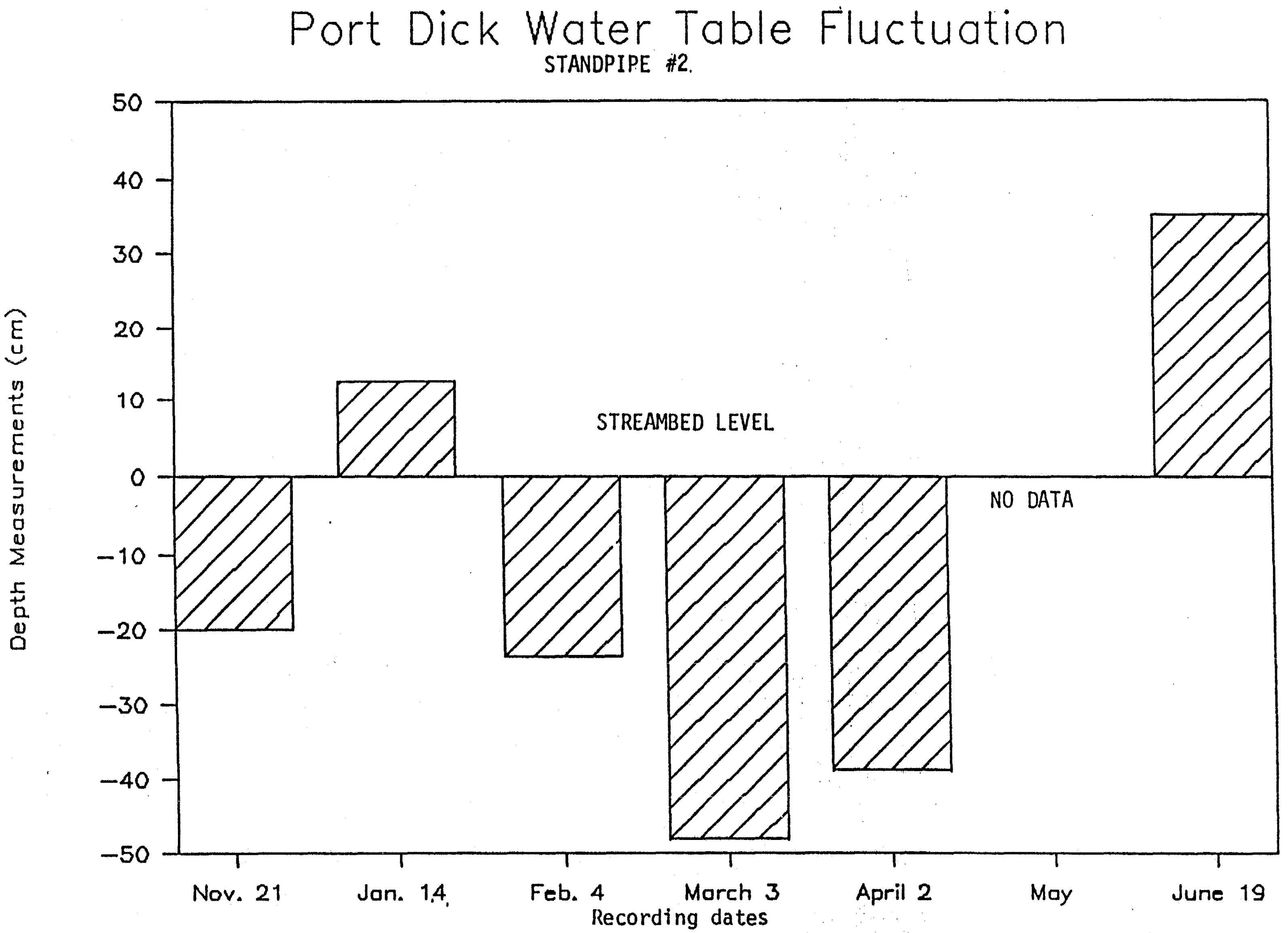

Figure 4. Standpipe #2 Water Table measurements, Port Dick Creek, November 1991 - June 19, 1992.

Table 1: Estimated pink salmon escapements in thousands of fish for the major spawning systems of Lower Cook Inlet, 1960 – 1971.

Stream	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
	Year											
Humpy Creek	10.0	22.6	56.0	34.7	18.5	28.0	30.0	25.0	24.7	5.4	55.2	45.0
China Poot	9.0	2.0	26.0	–	–	–	–	2.5	6.0	0.2	1.5	2.1
Tutka Lagoon	15.0	15.0	30.0	10.0	20.0	20.0	12.0	7.0	7.9	6.5	6.5	16.7
Barabara Creek	2.0	0.1	1.5	0.1	–	–	5.0	–	2.0	0.9	0.4	4.0
Seldovia River	25.0	25.0	50.0	13.0	60.0	30.0	86.0	55.0	53.2	60.0	23.0	31.1
Port Graham River	15.0	5.0	50.0	2.0	16.0	1.5	24.0	2.0	24.4	4.0	16.6	13.2
Dogfish Lagoon	2.0	–	3.0	–	–	–	–	–	–	–	–	0.3
Port Chatham Creeks	4.0	7.0	7.0	–	–	–	10.0	–	–	–	3.0	15.5
Windy Right Creek	8.0	10.0	12.5	4.9	6.2	2.0	7.0	6.0	2.8	3.2	2.1	13.0
Windy Left Creek	8.0	5.0	12.5	4.5	7.7	10.0	7.0	6.0	6.9	23.0	13.0	35.4
Rocky River	130.0	2.0	200.0	12.0	80.0	0.3	44.0	1.0	43.1	1.0	32.0	1.6
Port Dick Creek	35.0	14.0	40.0	16.0	31.5	50.0	35.0	20.0	29.0	12.0	34.5	97.8
Island Creek	23.2	2.0	15.0	3.6	30.0	0.5	7.0	0.5	4.3	0.1	5.5	0.1
South Nuka Creek	20.0	2.0	22.0	0.1	10.0	–	10.0	–	10.0	3.0	11.0	14.0
Desire Lake Creek	–	–	18.0	–	1.3	–	–	–	–	–	–	30.0
James Lagoon	–	–	–	–	–	–	–	–	–	–	–	–
Aialik Lagoon	–	–	25.0	0.3	–	–	2.0	–	–	–	–	–
Bear Creek	1.4	–	3.1	–	6.4	–	–	–	3.1	–	–	–
Salmon Creek	–	–	–	–	–	–	–	–	–	–	–	–
Thumb Creek	–	–	–	–	–	–	–	–	–	–	–	–
Humpy Cove	–	–	–	–	–	–	–	–	–	–	–	–
Tonsina Creek	–	–	–	–	–	–	–	–	2.9	0.1	–	–
Big Kamishak River	–	–	100.0	75.0	75.0	–	13.0	–	–	–	–	–
Little Kamishak River	–	–	100.0	24.0	–	–	28.0	3.5	–	0.5	2.0	–
Amakdedori Creek	60.0	–	80.0	–	10.0	–	8.0	–	–	1.0	13.0	–
Bruin Bay River	18.0	–	300.0	25.0	–	–	20.0	0.5	–	5.0	40.0	22.0
Sunday Creek	1.5	–	5.0	2.0	–	–	20.0	–	–	1.0	2.0	43.0
Brown's Peak Creek	–	–	25.0	10.0	20.0	10.0	11.0	–	–	2.0	–	8.0
Total	387.1	111.7	1181.6	237.2	392.6	152.3	379.0	129.0	220.3	128.9	261.3	392.8

COMPONENT 3

Kodiak and Afognak Islands

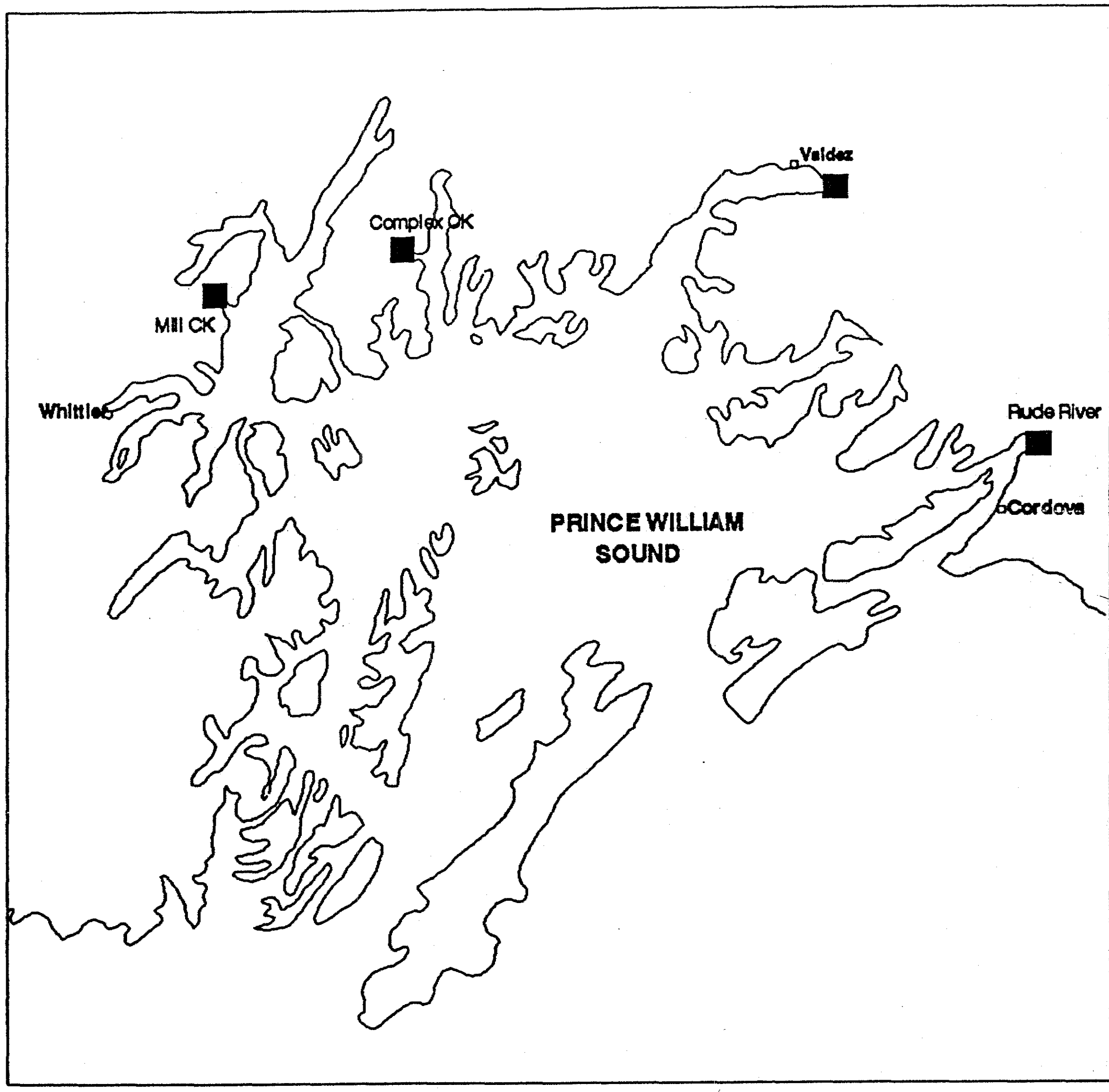

Figure 5: Location of spawning channel study sites selected for overwinter groundwater monitoring in Prince William Sound

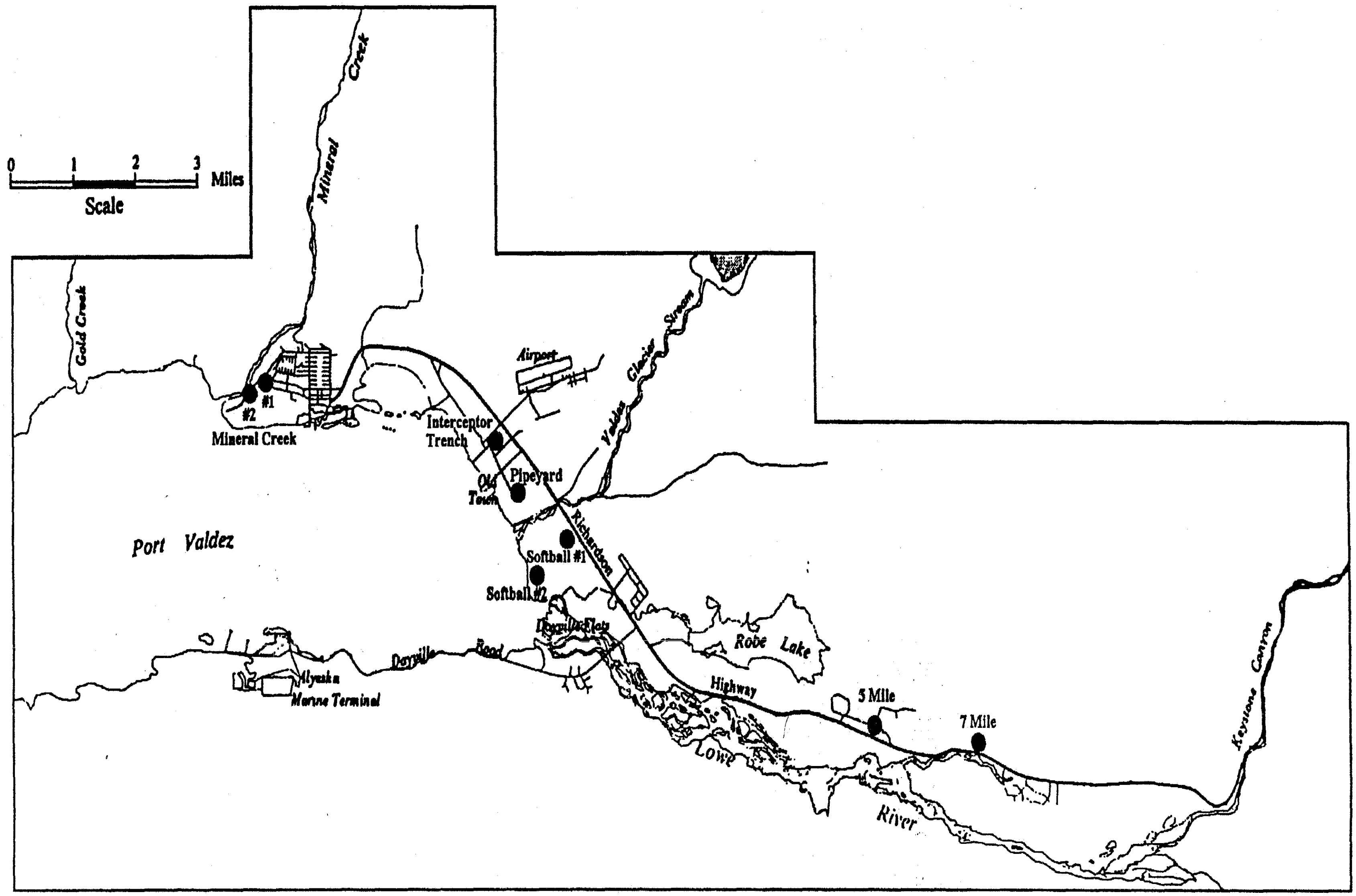

Figure 6: Location of spawning channel study sites selected for overwinter groundwater monitoring in the Valdez area

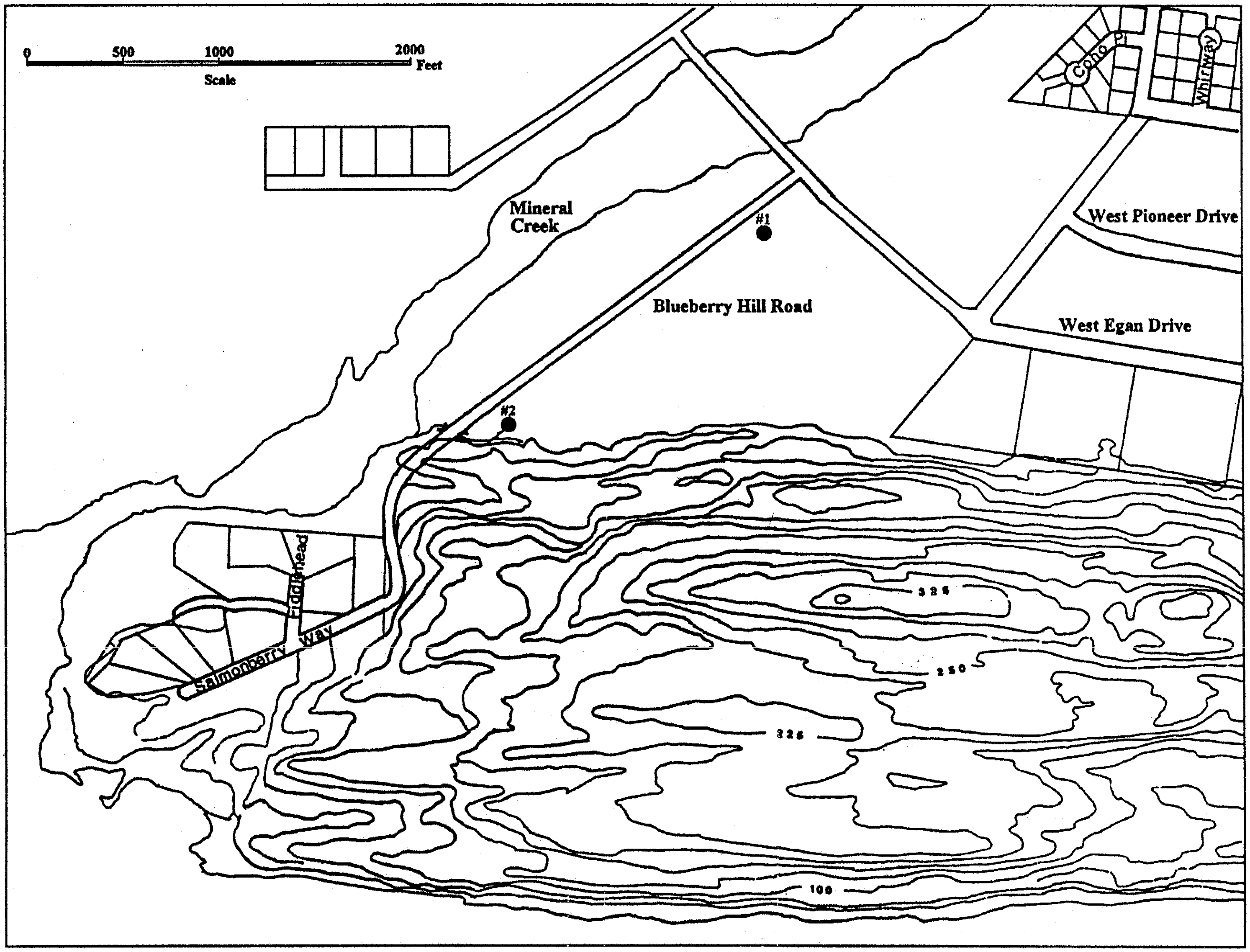

Figure 7: Location of standpipes installed near Mineral Creek, Valdez

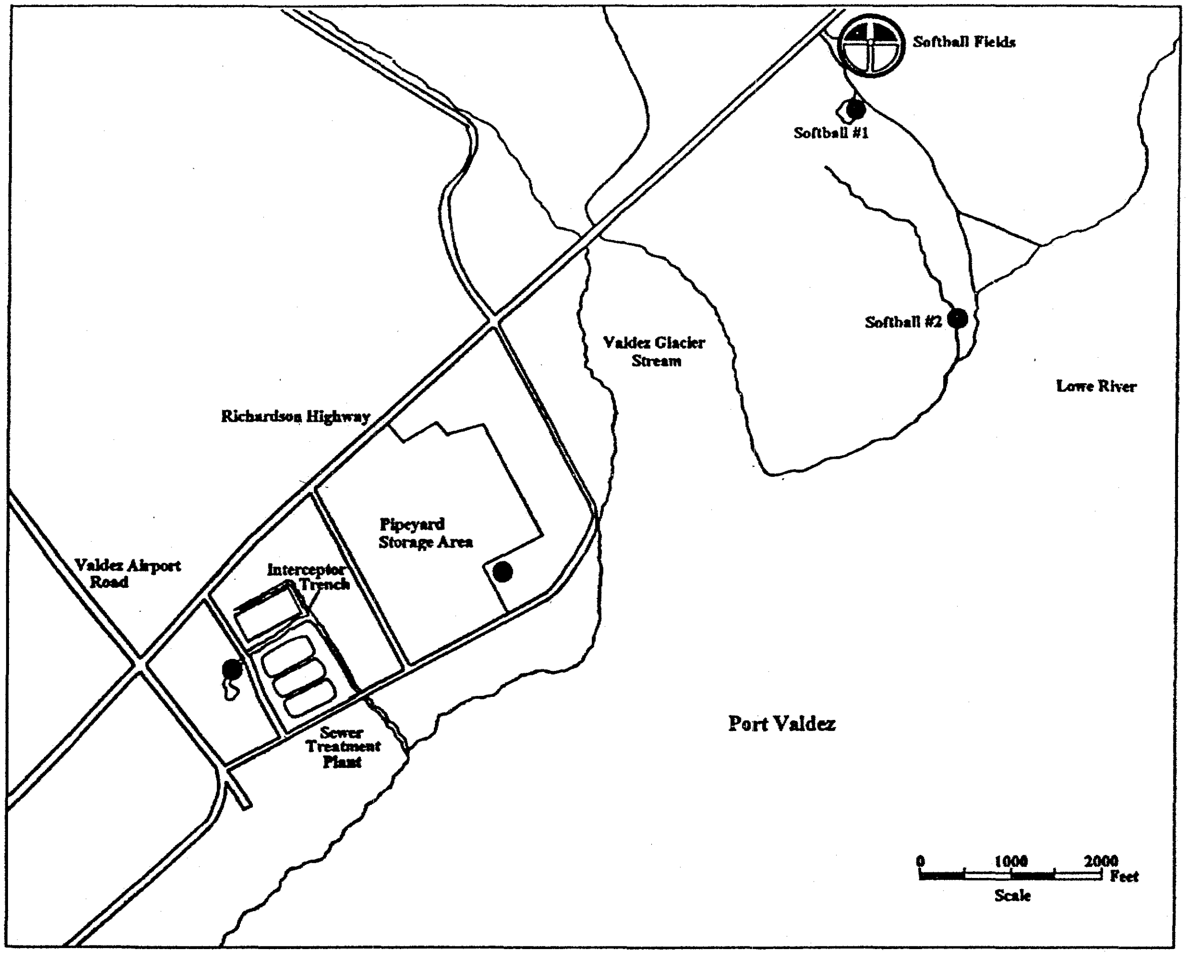

Figure 8: Location of standpipes installed near the sewage treatment plant and the softball fields, Valdez

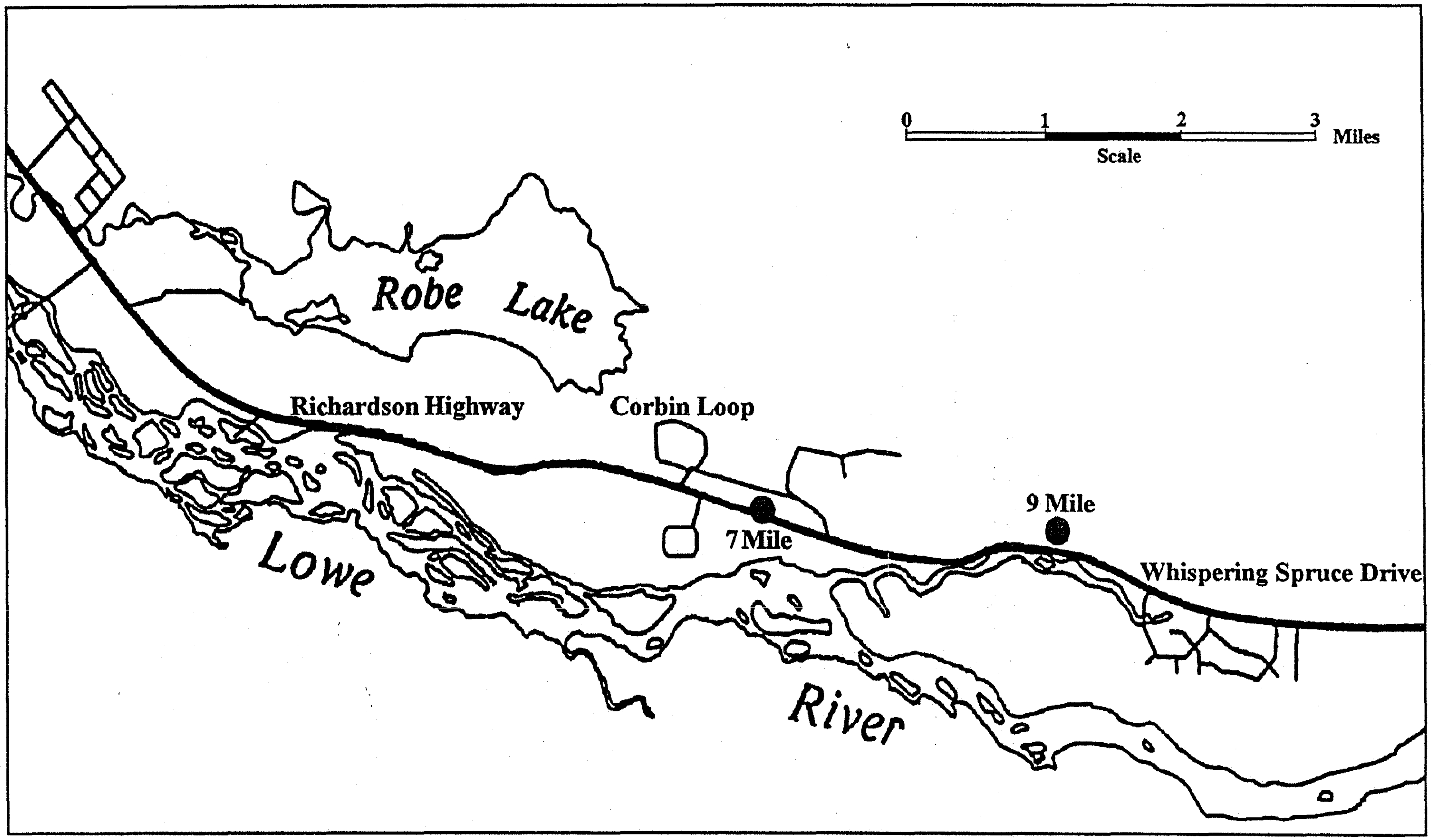

Figure 9: Location of standpipes installed along the Lowe River

Table 1: Criteria used to assess the suitability of sites for spawning channeldevelopment (Bonnell 1991).

Factor	Criteria
Gradient	Approximately 0.2% to 0.5% along the center of the channel
Substrate	Clear, firm gravel base with low proportion of fines
Water source	Unconfined aquifer with high percolation rate
Water table	Near ground surface with minimal fluctuation
Water quality	General suitability– dissolved oxygen, temperature and water chemistry suitable for incubation and preferably rearing
Spawner recruitment	Channels should be located within the upstream spawning limit, preferably with sufficient population size to recruit channel initially
Flood protection	Location to take advantage of existing protection such as high ground, dyke works, or road embankments. Low propensity for backwatering during floods
Sources of siltation	Low potential for siltation from intermittent surface flow or other sources
Access	For heavy machinery during construction and for maintenance later
Availability of materials	Channels should be near sources of quarry rock for bank armoring and natural or graded gravels for substrate if necessary
Maintenance	Low potential requirement; e.g. little or no beaver activity
Approvals	Property ownership (rights of way), and interagency approvals
Manageability	Proposed adult production to be consistent with stock management plans

Table 2: Streams initially evaluated for construction of fish passes in Prince William Sound.

Stream	No.	Location	Oil Spill Damage	Land Owner
Prince William Sound				
Waterfall Ck	10380	Sheep Bay	None	Eyak Corp.
Carlson Ck	10540	Port Gravina	None	National Forest
Shale Ck	10920	Fish Bay	None	National Forest
Millard Ck	11150	Galena Bay	None	Tatitlek Corp.
Johnson Cove Ck	11190	Valdez Arm	None	Tatitlek Corp.
Gregorioff Ck	11230	Jack Bay	None	State Land Selection
Vlasoff Creek	11290	Jack Bay	None	State Land Selection
Chuck's Ck	12020	Emerald Cove	None	Tatitlek Corp.
Unnamed	12390	Unakwik	None	National Forest
Papoose Ck	12920	Squaw Bay	None	National Forest
Chasm Ck	14270	Pirate Cove	None	National Forest
Halferty Ck	14540	Cochrane Bay	None	National Forest
Parks Ck	14580	Cochrane Bay	None	National Forest
Shrode Lake system	14760	Cochrane Bay	None	National Forest
Picturesque Cove	14790	Culross Passage	None	National Forest
Unnamed	14810	Port Nellie Juan	None	National Forest
Mink Ck	14820	Port Nellie Juan	None	National Forest
East Finger Ck	14840	Port Nellie Juan	None	National Forest
Derickson Ck	14920	Derickson Bay	None	National Forest
Point Nellie Juan Ck	15000	Port Nellie Juan	Light	National Forest
Elishansky Ck	15100	Eshamy	None	Chenega Corp.
Kompkoff Ck	16100	Jackpot Bay	None	Chenega Corp.
Unnamed	16150	Jackpot Bay	None	Chenega Corp.
Chenega Ck	16280	Chenega Island	Light	Chenega Corp.
Claw Ck	16320	Whale Bay	None	National Forest
Pablo Ck	16330	Whale Bay	None	National Forest
Johnson Ck	16550	S. Bainbridge Pass.	None	National Forest
Halverson Ck	16560	Bainbride Island	None	National Forest
Anderson Ck	16670	Sawmill Bay	None	Chenega Corp.
Unnamed	16780	Sleepy Bay	Heavy	Chenega Corp.
Unnamed	16820	Snug Harbor	Moderate	National Forest
Unnamed	16840	Marsha Bay	Moderate	Native Lands
Port Audrey Ck	16950	Port Audrey	None	National Forest
Barns Cove	16970	Drier Bay	None	National Forest
Whiskey Ck	17430	Hawkins Island	None	National Forest

Table 3: Potential fish pass sites eliminated from further consideration with description for action taken.

Stream	No.	SPGD	FLHG	LWWF	IUHB	CMPJ
Prince William Sound						
Waterfall Ck	10380				X	
Carlson Ck	10540		X		X	
Shale Ck	10920				X	
Millard Ck	11150		X			
Johnson Cove Ck	11190			X		
Vlasoff Creek	11290				X	
Chuck's Ck	12020		X			
Unnamed	12390	X				
Papoose Ck	12920				X	
Hobo Ck	14170					X
Chasm Ck	14270		X			
Halferty Ck	14540		X		X	
Shrode Lake system	14760					X
Picturesque Cove	14790		X			
Unnamed	14810	X			X	
Mink Ck	14820		X			
East Finger Ck	14840	X			X	
Derickson Ck	14920					X
Point Nellie Juan Ck	15000				X	
Elishansky Ck	15100	X			X	
Kompkoff Ck	16100		X			
Unnamed	16150	X			X	
Chenega Ck	16280		X			
Claw Ck	16320		X		X	
Pablo Ck	16330				X	
Johnson Ck	16550	X			X	
Halverson Ck	16560	X			X	
Anderson Ck	16670			X		
Unnamed	16780				X	
Unnamed	16820				X	
Unnamed	16840	X			X	
Port Audrey Ck	16950		X			
Barns Cove	16970				X	
Unnamed	16980			X		
Whiskey Ck	18430				X	

SPGD – Steep Gradient
FLHG – Falls too High
LWWF – Low Water Flow
IUHB – Inadequate Upstream Habitat
CMPJ – Completed Project

Table 4: Sites initially considered for construction of spawning channels in Prince William Sound.

Stream	No.	Location	Oil Spill Damage	Land Owner
Rude River	10160	Nelson Bay	None	Chugach Alaska Corp.
Simpson Creek	10260	Simpson Bay	None	Eyak Corp.
Gravina River	10500	Port Gravina	None	National Forest
Jack River	11270	Jack Bay	None	National Forest
Lowe River	11370	Valdez	None	State of Alaska
Valdez Creek	11420	Valdez	None	City of Valdez
Mineral Creek	11470	Valdez	None	City of Valdez
Miners Creek	12440	Unakwik Inlet	None	National Forest
Complex Creek (N)	12565	Unakwik Inlet	None	National Forest
Complex Creek (S)	12570	Unakwik Inlet	None	National Forest
Siwash River	12640	Unakwik Inlet	None	National Forest
Lafayette	13210	Coghill	None	National Forest
Hobo Ck	14170	Port Wells	None	National Forest
Mill Ck	14210	Bettles Bay	None	National Forest
Old Ck	14240	Hummer Bay	None	National Forest
Billings Creek	14370	Passage Canal	None	National Forest
Tebenkof River	14510	Blackstone Bay	None	National Forest
Kings River	14870	Kings Bay	None	National Forest
Nellie Juan River	14880	Kings Bay	None	National Forest
Unnamed	16980	Mallard bay	None	National Forest
Macleod Ck	17070	Macleod Harbor	Unobserved	National Forest

Table 5: Potential spawning channel sites selected for field studies in Prince William Sound.

Stream	No.	Location	Oil Spill Damage	Land Owner
Rude River	10160	Nelson Bay	None	Chugach Alaska Corp.
Simpson Creek	10260	Simpson Bay	None	Eyak Corp.
Lowe River	11370	Valdez	None	State of Alaska
Valdez Creek	11420	Valdez	None	City of Valdez
Mineral Creek	11470	Valdez	None	City of Valdez
Complex Creek	12570	Unakwik Inlet	None	National Forest
Siwash River	12640	Unakwik Inlet	None	National Forest
Mill Ck	14210	Bettles Bay	None	National Forest
Old Ck	14240	Hummer Bay	None	National Forest

Table 6: Summary of valley characteristics and escapements for potential spawning channel sites in Prince William Sound.

Stream	No.	Contour Level (ft)	Distance (miles)	Distance (feet)	Gradient	Stream Length (miles)	Escapement Even Year	Escapement Odd Year
Rude River	10160	100	5.75	30360	0.33%	17.0	–	–
Simpson River	10260	100	3.25	17160	0.58%	11.0	–	–
Lowe River	11370	100	6.00	31680	0.32%	19.0	3,102	2,525
Valdez Ck (upper)	11420	200	2.00	10560	1.89%	2.3	–	–
Valdez Ck (lower)	11420	100	2.75	14520	0.69%	2.4	–	–
Mineral Ck	11470	100	1.50	7920	1.26%	9.3	–	–
Complex Creek	12570	100	1.00	5280	1.89%	1.4	2,315	594
Siwash Ck	12640	100	1.60	8448	1.18%	3.0	35,685	8,751
Mill Ck	14210	100	1.20	6336	1.58%	1.5	15,568	3,855
Old Ck	14240	100	0.75	3960	2.53%	2.0	3,568	350

Table 7: Streams considered for fry rearing in Prince William Sound and average odd and even year pink salmon escapements. Determined from both aerial photographs and aerial surveys.

Stream	No.	Location	Weir Possible	Mean Escapement Even	Mean Escapement Odd
Duck River	11160	Galena Bay	No	63.3	23.5
Coghill River	13220	College Fiord	Yes	52.9	134.0
Millard Creek	11150	Galena Bay	Yes	48.0	26.8
Constantine Creek	18150	Constantine Harbor	No	44.2	44.3
Koppen Creek	10350	Sheep Bay	No	43.4	47.9
Jonah Creek	12590	Unakwik Inlet	No	39.0	31.8
Wells River	12340	Wells Bay	No	38.5	59.2
Swanson River	14320	Pigot Bay, Port Wells	No	37.9	31.9
Siwash River	12640	Unakwik Inlet	Yes	37.7	6.8
Jackpot River	16080	Jackpot Bay	Yes	33.5	41.9
Stellar Creek	11530	Sawmill Bay, Valdez Arm	No	31.0	22.9
Shrode Creek	14760	Long Bay	No	29.0	37.0
Olsen Creek	10510	Port Gravina	No	27.5	37.0
Nuchek Creek	18120	Constantine Harbor	No	26.6	69.5
Hardy Creek	18340	Fish Bay	No	16.8	32.7
Cook Creek	18280	Anderson Bay	No	15.3	24.5

Table 8: Streams considered for remote eggtakes and hatchery egg incubation in Prince William Sound.

Stream	No.	Location	Oil Impact
Unnamed	12995	Applegate	Moderate
Junction Creek	16180	Chenega Island	Moderate
Unnamed	16182	Preston Cove Chenega Island	Heavy
Moffittoffskilof	16280	Chenega Island	Moderate
Unnamed	16388	Bainbridge Passage	Heavy
Unnamed	16395	Bainbridge Passage	Heavy
Unnamed	16397	Bainbridge Passage	Heavy
Unnamed	16450	Prince Wales Passage	Heavy
Unnamed	16451	Prince Wales Passage	Heavy
Unnamed	16613	Shelter Bay, Evans Island	Heavy
Unnamed	16620	Shelter Bay, Evans Island	Heavy
Shelter Creek	16630	Evans Island	Heavy
Evans Point	16640	Evans Island	Moderate
Bjorn Creek	16650	Evans Island	Moderate
Unnamed	16780	Sleepy Bay, Latouche Island	Heavy
Unnamed	16782	Latouche Island, NE Side	Heavy
Unnamed	16783	Latouche Island	Heavy
Unnamed	16785	Latouche Island	Heavy
Hogan Creek	16810	Hogan Bay, Knight Island	Moderate
Snug Harbor	16820	Snug Harbor, Knight Island	Heavy
South Creek	16840	Marsha Bay, Knight Island	Heavy
Unnamed	16853	Rua Cove, Knight Island	Heavy
Unnamed	16869	Bay of Isles, Knight Island	Moderate
Unnamed	16875	Knight Island	Heavy
Unnamed	16902	Eleanor Island	Heavy
Unnamed	16916	Ingot Island	Heavy
Herring Creek	16920	Herring Bay, Knight Island	Heavy
Unnamed	16928	Knight Island	Heavy
Unnamed	16975	Herring Bay, Knight Island	Heavy
Unnamed	16982	Herring Bay, Knight Island	Heavy
Unnamed	16996	Knight Island, NW Side	Heavy
Unnamed	17880	Green Island	Heavy

Table 9: Preliminary cost–benefit analysis for Gregorioff and Parks Creeks in Prince William Sound.

Stream	No.	Falls Height (m)	Estimated Spawning Area (sq m)	Gradient	Stream Length (km)	Number Females	Adult Return	Harvest Numbers	Harvest Value (dollars)	Total Cost (dollars)	Annual Cost (dollars)	Project Life (years)	Benefit/ Cost
Gregorioff Ck	11230	3.6	10,563	2.00%	2.9	5,282	17,442	12,209	12,580	90,000	3,000	30	2.1
Parks Ck	14580	3.1	15,792	1.80%	2.3	7,896	26,076	18,253	18,808	77,500	2,583	30	3.6

Assumptions: Project Life – 30 years
Average weight – 3.6 lbs.
Average price – $0.28/lb.
Expl. Rate – 70%

Table 10: Preliminary results for potential spawning channel sites with standpipes in Prince William Sound.

Standpipe Location	No.	Elevation Level (ft)	Gradient (%)	Date	Water Temp (C°)	Water Table Depth (m)	Date	Water Temp (C°)	Water Table Depth (m)	Land Owner
Rude River (West #1)	10160	5	0.33	08/14/92	4.5	Surface	–	–	–	Chugach Alaska Corp.
Rude River (East #2)		5	0.33	08/14/92	5.9	Surface	–	–	–	Chugach Alaska Corp.
Rude River (North #3)		5	0.33	08/14/92	7.0	Surface	–	–	–	Chugach Alaska Corp.
Softball #1	–	20	0.60	08/19/92	11.3	Surface	11/19/92	2.0	Surface	City of Valdez
Softball #2	–	5	0.50	08/19/92	4.8	Surface	11/19/92	2.0	0.5	State of Alaska
Interceptor Trench	11390	10	0.70	08/19/92	2.3	Surface	11/19/92	3.0	Surface	State of Alaska
Pipeyard	–	6	0.60	08/19/92	9.1	0.4	11/19/92	4.0	0.4	State of Alaska
7 mile Richardson Hwy	–	85	0.30	08/19/92	3.2	Surface	11/19/92	3.0	Surface	State of Alaska
9 mile Richardson Hwy	–	125	0.40	08/19/92	2.2	Surface	11/19/92	2.0	Surface	State of Alaska
Mineral Ck #1	11470	25	0.80	08/19/92	6.5	1.8	11/19/92	Dry	Dry	City of Valdez
Mineral Ck #2	–	25	0.80	08/19/92	3.5	Surface	11/19/92	4.0	0.5	City of Valdez
Complex Creek	12570	15	1.89	09/29/92	7.0	0.2	–	–	–	National Forest
Mill Ck	14210	10	1.58	09/29/92	5.0	0.3	–	–	–	National Forest

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INTRODUCTION

The purpose of the Kodiak pink salmon (Oncorhynchus gorbuscha) restoration project was to evaluate specific sites that have been recommended by the public, United States Forest Service (USFS); Alaska Department of Fish and Game (ADF&G), Fisheries Rehabilitation, Enhancement and Development (FRED) and Commercial Fish Divisions; and Kodiak Regional Aquaculture Association (KRAA) for installation of barrier bypass structures (Figure 1). These structures will bypass barrier falls that impede salmon migration to potential upstream spawning habitat. This access to additional spawning habitat could potentially increase pink salmon production in areas that were directly impacted by the Exxon Valdez Oil Spill (EVOS) or in areas of close proximity to damaged areas. The spawning habitat above these barriers was not impacted by the EVOS; however, in some cases oil was found in lower spawning habitat below barriers (Barnhart[1], pers. comm.). Resource damage assessment was not conducted in the Kodiak area, however, oil spilled on area beaches was documented in 1989 and 1990 (Table 1). Some beaches, most notably on Shuyak and Afognak Islands, were heavily oiled. In Prince William Sound (PWS), damage to pink salmon eggs and juveniles has been documented under similar conditions of oil contamination (Exxon Valdez Oil Spill Trustees, 1992).

The evaluation procedure requires biological, hydrological as well as engineering information be collected to facilitate feasibility decisions to be made regarding the cost effectiveness of a particular bypass technique. The appropriate techniques can then be applied to bypass barriers.

FRED division has managed barrier bypass structures on four salmon producing systems on Afognak Island since 1972 (Figure 2). These structures consist of varying lengths of Denil-type fish pass sections. These fish passes bypass barrier falls providing sockeye (Oncorhynchus nerka), pink and coho (Oncorhynchus kisutch) salmon access to upstream spawning habitat. These fish passes were originally constructed by cooperative ventures involving the ADF&G and the USFS. Increased salmon escapements and harvests at these Afognak systems can be attributed to the increased utilization of otherwise inaccessible spawning habitat. Portage Creek and Waterfall Creek pink salmon runs have been significantly enhanced by the installation of fish passes (Table 2). The cost to benefit ratios of 1:10.5 and 1:1.7, respectively, illustrate the variability of project benefits but also show that such projects can be economically feasible. The Laura/Gretchan and Little Kitoi fish passes have primarily benefitted sockeye and coho salmon but have also enhanced pink salmon runs. Other sites for potential installation of fish passes to bypass barrier falls have been

[1] ADF&G, Subsistence Division, 211 Mission Road, Kodiak, AK 99615.

considered by FRED Division, in past years, based on aerial and onsite surveys. Additional information on potential fish pass sites has been provided by Commercial Fish Division, USFS, KRAA, and the public.

On the basis of available information and interest in additional sites, seven systems were selected for barrier bypass potential. Feasibility surveys were conducted at the following sites:

1. <u>Bauman's Creek, Uganik Passage, Kodiak Island</u> (253-332)

   A falls approximately 0.5 miles upstream blocks pink salmon from reaching upstream spawning habitat. Problem identified by Commercial Fish Division.

2. <u>Cold Creek, Kazakof Bay, Afognak Island</u> (252-331)

   A steep gradient 180 meters from the estuary impedes migration of pink salmon to spawning habitat. Problem identified by USFS/Afognak Natives and FRED Division.

3. <u>Horse Marine, Olga Bay, Kodiak Island</u> (257-402)

   A falls is blocking pink salmon migration. Problem identified by FRED Division.

4. <u>Pink Creek</u> (Afognak River tributary 252-342)

   A falls blocks pink salmon from reaching potential spawning habitat. Problem identified by Commercial Fish and FRED Divisions.

5. <u>Seven Rivers, Humpy Cove, Kodiak Island</u> (258-701)

   Upstream spawning habitat is inaccessible to pink salmon due to a falls approximately 2 kilomenters upstream on the east fork of the stream. Problem identified by Commercial Fish Division.

6. <u>Twin Lake Creek, Viekoda Bay</u> (253-321)

   A falls is blocking pink salmon migration. Problem identified by FRED Division.

7. <u>Waterfall Creek (Little), Afognak Island</u> (251-822)

   Three fish passes have increased pink salmon spawning area in this system. The largest fish pass, furthest upstream; however, is not utilized fully, possibly due to structural problems. The average escapement above this fish pass has been 5,962 while the spawning area will support 18,893 pink salmon. The EVOS spill directly impacted areas near Little

Waterfall Creek in 1989. Beaches and adjacent bays were significantly oiled. In addition, pink salmon escapement in 1989 (117,200), due to harvest closure, was well over the desired optimum escapement of approximately 20,351 pinks. This may have resulted in over utilization of the system as reflected in a very low (69.94) pre-emergent index in 1990.

Feasibility work at Waterfall consists of the re-evaluation of the third barrier falls and the present fish pass structure. An engineering survey was conducted to determine if improvements can be made to the third fish pass to increase utilization of upstream spawning habitat. In addition, spawning habitat below all barriers was assessed and original spawning habitat data was re-evaluated.

OBJECTIVES

1. Delineate the geographic features of the site: height, length and slope of barrier, stream width and depth above and below barrier, stream discharge and velocity above and below barrier and above and below any tributary streams, stream channel rock characteristics; and provide photographic documentation of each site.

2. Survey the potential spawning habitat above barriers and also evaluate currently used spawning habitat below barriers.

3. Determine the timing of the pink salmon run to each system and count and record pink salmon present in each system, once during peak spawning period.

METHODS

The height, length, and slope of system barriers was measured with a clinometer and measuring tape. Clinometer readings were recorded as percent (%) slope while all other reading were in meters (m). Stream discharge was measured with a staff gauge and flow meter above and below barriers and above and below each tributary stream (Figure 3). Water velocity and water depth was measured at 0.3 m intervals across the stream for each transect. Other barrier and stream channel characteristics were also noted. Each system and all barriers were aerial photographed from a Bell 206 helicopter.

Photographs were also taken on site, above and below the barriers.

The available spawning habitat above and below barriered areas was measured and evaluated to estimate the number of pink salmon that could be supported. Two transects were randomly selected in each section of the stream surveyed and the cross-section was measured. The distance between each transect on each bank was measured, thus giving rectangular dimensions. The dimensions of the two banks, as well as the two transects, were averaged. The resulting average dimension of width and length were multiplied to estimate the total area (m^2) of the spawning section. The total useable spawning habitat was determined by estimating the percentage of usable spawning habitat in each survey section, and multiplying by the estimated total area. Useable spawning habitat was defined as flows of approximately 0.5 m/sec, water depth of 0.3-0.5 m, gravel size of 6-150 mm with <25% by volume of the gravel $\leq$6 mm, and minimal compactness (Chambers et al. 1955).

During spawning habitat evaluation work, pink salmon were enumerated below the barriers to salt water. Salmon observed above the barriers were also counted. Live and dead counts were tallied in both cases. In cases where surveys were conducted when pink salmon were not present, historical odd year escapement data was reviewed to determine mean peak spawning numbers. ADF&G personnel provided escapement timing information in these instances.

A detailed description of each site and the recommended solutions to provide fish passage are included in this report. Also, an estimate of the extent and cost of implementation of these recommendations is outlined for each site. An estimate of the potential benefit is compared to the cost of implementation of bypass solutions and recommendations of further study, rejection, or implementation is included.

PRELIMINARY STUDY RESULTS

Bauman's Creek

Bauman's Creek is located on the west side of Kodiak Island and drains into Uganik Bay (Figure 1). Figure 4 illustrates the steep topography of the land adjacent to the stream and also shows locations of barrier falls as well as the extensive stream area above the falls. Much of this system lies within the boundaries of the Kodiak National Wildlife Refuge (KNWR).

Bauman's Creek was not surveyed in 1992 due to access limitations by the KNWR managers during bear denning periods and also due to helicopter unavailability. Information, however, was collected on August 8, and September 29, 1972 by FRED Division personnel and is summarized here. Geographic information was difficult to ascertain due to the nature of the topography. Figure 5 is a satellite photograph of Bauman's system, while figure 6 is a closer look at the system, photographed from a helicopter. As seen in figure 7, a series of barriers, 800 m upstream from salt water, impedes salmon migration. A series of 9 - 10 falls is located in a steep narrow canyon and would require fish ladders (Blackett[1], pers. comm.). There is also another series of 4 - 5 falls 1.6 kilometers (km) further upstream and a third series of 8 - 10 falls 4 km further upstream. Finally, a fourth series of 12 falls is located 1.6 km further upstream. Photographs from the August 8, 1972 survey show the first five obstacles observed upstream of salt water. The first barrier, as seen from the photograph, is a chute approximately 6.0 to 7.0 m in length and over 3.0 m high (Table 3, Figure 8). The next barrier is a falls of approximately 4.0 to 5.0 m length and 3.0 to 4.0 m height (Figure 9). The third barrier is a S shaped chute of approximately 9.0 to 10.0 m in length and 2.0 to 3.0 m high (Figure 10). The fourth obstacle is a second, almost vertical, falls, approximately 3.7 m in height (Figure 11). It also drops into a smaller cataract of approximately 1.0 m height.

The last barrier is a third, near vertical, falls approximately 3.0 m high (Figure 12). Stream discharge was not measured during the 1972 survey, however, from the photographs, the flows appear high. The nature of the barriered areas, as with a large portion of the system, is steep sided, rocky terrain. There also appear to be a number of large boulders and rock out croppings in the falls or directly below the falls and chutes. The canyon walls and stream bed appears to be unstable in some areas. Stream width above the barriers was 16.8 m while stream width below the barriers was 19.8 m during this period.

Spawning habitat at Bauman's was measured during September 29, 1972 aerial survey by Blackett. From these measurements and assuming 50% of the available area would be useable habitat, it is estimated that 96,200 m^2 of spawning habitat occurs above the barriers (Appendix Table 1). Spawning habitat below the barriers was not evaluated. Using an optimum spawning density of 2.0 m^2 per female, the habitat above the barriers would support 48,100 females (Burgner <u>et al.</u>, 1969; Willette, 1991). The desired escapement above the barriers at a 50:50 sex ratio would be 96,200 pink salmon (Table 4).

[1]ADF&G, FRED Division, 211 Mission Road, Kodiak, AK 99615.

A peak spawning survey was not conducted. The average peak spawning count on odd years for Bauman's Creek from 1969 - 1987 is 14,515 (Swanton, 1992). Using the stream life model calculation from Barrett et al. (1990), this equates to a mean odd year escapement of 26,708 (Table 5). The timing of escapement is similar to other pink salmon systems on Kodiak Island with time of entry in mid to late July and peak escapement in mid August (Brennan[1], pers. comm.). Pink salmon have never been observed above the barriered area. It can be assumed that the mean odd year escapement number equates to full utilization of the spawning habitat below the barriers. Therefore, the optimum escapement for the entire system, if barriers were bypassed, would be 122,908 (Table 4).

Bauman's Creek has four series of barriers for a total of over 30 barriers impeding pink salmon passage. These barriers are located in a steep-sided canyon which is unstable in areas and prevents or impedes access. Most of the barriers would require Denil-type fish passes to be installed to allow pink salmon passage to spawning habitat above the barriers (96,200 m^2). Pink salmon require a fish pass grade of approximately 7:1 as observed at other fish pass projects on Afognak Island. With 30 barriers of approximately ≥ 1.5 m height, it would be anticipated that over 300 m of fish pass sections would be required (Table 6). At a conservative cost of $3,280 per meter of fish pass, this equates to over $980,000 for initial installation (Blackett, pers. comm.). If we assume a 60% exploitation rate based on the optimum escapement above the barriers, 144,300 pink salmon would be added to the odd year harvest at Bauman's. Assuming 3 pound pink salmon at $.30/lb., this additional harvest would be worth $43,290. Assuming stable annual production and prices, it would take approximately 23 years to have a 1:1 cost to benefit (C:B) ratio. Obviously, this project would not be cost effective. Therefore, this system is not considered feasible for barrier bypass work.

Cold Creek

Cold Creek is located on the south side of Afognak Island and drains into Kazakof Bay (Figure 1). Afognak Native Corporation (ANC) owns the land adjacent to the stream and operates a logging camp with a significant road system in the area. Figure 13 shows locations of barriers and spawning habitat not presently utilized by pink salmon. Aerial photographs have not been taken to date of this drainage. Dense stands of Sitka Spruce (Picea sitchensis) prevent an aerial view of the barriered area of the system. This system was surveyed September 23, 1992.

[1]ADF&G, Commercial Fish Division, 211 Mission Rd., Kodiak, AK 99615.

As seen in figure 14, three small barriers, 55 m upstream from salt water, impede salmon migration. The first barrier upstream from salt water is 1.2 meters high and 3.7 m long (Figure 15, Table 3). The second and third barriers are 0.6 m and 1.2 m high and 1.2 m and 2.4 m long, respectively. The slope at the water surface was 13% from the top of the third barrier to the base of the second barrier. The slope from the top of the third barrier to it's base was 11%. Stream width above the barriers was 8.8 m. Due to icy conditions and steep topography, stream width below the barrier was not measured. Stream depth above the barriers was 0.3 m. The stream discharge was not measured due to a flow meter malfunction. The barriered area is composed of primarily bedrock. The topography adjacent to the stream is also composed of bedrock and is steep sided in some areas. Access, however, is not difficult. There is a logging road a short distance (100 m) from the barriered area. The canyon walls and stream bed are unstable in some areas as witnessed by the debris load at the base of the barriers and also evidenced by fractures in the bedrock. These barriers would not appear to be an obstacle to fish passage at high water periods.

The total stream spawning area above the barriers was estimated to be 10,411 m^2 (Appendix Table 2). Spawning habitat below the barriers was not evaluated due to time constraints. Using an optimum spawning density of 2.0 m^2 per female, this area would support 5,205 females (Burgner <u>et al.</u>, 1969; Willette, 1991). The desired escapement above the barriers at a 50:50 sex ratio would be 10,411 pink salmon (Table 4).

A peak spawning survey was not conducted. The average peak spawning count on odd years for Cold Creek from 1969 - 1987 is 2,515 (Swanton, 1992). Using the stream life model calculation from Barrett <u>et al.</u> (1990), this equates to a mean odd year escapement of 4,628 (Table 7). The timing of escapement is similar to other pink salmon systems on Kodiak Island with time of entry in mid to late July and peak escapement in mid August (Brennan, personal communication). Pink salmon have been observed above the barriered area, however, only after high water periods (Olson[1], pers. comm.). Coho salmon have been observed to ascend the barriered area but also have difficulty at low flow periods. During the spawning habitat survey, 51 pink salmon carcasses and 21 live coho salmon were observed above the barriers. None were observed below the barriers.

It can be assumed that the mean odd year escapement number equates to full utilization of the spawning habitat below the barriers. Therefore, the optimum escapement for the entire system, if barriers were bypassed, would be 15,039 (Table 4).

[1]Afognak Native Corporation, 214 Rezanof Drive, Kodiak, AK 99615.

Cold Creek has three partial barriers impeding pink and coho salmon passage at low flow periods. These barriers are located in an easily accessible area near a logging road. Since these are partial barriers of small size, fish passes would not be required. Stream channel alteration and diversion of water would be sufficient to allow pink salmon passage to spawning habitat above the barriers (10,411 m^2). Initial bypass work would require cutting or blasting a channel in the stream bed, securing permanent diversion attachments, and attaching removable diversion structures at a cost of approximately $25,000, including labor (Table 6). If we assume a 60% exploitation rate based on the optimum escapement above the barriers, 15,617 pink salmon would be added to the odd-year harvest at Cold Creek (Table 6). Assuming 3 pound pink salmon at $.30/lb., this additional harvest would be worth $4,685. Initial C:B ratio would be 5.3:1, however, since it would require minimal construction and post project maintenance cost would be low, therefore, benefits will out weight costs in an estimated 5 years. Thereafter, the C:B ratio would be 1:4.7. Therefore, this system is considered feasible for barrier bypass work. Also, the added value of improved coho passage during low flow would improve the cost/benefit of this project.

Horse Marine Creek

Horse Marine Creek is located on the southwest side of Kodiak Island and drains into Olga Bay (Figure 1). Figure 16 shows location of this system, barriers, and area that is inaccessible to pink salmon. Aerial photographs have not been taken to date of this drainage. This system was not surveyed as part of this project, however, previous data collected by FRED Division personnel is summarized here. Data reviewed is from a September 16, 1978 survey. There are two barriers between Horse Marine Lake and salt water that impede pink salmon migration upstream. The first barrier upstream from salt water is 1 m high and 3 m long (Table 3). This is only a partial barrier and would only effect pink salmon migration at extremely low flow periods (White[1], pers. comm.). There is also tidal influence that would probably assist migration at low flow periods. The second barrier is 3 m in height and 12 m in length (Figure 17). It was reported that several hundred pink salmon were below this falls with none observed ascending above the barrier. Stream width above the barriers was 12.8 m and was not measured below the barriers. Stream depth was not measured. The stream discharge information was also unavailable. The barriered area is composed of fractured rock. The topography adjacent to the stream is moderate. Access is relatively easy from Olga Bay but would require helicopter support.

[1]ADF&G, FRED Division, 211 Mission Road, Kodiak, AK 99615.

The total stream spawning area above the barriers was estimated to be 10,934 m^2 (Appendix Table 3). Spawning habitat below the barriers was not evaluated. Using an optimum spawning density of 2.0 m^2 per female, habitat above barriers would support 5,467 females (Burgner et al., 1969; Willette, 1991). The desired escapement above the barriers at a 50:50 sex ratio would be 10,934 pink salmon (Table 4).

A peak spawning survey was not conducted. The average peak spawning count on odd years for Horse Marine Creek from 1969 - 1987 is 2,246 (Swanton, 1992). Using the stream life model calculation from Barrett et al. (1990), this equates to a mean odd year escapement of 4,132 (Table 8). The timing of escapement is similar to other pink salmon systems on Kodiak Island with time of entry in mid to late July and peak escapement in mid August (Brennan, pers. comm.). It can be assumed that the mean odd year escapement number equates to full utilization of the spawning habitat below the barriers. Therefore, the optimum escapement for the entire system, if barriers were bypassed, would be 15,066 (Table 4).

Horse Marine Creek has two barriers impeding pink salmon passage. The barrier closest to salt water is probably only an obstacle at extremely low flow periods. These barriers are located adjacent to Olga Bay which improves access to the area. Since pink salmon often move into a stream system during high flow or high tide periods, the first barrier upstream from salt water would not need significant bypass work (White, pers. comm.). An additional survey during low flow and low to moderate tide periods would be recommended to verify pink salmon passage through this partial barrier. The second barrier is more substantial and would require approximately 24.4 m of fish pass at the optimum grade (Blackett, 1978). At a cost of $3,280 per meter of fish pass, this initial installation would cost approximately $80,000 (Blackett, personal communication). Water diversion structures and a diversion weir will also be required at this site, increasing cost to over $100,000 (Table 6). If we assume a 60% exploitation rate based on the optimum escapement above the barriers, 22,599 pink salmon would be added to the odd year harvest at Horse Marine Creek (Table 6). Assuming 3 pound pink salmon at $.30/lb., this additional harvest would be worth $6,780. As expected, initial cost would out weigh benefits, plus would require approximately 15 years to equalize. With the addition of annual maintenance and evaluation costs of $14,000, it is highly unlikely that this barrier could be bypassed cost effectively for pink salmon alone. Therefore, this system is not considered feasible for barrier bypass work for pink salmon alone. This system does, however, support a run of sockeye salmon which have also been reported to have difficulty ascending barriered areas at low flow periods (White, pers. comm.). With the additional spawning area also accessible to sockeye salmon and consequent additional production, cost effectiveness would improve.

Pink Creek

Pink Creek drains into Afognak River which enters Afognak Bay on southeast Afognak Island (Figure 1). Afognak Native Corporation (ANC) owns the land adjacent to the stream and ADF&G, Commercial Fish Division, operates a weir camp in the vicinity of where Pink Creek drains into Afognak River. Figure 18 shows location of this system, barrier falls and inaccessible upstream spawning habitat. Aerial photographs have not been taken to date of this drainage. Dense stands of Sitka Spruce prevent an aerial view of the barriered area of the system. This system was surveyed June 20, 1991 and January 7, 1992. As seen in figure 19, the barrier falls, was obscured by ice during the winter survey. The barrier is 172 m upstream from salt water and is 1.5 meters high and 5.8 m long (Table 3). The slope from the top of the barrier to it's base was approximately 10%. Stream width below the barrier was 5.2 m, while stream width above the barrier was 4.6 m. Stream depth below and above the barrier was 0.3 m. The mid stream flows below (Transect 1) and above (Transect 2) the barrier were 0.03 and 0.02 m^2/s, respectively (Appendix Tables 4 and 5). The total stream discharge was 0.17 and 0.15 m^2/s below and above the barrier, respectively. Due to ice cover, tributaries to Pink Creek were not evaluated for flow data. The barriered area is composed primarily of bedrock (Neff[1], pers. comm.). The topography adjacent to the stream is also composed of bedrock and is steep sided in some areas. Access, however, is not difficult.

The total stream spawning area above the barriers was estimated to be 3,223 m^2 (Appendix Table 6). Spawning habitat below the barriers was calculated to be 752 m^2. Using an optimum spawning density of 2.0 m^2 per female, the upper area would support 1,612 females (Burgner et al., 1969; Willette, 1991). The desired escapement above the barriers at a 50:50 sex ratio would be 3,224 pink salmon (Table 4). The lower (below barrier) habitat would support 376 females or a total of 752 pink salmon.

A peak spawning survey was not conducted. In 1989, when a commercial fishery did not occur in response to EVOS, the escapement to Pink Creek was approximately 4,300 pink salmon (Appendix Table 7). It has, however, been reported that the average escapement for Pink Creek is only several hundred pink salmon with the majority impeded by the barrier (Neff, pers. comm.). The timing of escapement is similar to other pink salmon systems on Kodiak Island with time of entry in mid to late July and peak escapement in mid August. Pink salmon have been observed above the barriered area, however, only after a high water period. Assuming that the escapement below the barrier is negligible, the potential optimum escapement for the entire system, if barriers were bypassed, would be 3,224 (Table 4).

[1]ADF&G, Commercial Fish Division, 211 Mission Road, Kodiak, AK 99615.

Pink Creek has one barrier impeding pink salmon passage at normal to low flow period. This barrier is located in an accessible area near a Commercial Fish Division weir camp. Since this is a barrier of small size, fish passes would not be required. Stream channel alteration and diversion of water would be sufficient to allow pink salmon passage to a spawning habitat above the barriers. Initial bypass work would require cutting or blasting a channel in the stream bed, installing permanent diversion attachments, and attaching removable diversion structures at a cost of approximately $26,000 including labor costs (Table 6). Annual maintenance should be negligible since weir camp personnel could monitor the bypass area. If we assume a 60% exploitation rate based on the optimum escapement above the barriers, 4,835 pink salmon would be produced by the additional escapement to Pink Creek (Table 6). Assuming 3 pound pink salmon at $.30/lb., this additional harvest would be worth $1,450. This project, initially, would not be cost effective and would require an estimated 18 years to reach a 1:1 C:B ratio. Since Pink Creek is located in close proximity to Cold Creek and barrier bypass construction would be similar at both systems, combining these projects would decrease the number of years to reach a 1:1 C:B ratio and would reach a 1:3.1 C:B ratio post installation. Both systems combined could produce 20,452 pink salmon annually (assuming odd and even year production to be the same) worth $6,136. Barrier bypass construction is estimated to cost $51,000. Therefore, this system is considered feasible for barrier bypass work only if conducted in conjunction with Cold Creek restoration work.

Seven Rivers Creek

Seven Rivers Creek is located at the southern most end of Kodiak Island, just west of Kuguyak Bay, draining into Geese Channel (Figure 1). The drainage lies on Koniag Native Corporation (ANC) land within KNWR. Figure 20 shows location of this system, barriers to pink salmon migration and inaccessible upstream spawning habitat. Figure 21 is an aerial view of the area surveyed April 09, 1992. The area that blocks pink salmon migration upstream is located approximately 800 m upstream from salt water on the west fork of the system. There are five potential barriers in a series. The first upstream barrier is a cataract 0.9 meters high and 4.6 m long (Table 3, Figure 22). The second barrier is a 0.9 m falls, 2.4 m long (Figure 22). The third barrier is a 2.4 m falls, 4.0 m in height (Figure 23). The fourth and fifth barriers are 1.8 m high and 1.8 m and 3.0 m long, respectively (Figures 24 and 25). Stream width below the barriers was 5.2 m, while stream width above the barriers was 4.9 m. Stream depth below and above the barriers was 0.3 m. The mid stream flows below (Transect 1) and above (Transect 2) the barriers were 0.07 and 0.04 m^2/s, respectively (Appendix Tables 8 and 9). The total stream discharge was 0.30 and 0.23 m^2/s below and above the barriers, respectively. The tributaries to Seven Rivers Creek were not evaluated for flow data since they appeared insignificant. The barriered area is composed of bedrock and many large boulders. The topography adjacent to the stream is also composed similarly and is steep sided in most areas. Access is difficult in many areas near the barriers. The substrate appears unstable with many fractured areas observed. The first two barriers may be passable by pink salmon at high flow periods but would limit some movement at low flow periods. This is evidenced by many salmon carcasses below the barriers and fewer near the first two barriers. The third through fifth barriers are impassable with no evidence of pink salmon carcasses observed. The total stream spawning area above the barriers was estimated to be 7,528 m^2 (Appendix Table 10). Spawning habitat below the barriers was not calculated. Using an optimum spawning density of 2.0 m^2 per female, the upper area would support 3,764 females (Burgner et al., 1969; Willette, 1991). The desired escapement above the barriers at a 50:50 sex ratio would be 7,528 pink salmon (Table 4).

A peak spawning survey was not conducted. The average peak spawning count on odd years for Seven Rivers Creek from 1969 - 1987 is 79,510 (Swanton, 1992). Using the stream life model calculation from Barrett et al. (1990), this equates to a mean odd year escapement of 229,098 (Table 9). The timing of escapement is similar to other pink salmon systems on Kodiak Island with time of entry in mid to late July and peak escapement in mid August (Brennan, pers. comm.). It can be assumed that the mean odd year escapement number equates to full utilization of the spawning habitat below the barriers (this includes the east fork). Therefore, the optimum escapement for the entire system, if barriers were bypassed, would be 236,626 (Table 4).

Seven Rivers Creek has a series of five barriers impeding pink salmon passage. The first and second barriers upstream would not require ladders, however, some channel alteration and water diversion work would enhance pink salmon passage at low flow periods. The three furthest upstream barriers would require fish pass sections to allow pink salmon passage. All of these barriers are difficult to access and would probably be difficult to anchor due to the nature of the substrate. Using a 7:1 slope (length of fish pass sections to barrier height) for the Denil-type fish pass, this would equate to 42 m needed to bypass the three largest barriers (Table 6). At a conservative cost of $3,280 per meter of fish pass, this equates to over $137,760 for initial installation (Blackett, personal communication). This estimate is probably low considering the difficulty logistics would pose due to the great distance from Kodiak to Seven Rivers Creek. If we assume a 60% exploitation rate based on the optimum escapement above the barriers, 11,292 pink salmon would be produced by the additional escapement to Seven Rivers Creek. Assuming 3 pound pink salmon at $.30/lb., this additional harvest would be worth $3,388. It would require 41 years to reach a 1:1 C:B ratio and post installation C:B would be 1:01. Therefore, this system is not considered feasible for barrier bypass work.

Twin Lakes Creek

Twin Lakes Creek is located on the west side of Kodiak Island, draining into Viekoda Bay (Figure 1). The system has downstream barriers which impede pink salmon migration to upstream spawning habitat (Figure 26). Figure 27 is an aerial view of the area of blockage and beginning of upstream habitat surveyed January 30, 1992. The area that blocks pink salmon migration upstream begins approximately 300 m upstream from salt water. There are a series of cataracts and small falls in an 800 m area of the stream that are potential barriers to pink salmon. This area is densely covered with Sitka Spruce canopy which made aerial observation difficult. Due to icy conditions and the vertical nature of the stream banks, an on site investigation was not undertaken past the first barrier upstream from salt water. The first upstream barrier is a small falls approximately 1.8 meters high. Additional cataracts are directly upstream from the top of this falls. Stream width below the barriers was 11.0 m while stream width above all barriers was 4.9 m. Stream depth below and above the barriers was 0.9 m and 0.7 m, respectively. The mid stream flows below (Transect 1) and above (Transect 2) the barriers were 0.14 and 0.10 m^2/s, respectively (Appendix Tables 11 and 12). The total stream discharge was 1.05 and 0.92 m^2/s below and above the barriers, respectively. Discharge from tributaries draining into Twin Lakes Creek were 0.92, 0.44, 0.65, 0.49 and 0.38, respectively (Appendix Tables 13 - 16). The barriered area is composed of bedrock and many large boulders. The topography adjacent to the stream is also composed similarly and is steep sided in most areas. Access is difficult in areas near the barriers. The substrate was ice covered which made it difficult to ascertain geological characteristics. It appears that the majority of these barriers would be impassable to pink salmon at all flow periods.

The total stream spawning area above the barriers was estimated to be 19,863 m^2 (Appendix Table 17). Spawning habitat below the barriers was not calculated. Using an optimum spawning density of 2.0 m^2 per female, the upper area would support 9,932 females (Burgner et al., 1969; Willette, 1991). The desired escapement above the barriers at a 50:50 sex ratio would be 19,863 pink salmon (Table 4).

A peak spawning survey was not conducted. The average peak spawning count on odd years for Twin Lake Creek from 1969 - 1987 is 3,478 (Swanton, 1992). Using the stream life model calculation from Barrett et al. (1990), this equates to a mean odd year escapement of 6,400 (Table 10). The timing of escapement is similar to other pink salmon systems on Kodiak Island with time of entry in mid to late July and peak escapement in mid August (Brennan, pers. comm.). It can be assumed that the mean odd year escapement number equates to full utilization of the spawning habitat below the barriers (this includes the east fork). Therefore, the optimum escapement for the entire system, if barriers were bypassed, would be 26,263 (Table 4).

Twin Lakes Creek has a series of barriers impeding pink salmon passage. The area was difficult to access to determine the exact nature of the barriers. It does appear, however from an aerial view, that many of these barriers would require fish pass sections. An additional survey is required to accurately measure geographic features to delineate the number and length of fish pass sections required and if other bypass construction techniques would apply. The initial survey indicates, however, that a substantial length of fish pass sections would be required. If this proves to be accurate, we would expect annual maintenance, after initial installation, to be costly. If we assume a 60% exploitation rate based on the optimum escapement above the barriers, 29,795 pink salmon would be produced by the additional escapement to Twin Lakes Creek (Table 6). Assuming 3 pound pink salmon at $.30/lb., this additional harvest would be worth $8,939. At $3,280 per meter of fish pass, it is likely that costs of bypass construction and maintenance will out weigh benefits of fish production increases. Therefore, this system is not presently considered feasible for barrier bypass work.

Little Waterfall Creek

Little Waterfall Creek is located on the north side of Afognak Island, draining into Little Waterfall Bay (Figures 1, 2, and 28). The system has three operational fish passes constructed in the late 1970's and early 1980's that allow pink salmon to bypass falls and reach upstream spawning habitat (Figure 29). The area that originally blocked pink salmon migration upstream begins approximately 200 m upstream from salt water. The first falls upstream from salt water is 1.5 m high and 1.0 m long (Table 3). The second and third falls are 2.4 m and 7.9 m in height and 3.0 m and 1.5 m in length, respectively. The stream width below the first, second and third falls is 3.0 m, 7.0 m, and 7.9 m, respectively. The stream width above the first, second and third falls is 6.0 m, 9.1 m, and 5.4 m, respectively. The stream bed is composed of bedrock in the immediate areas of the falls. Stream discharge information was not collected.

The total stream spawning area above all barriers is estimated to be 16,986 m^2 (Appendix Table 18). Spawning habitat above the first barrier but below the third barrier is calculated to be 1,907 m^2. Total spawning habitat that was originally limited by barriers is 18,893 m^2. The spawning habitat below all barriers is 1,546 m^2. Using an optimum spawning density of 2.0 m^2 per female, the area above the third barrier will support 8,493 females (Burgner et al., 1969; Willette, 1991). The desired escapement above the barriers at a 50:50 sex ratio is 16,986 pink salmon (Table 4). The area between the first and third barriers will support 954 females or desired escapement of 1,907 males and females. Total desired escapement above all barriers is 9,447 females or 18,893 total pink salmon. The area below all barriers will support 773 females for a desired escapement of 1,546. The desired optimum escapement for the entire system is 20,351 pink salmon.

The mean pink salmon escapement for Little Waterfall Creek from 1968 to 1980, prior to completion of fish pass construction was 3,365 (Appendix Table 19). No pink salmon reached the area above the third barrier during these years. From 1981 to 1992 the mean escapement is 58,229, with 5,962 the mean above the third barrier (Table 11). The timing of escapement is similar to other pink salmon systems on Kodiak Island with time of entry in mid to late July and peak escapement in mid August.

Little Waterfall Creek has three barrier falls, originally impeding pink salmon passage, that have been bypassed with fish passes. Pink salmon production has been increased significantly since the barrier falls were bypassed. The first two fish passes have successfully allowed pink salmon to bypass barrier falls (Figure 30). The third fish pass, however, has not enhanced pink salmon passage to the stream area with the majority of spawning habitat (Figure 31). The focus of the survey conducted June 16, 1992 was to re-evaluate the engineering of the third fish pass. The grade of the fish pass was found to be 27% It has been reported that a fish pass slope of 22% or less is recommended for sockeye salmon if resting pools are employed (Blackett, 1987). Since pink salmon are smaller, less vigorous fish, a smaller gradient may be optimal. This implies that the gradient at the third fish pass is too great for pink salmon passage. To provide access to spawning habitat above the third barrier falls, the gradient of the third fish pass must be reduced (McCurtain[1], pers. comm.). This will require removing the existing concrete resting tanks and extending the lower portion of the fish pass to lower the gradient. This will require adding an extension of 9.1 m of fish pass, adding two new resting tanks, and adding a new entrance tank. The estimated cost of these changes by formal contract is $70,000 (Table 6). This does not include engineering and other indirect costs. If we assume a 60% exploitation rate based on the optimum escapement above the barriers, 28,340 pink salmon would be produced by the additional escapement to upstream spawning habitat. Assuming 3 pound pink salmon at $.30/lb., this additional harvest would be worth $8,501.

[1]ADF&G, FRED Division, 333 Raspberry Road, Anchorage, AK 99518.

Initially, fish pass improvement costs would be greater than benefits by more than eight fold. After approximately eight years, however, production benefits would equal costs. Thereafter, since KRAA will fund post installation maintenance costs, benefits will greatly increase making this, potentially, a highly cost effective restoration project.

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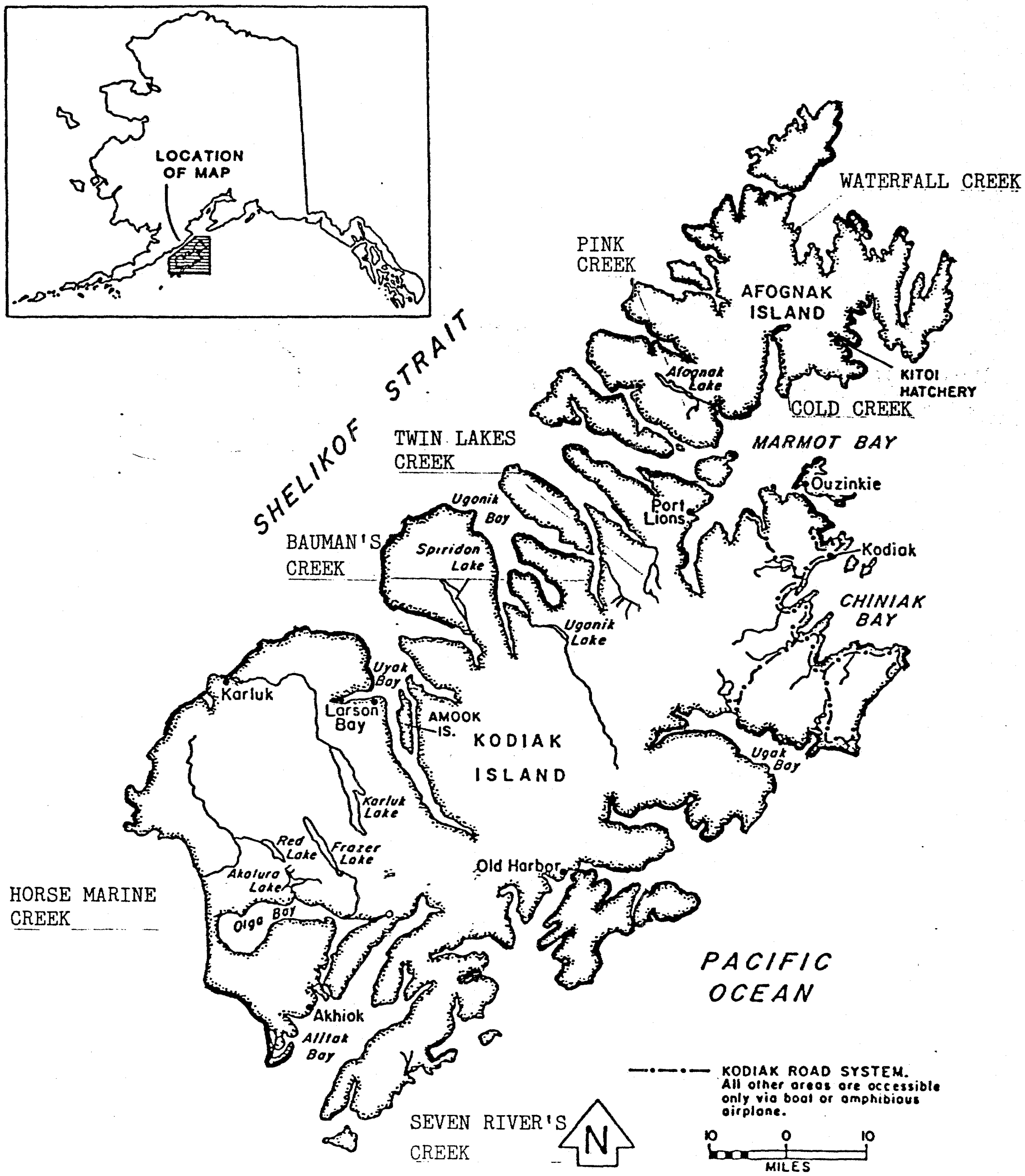


Figure 1. Area map of Kodiak and Afognak Islands showing pink salmon restoration systems and 1989 oiled areas.

RED —= restoration system
BLUE—= 1989 oiled areas

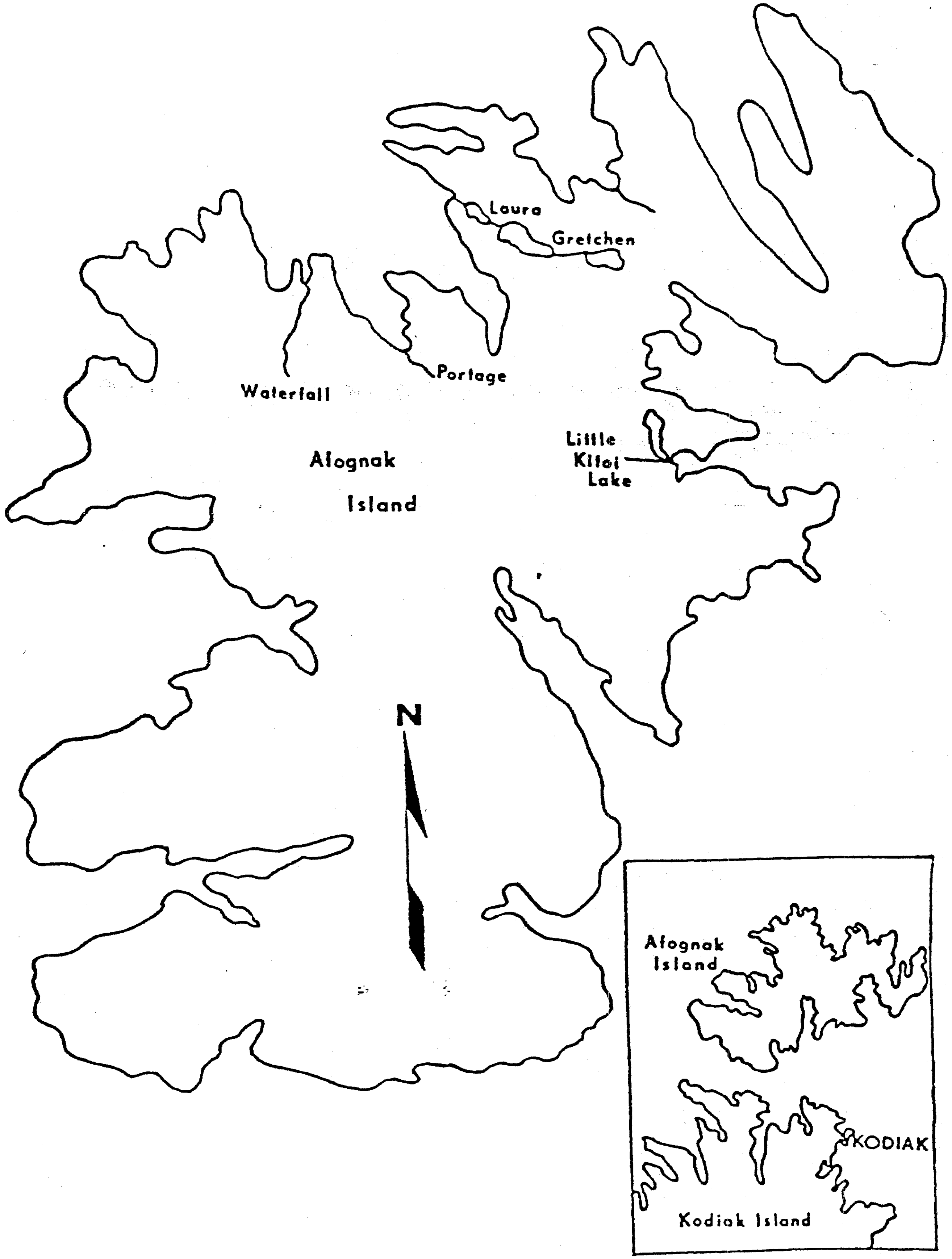


Figure 2. Map of Afognak Island showing location of operational fish passes managed by FRED Division.

Figure 3. Collecting stream discharge data, 1992 pink restoration survey, Afognak Island.

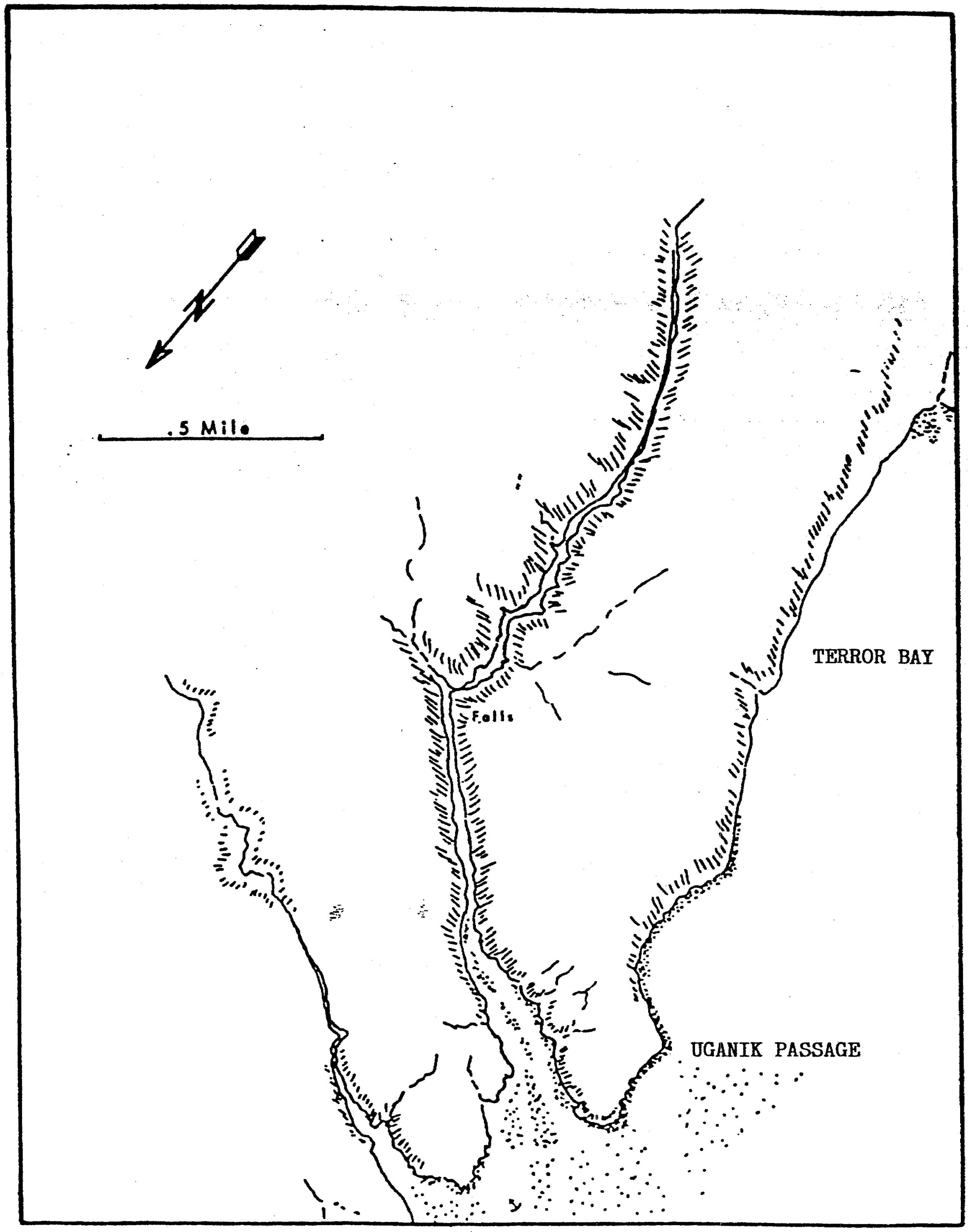


Figure 4. Map of Bauman's Creek drainage, Kodiak Island, showing location of barrier falls and nature of topography.

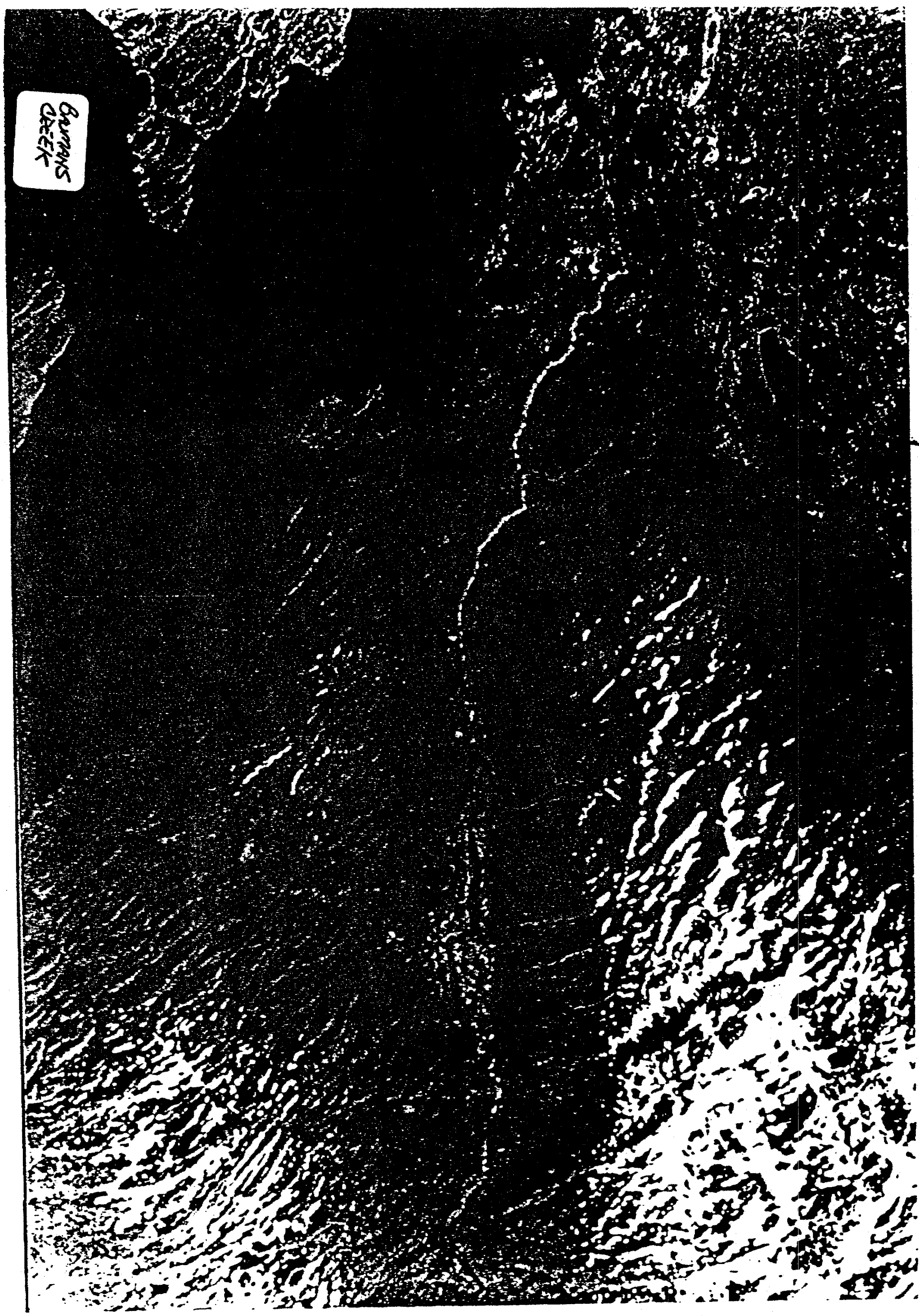


Figure 5. Satellite photograph of Bauman's Creek showing location of barriers to pink salmon migration.

Figure 6. Aerial photograph of Bauman's Creek drainage.

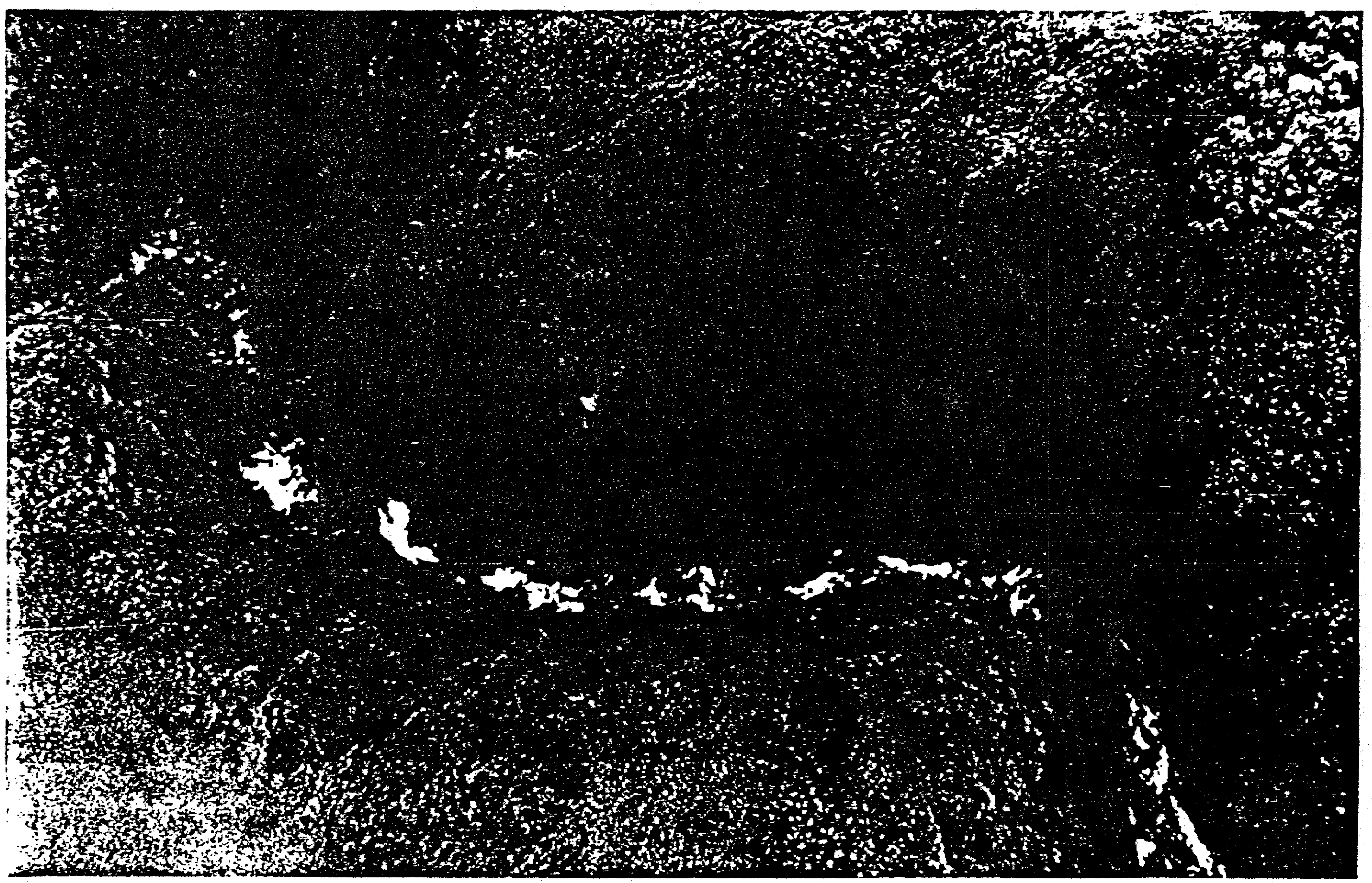


Figure 7. Aerial photograph of first series of barriers at Bauman's Creek.

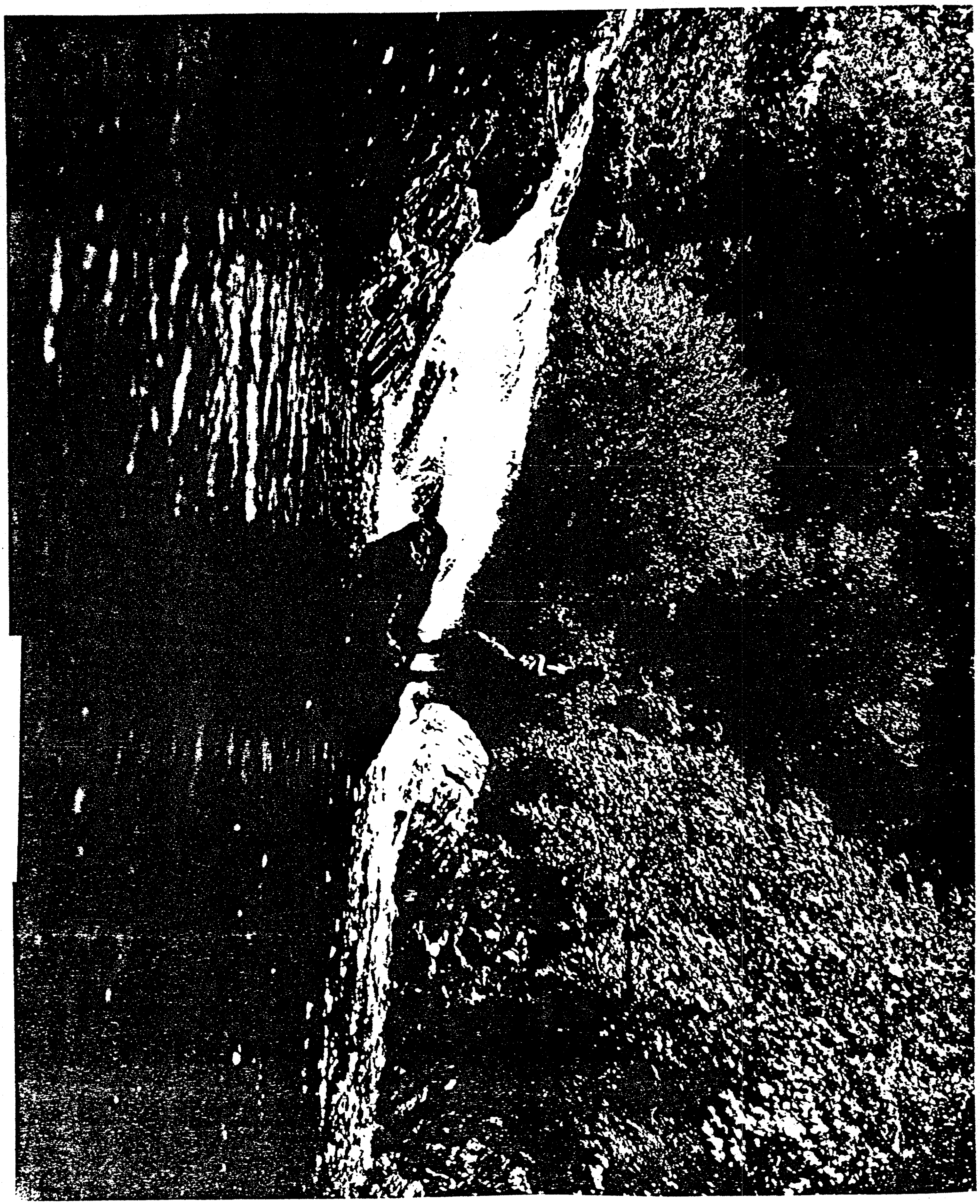


Figure 8. Photograph of the first barrier, upstream of salt water, at Bauman's Creek.

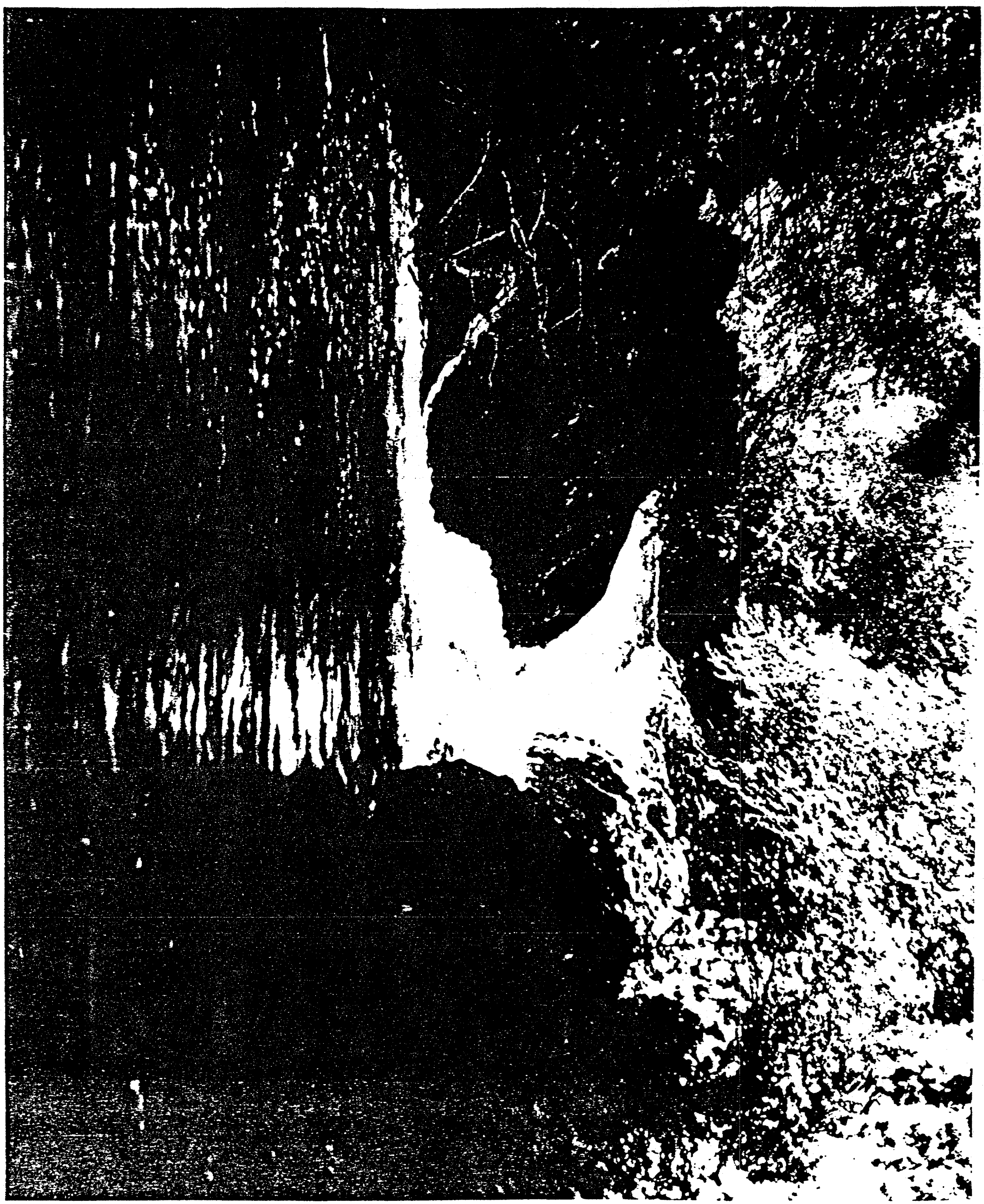


Figure 9. Photograph of the second barrier falls, upstream of salt water, at Bauman's Creek.

Figure 10. Photograph of the third barrier, upstream of salt water, at Bauman's Creek.

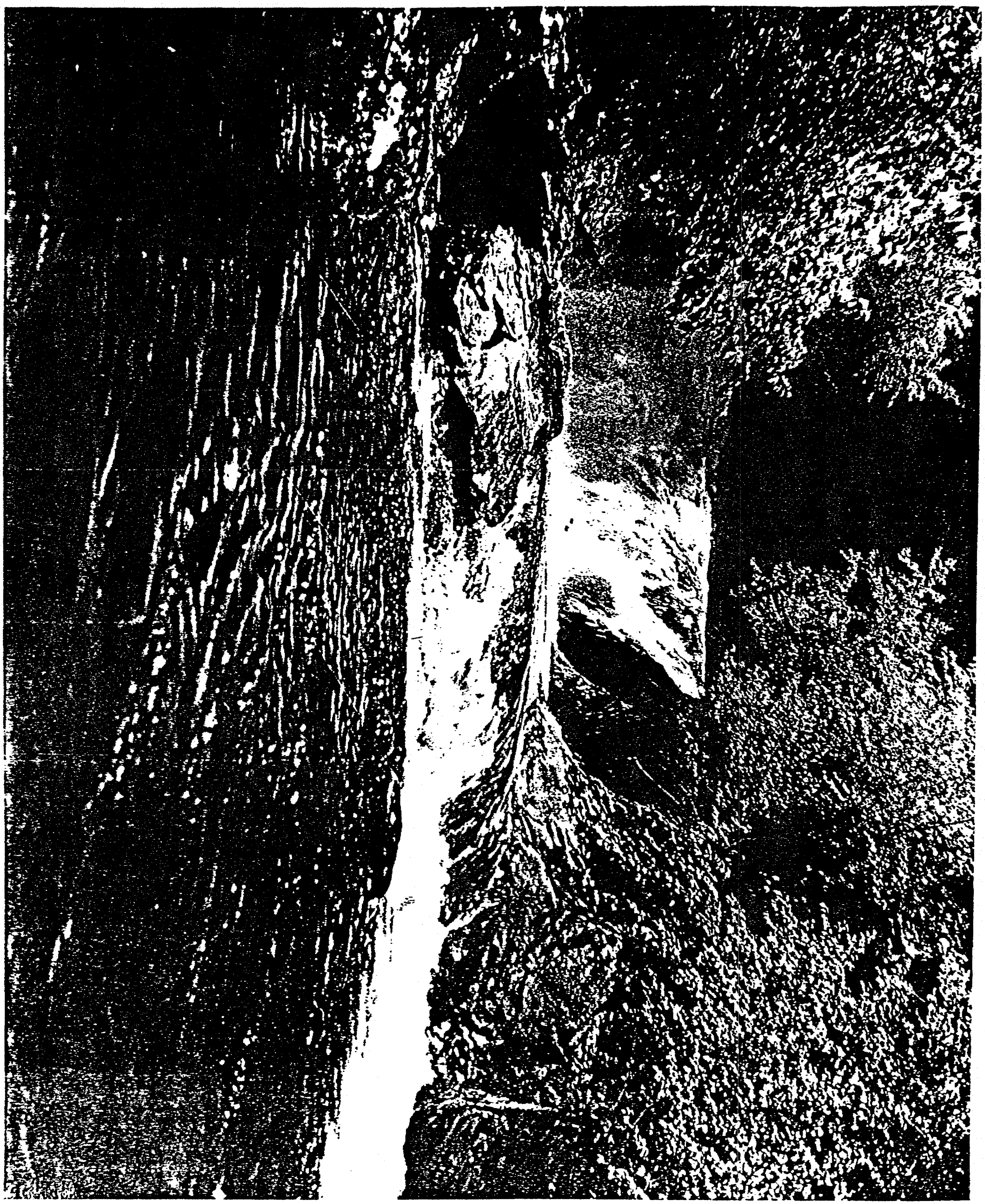
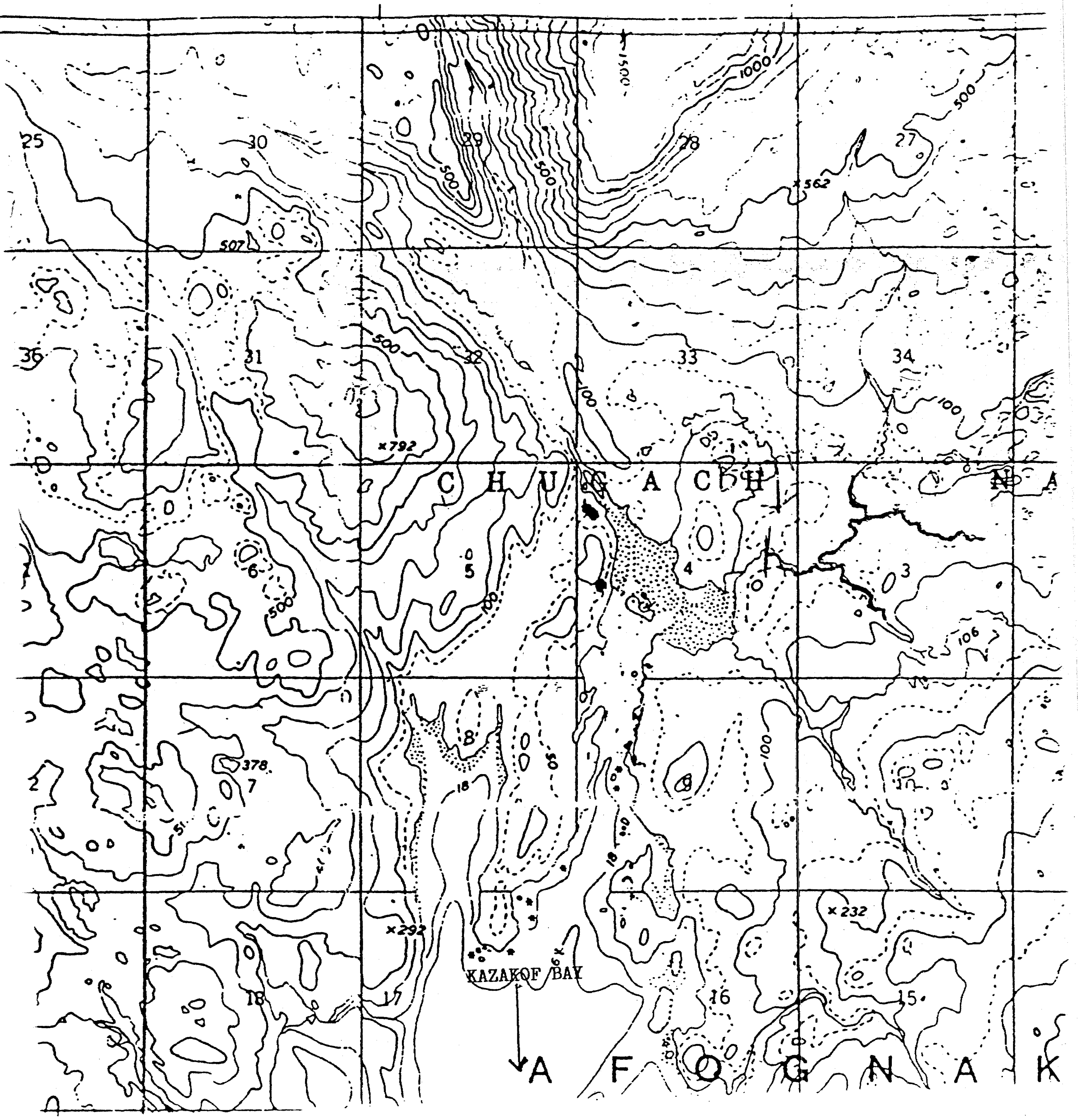


Figure 11. Photograph of fourth barrier, upstream of salt water, at Bauman's Creek.

Figure 12. Photograph of the fifth barrier, upstream of salt water, at Bauman's Creek.

Figure 13. Topographical map showing location of Cold Creek, partial barriers, and upstream spawning habitat.



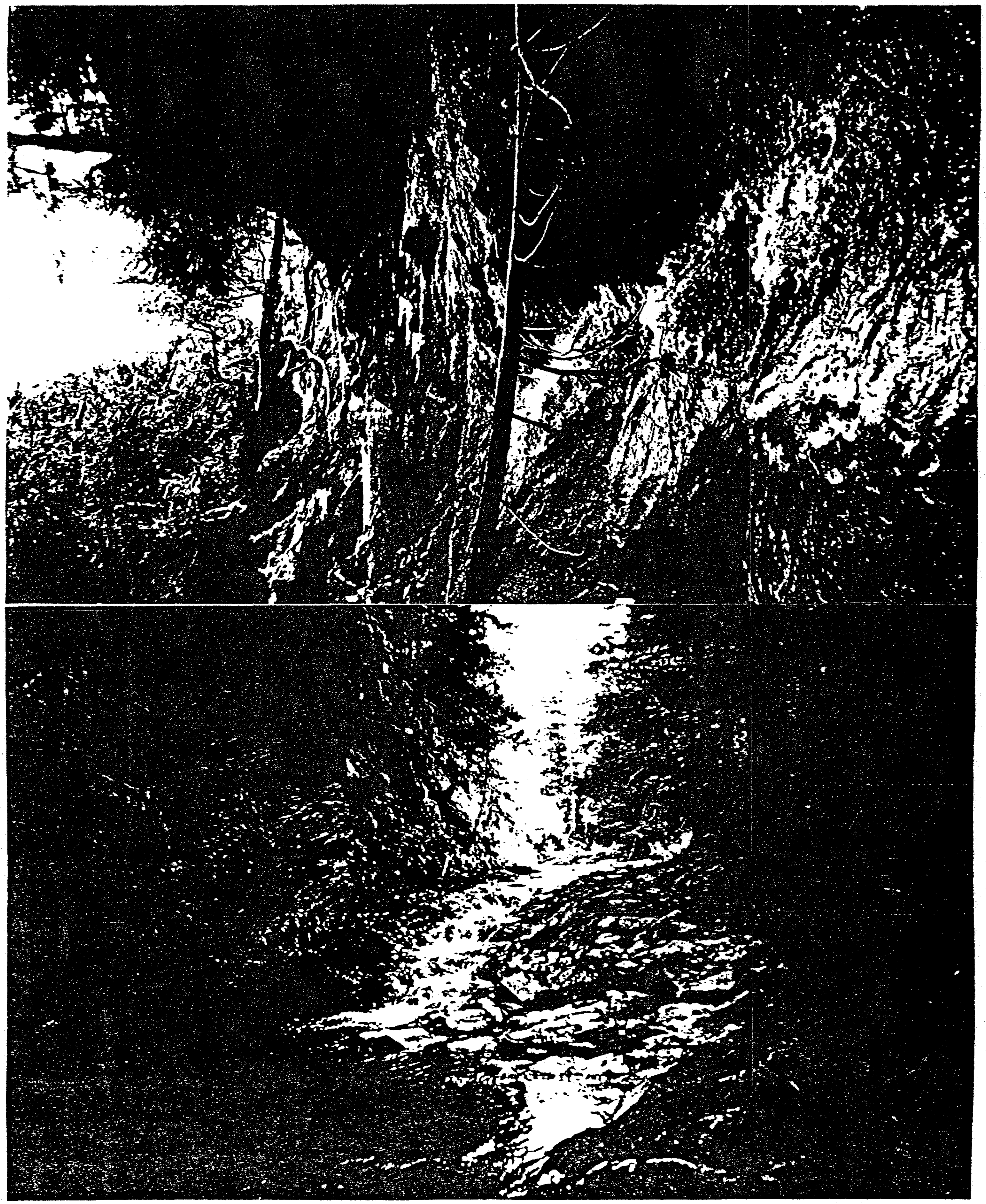
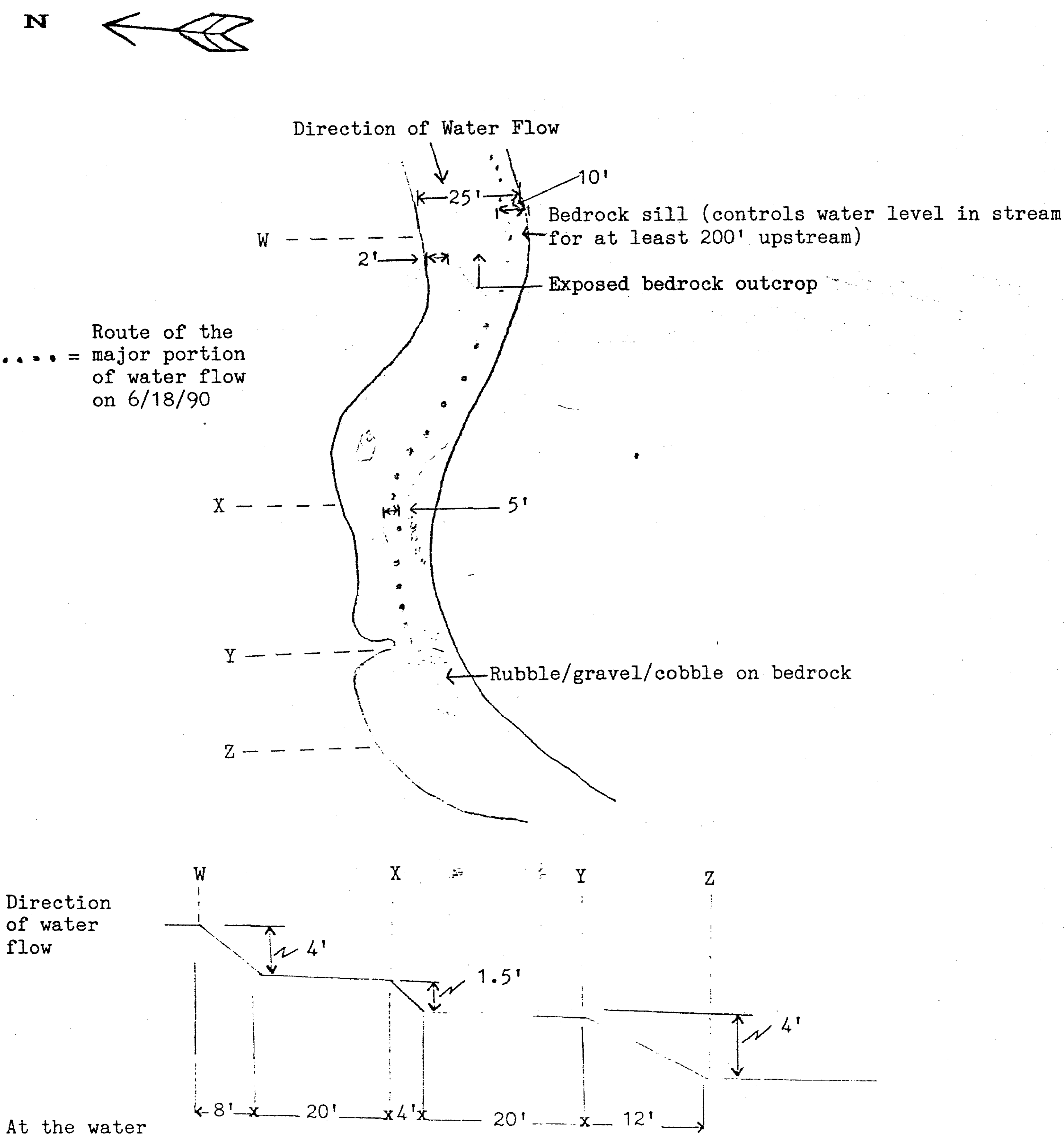


Figure 14. Photographs of three partial barriers, upstream of salt water, located at Cold Creek, Afognak Island.

COLD CREEK PARTIAL BARRIER
(Not to Scale)



At the water surface the slope is: Y to W = 11% (about 6.3°)
Z to Y = 13% (about 7.3°)

Source: Wayne Dolezal, Biologist, Habitat Division, field notes, 1990.

Figure 15. Diagram of dimensions, slopes, and rock features of Cold Creek partial barriers.

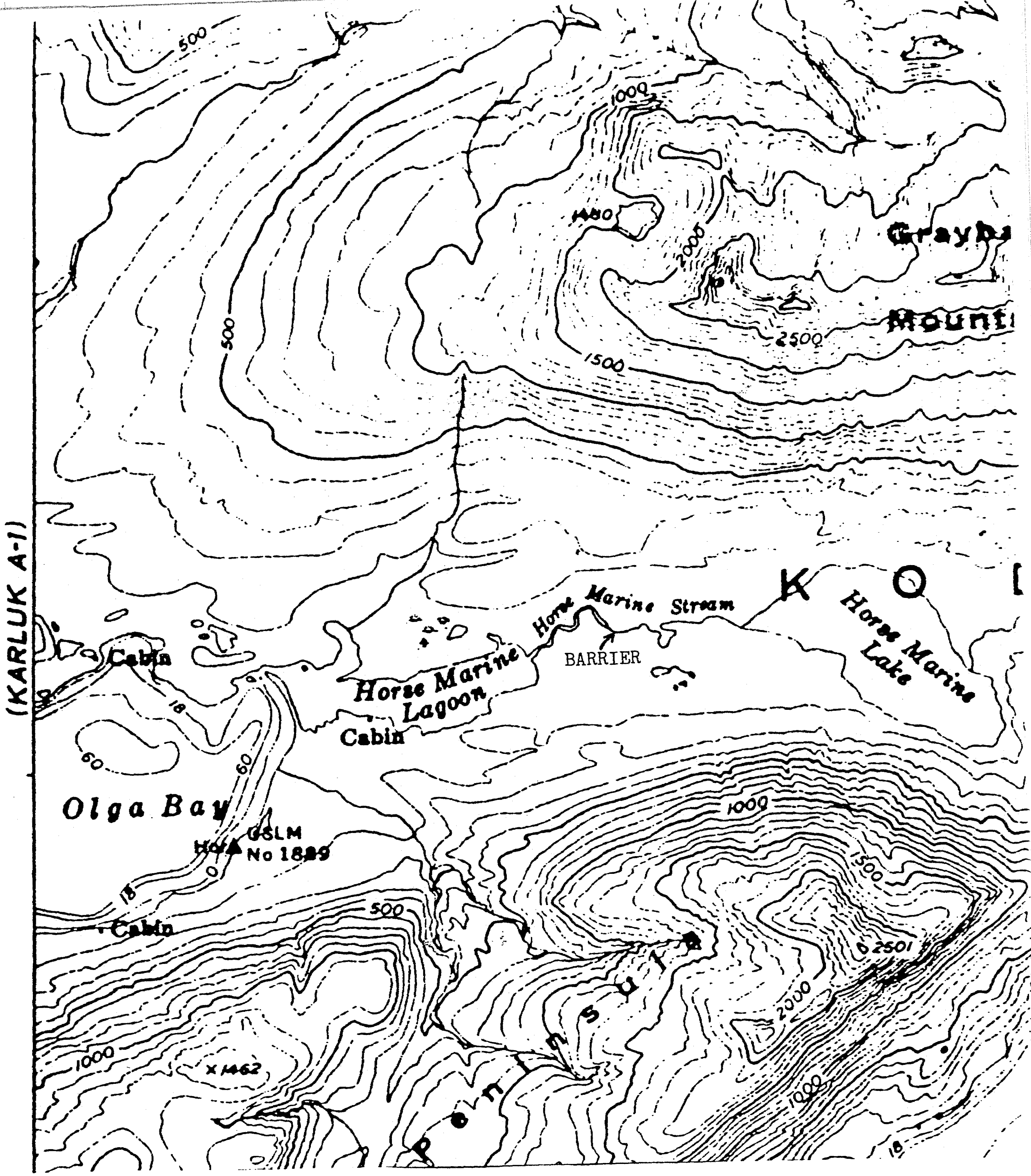


Figure 16. Topographical map showing location of Horse Marine system, barrier area, and area inaccessible to pink salmon.

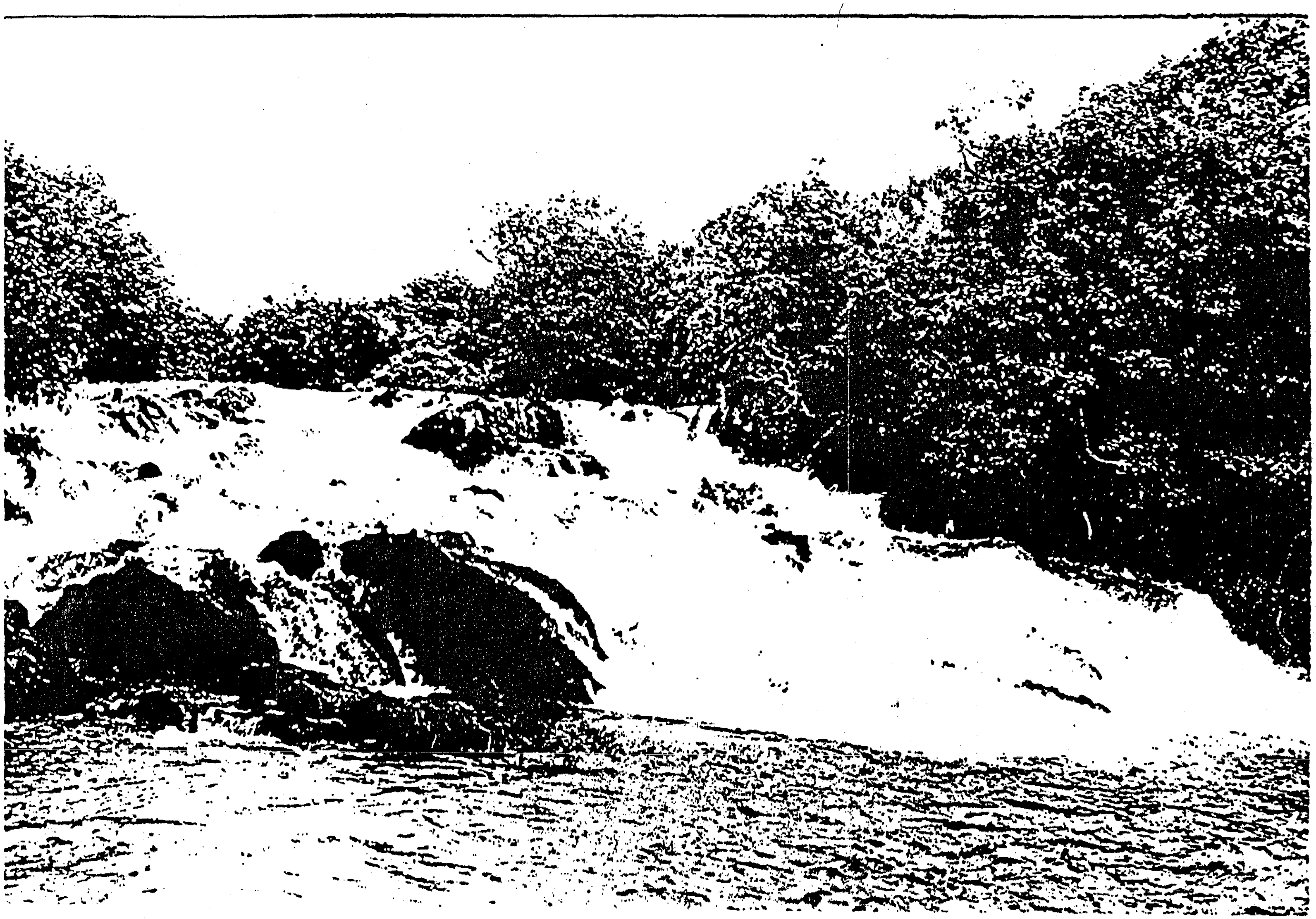


Figure 17. Photograph showing the second barrier, upstream of salt water, at Horse Marine Creek.

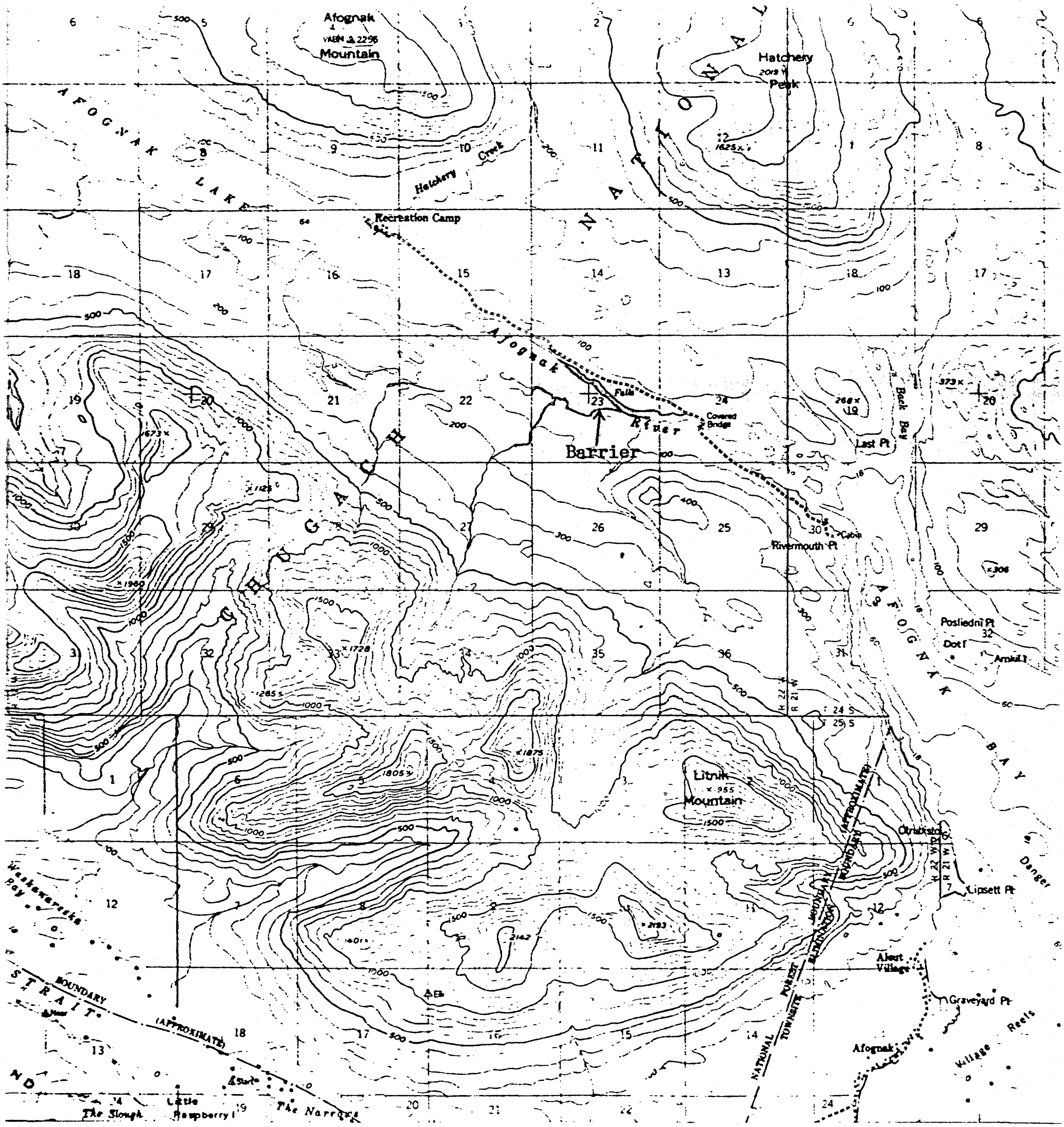


Figure 18. Topographical map showing location of Pink Creek, barrier falls, and Afognak River.

Figure 19. Photograph of ice covered barrier falls at Pink Creek, a tributary to Afognak River.

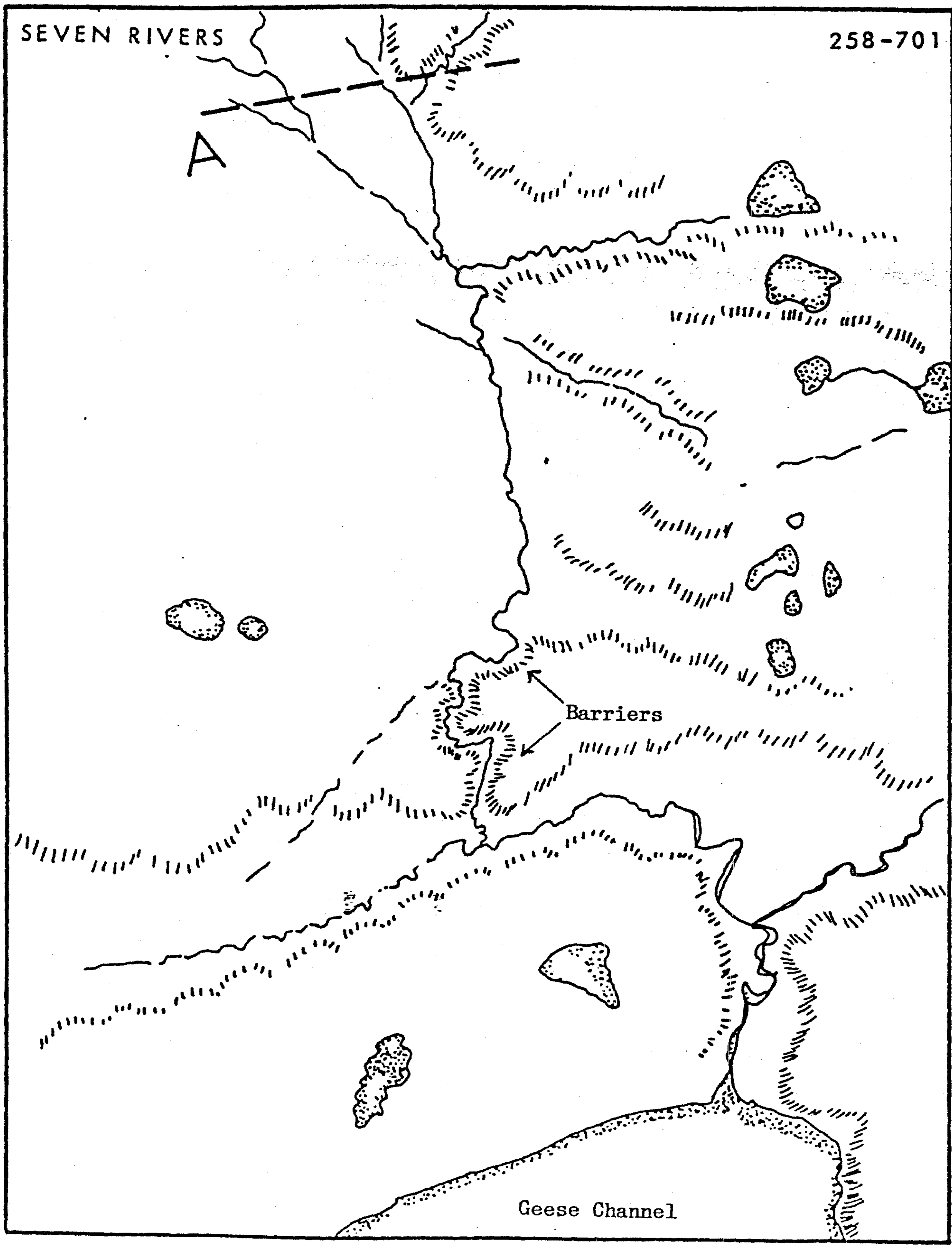


Figure 20. Map showing location of Seven Rivers Creek, barriers to pink salmon migration, and inaccessible spawning habitat.

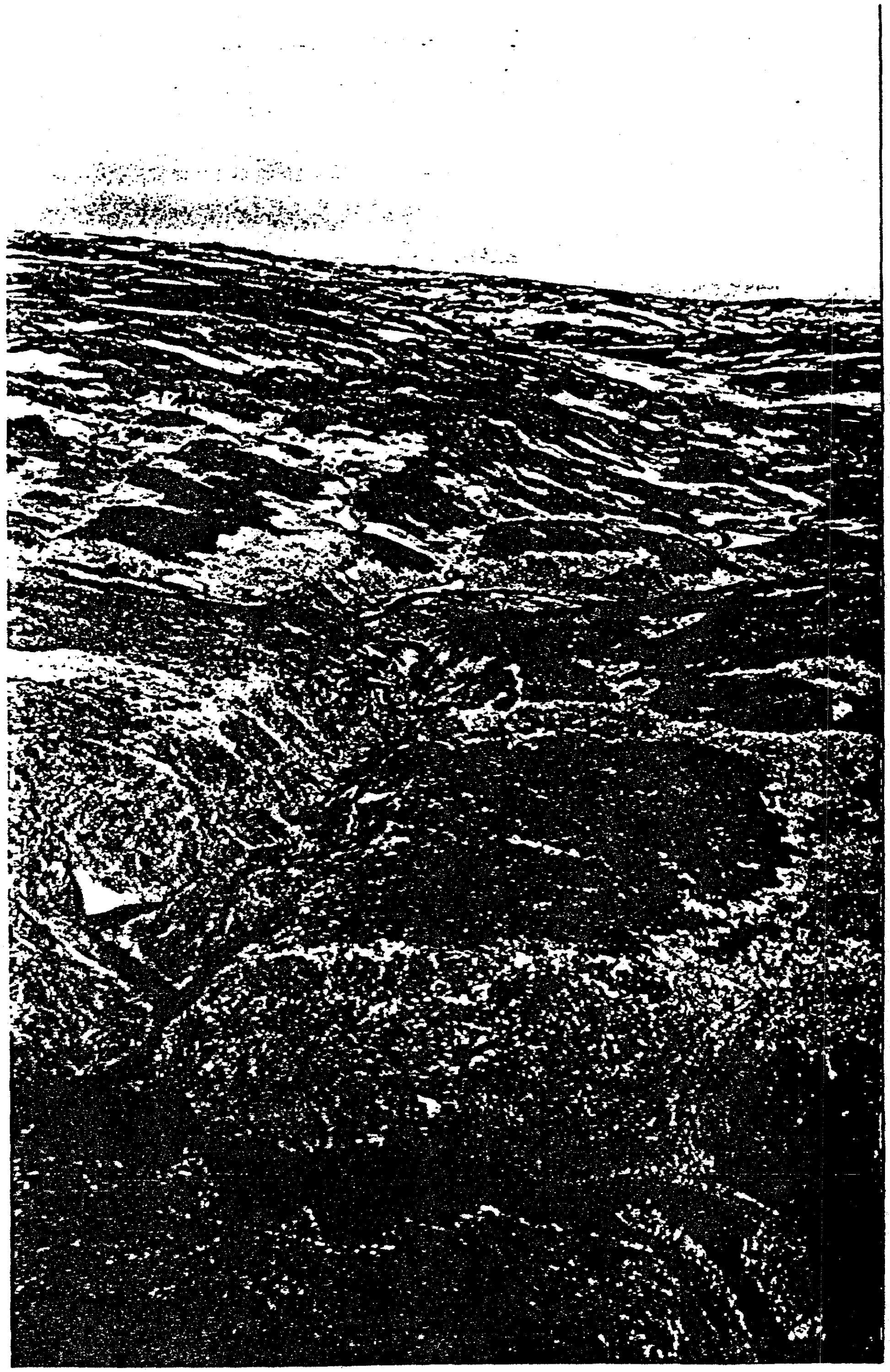


Figure 21. Aerial photograph of the west fork of Seven Rivers Creek, showing location of barriers and potential upstream spawning habitat.

Figure 22. Photograph of first and second barriers, located upstream of salt water on the west fork of Seven Rivers Creek.

Figure 23. Photograph of third barrier, located upstream of salt water, on the west fork of Seven Rivers Creek.

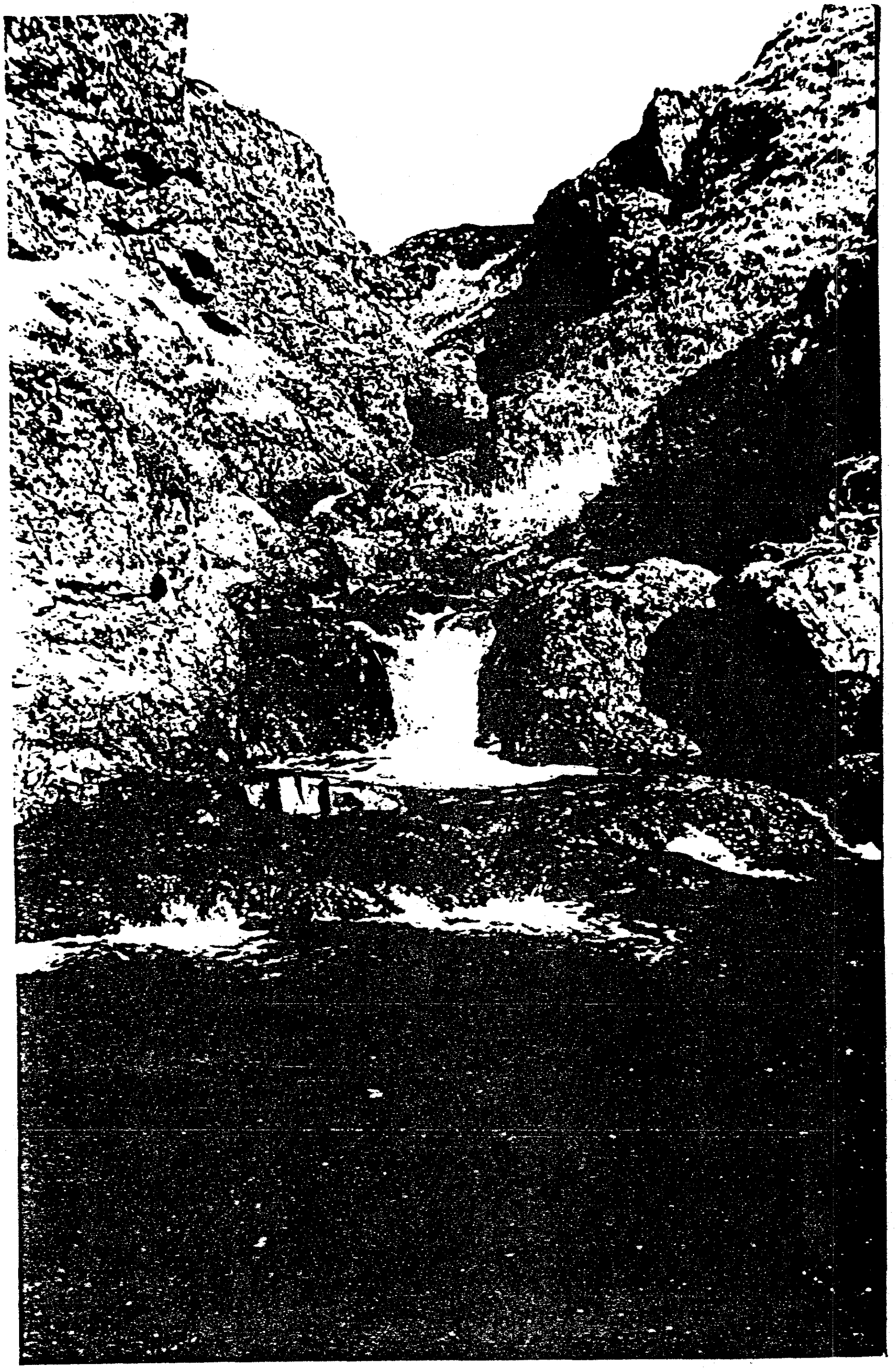


Figure 24. Photograph of fourth barrier, located upstream of salt water, on the west fork of Seven Rivers Creek.

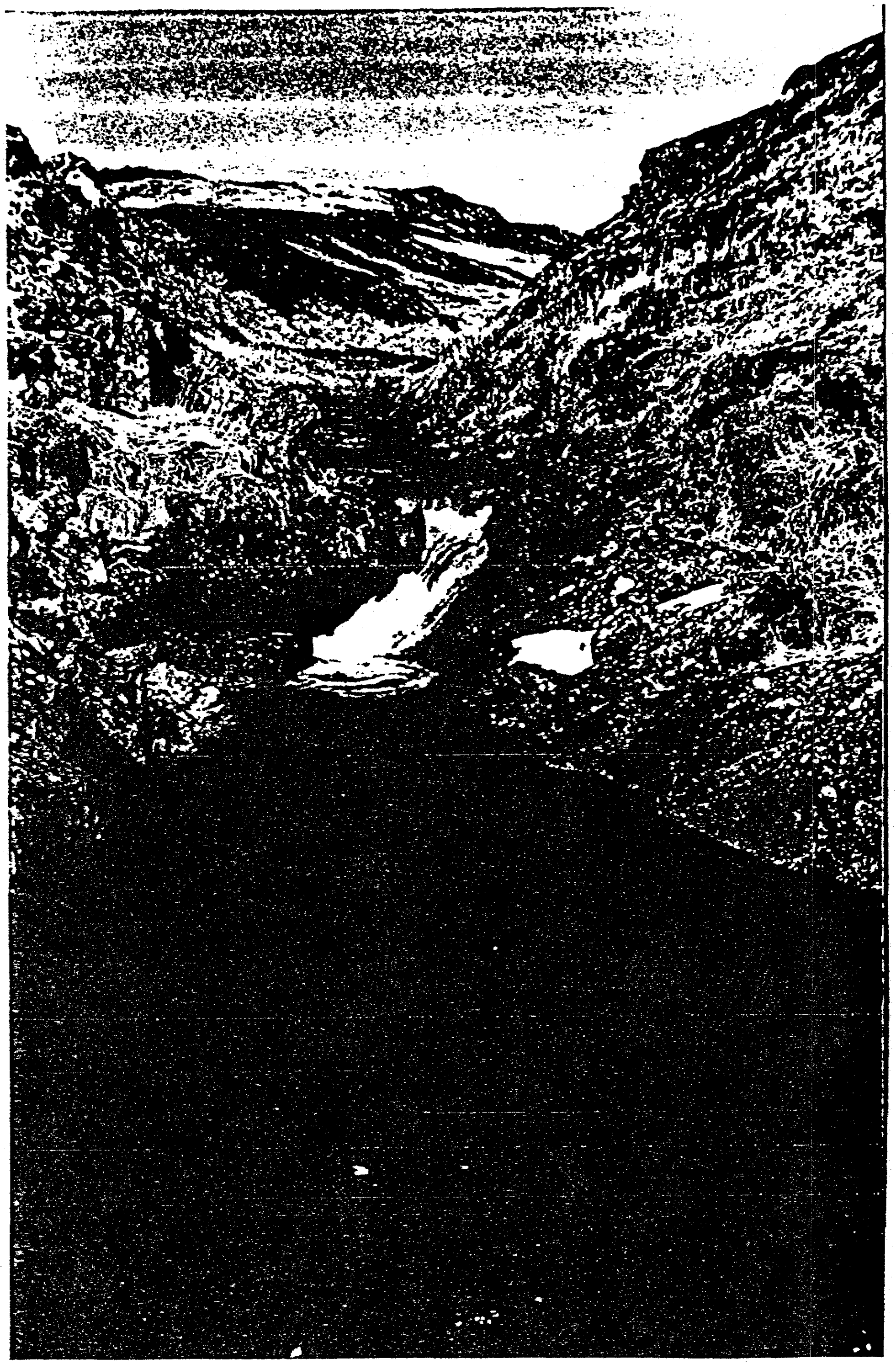


Figure 25. Photograph of fifth barrier, located upstream of salt water, on the west fork of Seven Rivers Creek.

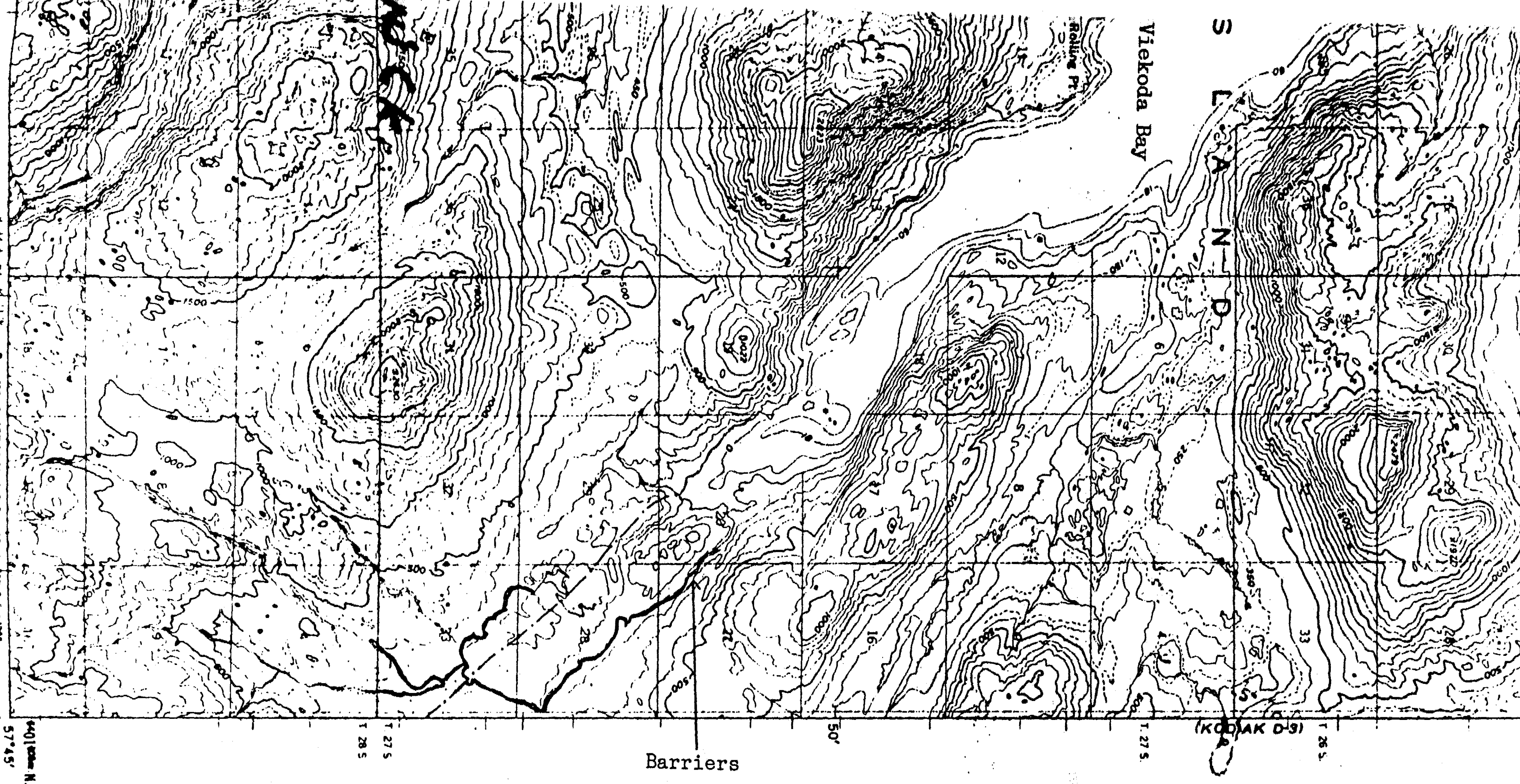


Figure 26. Topographical map showing location of Twin Lakes Creek, barriers impeding pink salmon migration and potential spawning habitat above barriers.

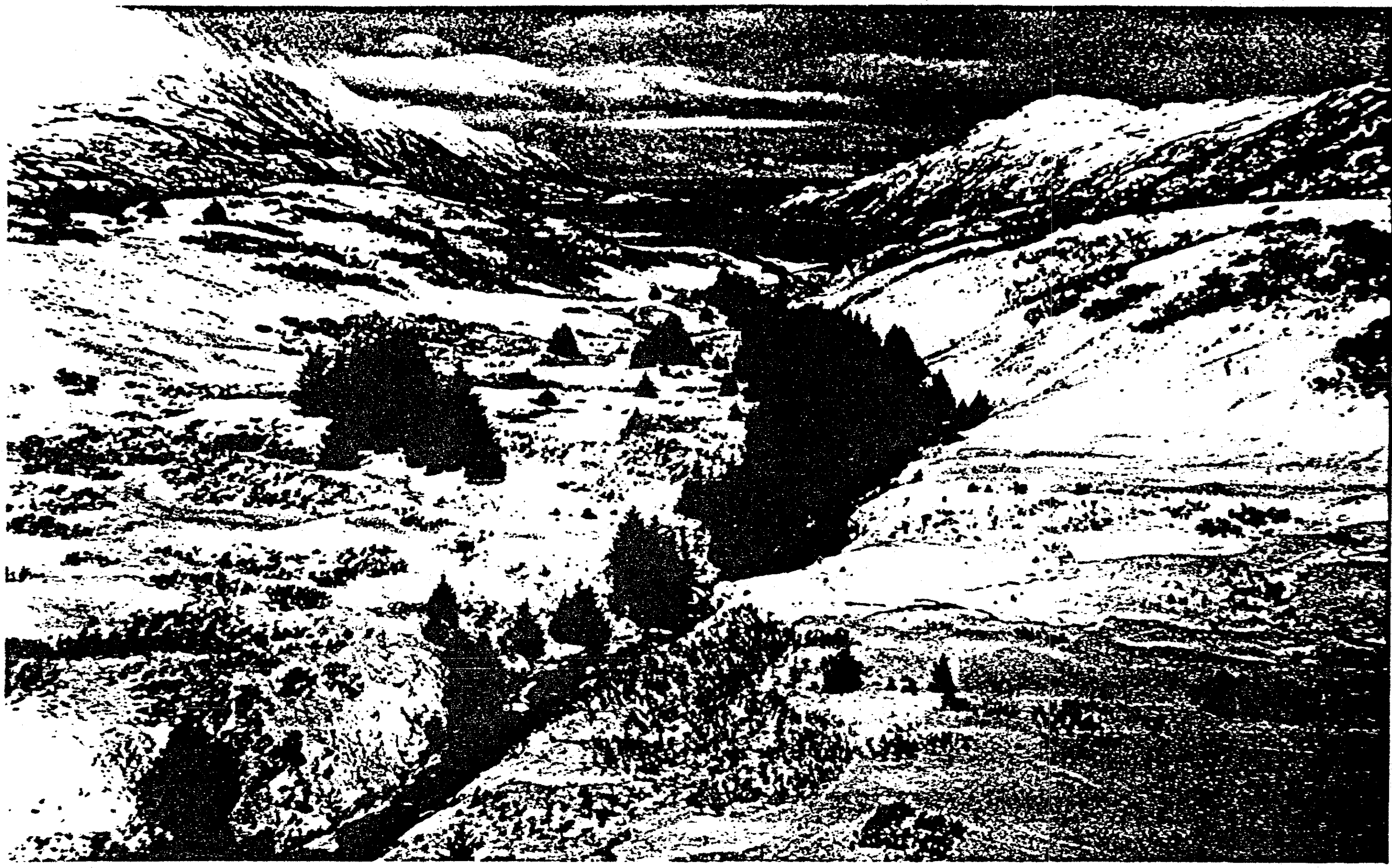
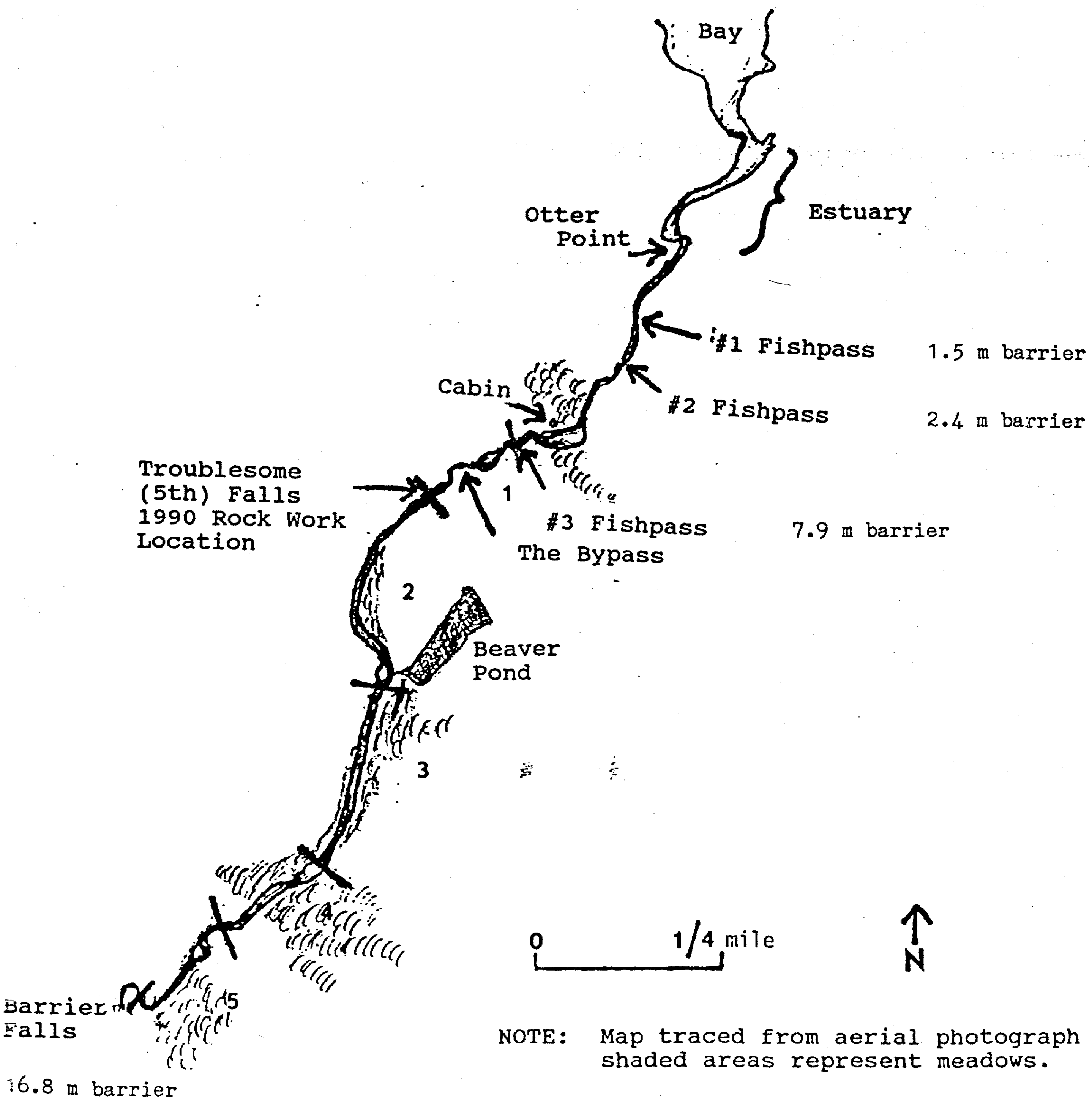


Figure 27. Aerial photograph of Twin Lakes Creek showing location of barriers and area where spawning habitat evaluation was conducted.

Figure 28. Satellite photograph of Little Waterfall Creek, Afognak Island; lines indicate the location of barrier falls.

Figure 29. Diagram of Little Waterfall Creek showing barrier falls locations and heights, and fish pass locations.



NOTE: Map traced from aerial photograph shaded areas represent meadows.

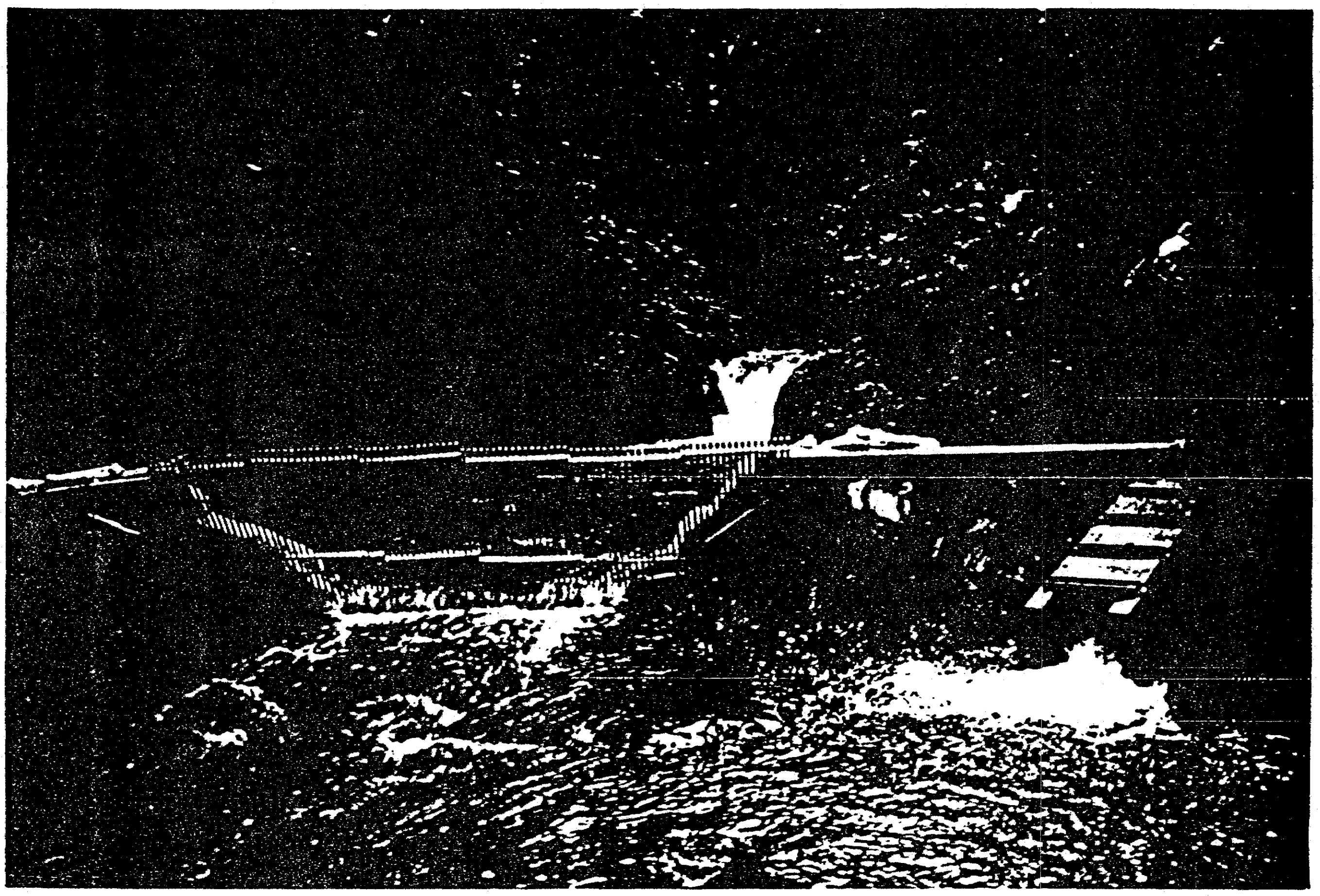


Figure 30. Photograph of the first fish pass and diversion weir which allows pink salmon migration past barrier falls at Little Waterfall Creek.

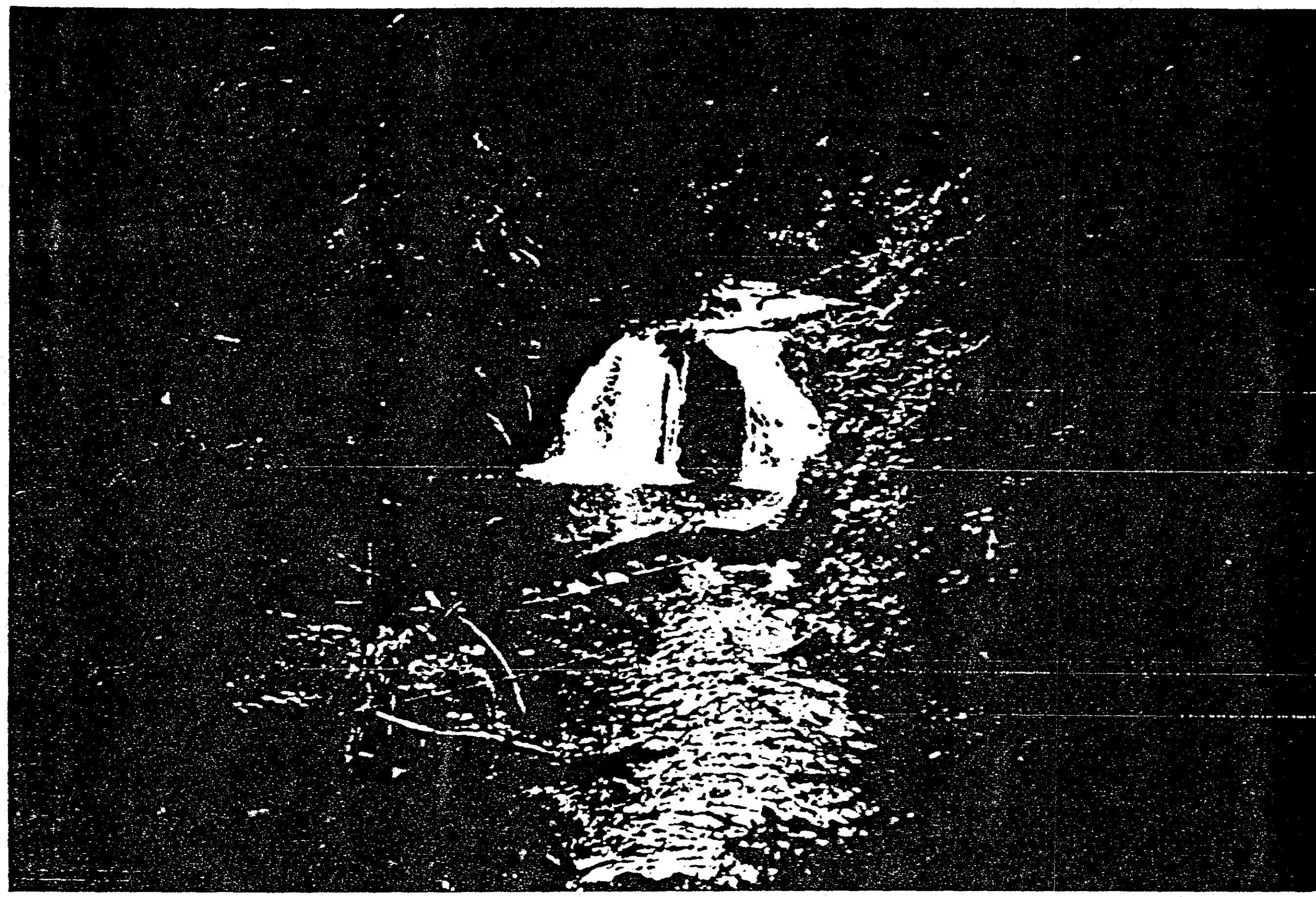


Figure 31. Photograph of the third fish pass and diversion weir located at third upstream barrier falls at Little Waterfall Creek.

Table 1. Kodiak Island pink salmon restoration survey sites and areas of significant oiling as result of Exxon Valdez oil spill.

1992 Survey Site	Outlet Bay/Area	1989 Oiled Areas \a	1990 Oiled Areas \a
Bauman's Creek	Uganik Passage	Uganik Island Uganik Bay	Uyak Bay Spiridon Bay
Seven Rivers	Geese Channel	Kagugak Bay Kiavak Bay	None
Horse Marine	Olga Bay	Alitak Bay	None
Cold Creek	Kazakof Bay	Ishut Bay Shuyak Island	Ishut Bay Shuyak Island
Pink Creek	Afognak Bay	Afognak Bay Raspberry Island	None
Twin Lakes Creek	Veikoda Bay	Veikoda Bay Uganik Island	Uyak Bay Spiridon Bay
L. Waterfall Creek	L. Waterfall Bay	L. Waterfall Bay B. Waterfall Bay Shuyak Island	Shuyak Island

a\ closest proximity to survey locations; data acquired from maps prepared by Data Assessment Geoprocessing Group (GEO).

Table 2. Pre and post fish pass pink salmon escapements, harvests, harvest value, costs and benefits for Portage and Waterfall systems located on Afognak Island.

	Portage		Waterfall	
	Pre (68-78)	Post (79-90)\a	Pre (68-80)	Post (81-92)
Mean Escapement	19,400	44,100	5,500	61,581
Mean Harvest \b	29,100	66,150	8,250	92,372
Mean Harvest Value \c	$26,190	$59,535	$7,425	$83,135
Total Harvest	320,100	793,800	107,250	1,108,464
Total Harvest Value	$288,090	$714,420	$96,525	$997,618
Fish pass Cost \d	-	$68,000	-	$600,000
C/B Ratio(1:B)	-	10.5	-	1.7

\a escapement data through 1990.

\b harvest estimate based on 60% exploitation rate.

\c harvest value based on 1980-1989 average pink salmon $/# of .30 and average weight for pinks of 3 lbs.

\d cost at time of installation plus costs associated with operation and maintenence for all years post installation.

Table 3. Physical characteristics of barriered pink salmon systems surveyed on Kodiak Island for fish pass feasibility in 1992 \a.

Creek Name	Survey Date	Barrier Height #	Barrier Height (m)	Barrier Length (m)	Barrier Slope (%)	Stream Width \b Above (m)	Stream Width \b Below (m)	Stream Depth Above (m)	Stream Depth Below (m)	Midstream Flows Above (m^2/s)	Midstream Flows Below (m^2/s)	Upstream Slope (%)	Water Temperature (C)
Bauman's	August 8	1	3.0	6.5	nd	16.8	19.8	nd	nd	nd	nd	nd	nd
		2	3.5	4.5	nd								
		3	2.5	9.5	nd								
		4	3.7	0.5	nd								
		5	3.0	0.5	nd								
Cold	September 23	1	1.2	3.7	13	8.8	nd	0.3	nd	nd	nd	5.1	4.0
		2	0.6	1.2	nd								
		3	1.2	2.4	11								
Horse Marine	September 16	1	1.0	3.0	nd	12.8	nd	nd	nd	nd	nd	nd	12.0
		2	3.0	12.0	nd								
Pink	January 7	1	1.5	5.8	10	4.6	5.2	0.3	0.3			4.8	0.5
Seven Rivers	April 9	1	0.9	4.6	nd	4.9	5.2	0.3	0.3			5.0	2.0
		2	0.9	2.4	nd								
		3	2.4	4.0	nd								
		4	1.8	1.8	nd								
		5	1.8	3.0	nd								
Twin Lakes	January 30		1.8 \c	30.5	nd	4.9	11.0	0.7	0.9			3.6	0.5
Waterfall	June 15	1	1.5	1.0	nd	6.0	3.0	nd	nd	nd	nd	nd	nd
		2	2.4	3.0	nd	9.1	7.0						
		3	7.9	1.5	nd	5.4	7.9						

\a data for Bauman's and Horse Marine acquired from surveys in 1972 and 1977, respectively; nd = no data

\b above - above barrier; below - below barrier.

\c barrier composed of a series of cataracts and small falls as viewed from aerial survey; steep canyon and icey conditions prevented on site survey.

Table 4. Mean odd year pink salmon escapements for Kodiak pink salmon restoration systems from 1969 - 1987, potential escapement above barriered areas, and potential total escapement.

Stream	No.	Mean Escapement (1969-1987)\a	Potential Escapement Above Barriers\b	Potential Total Escapement\c
Bauman's	253-332	26,708	96,200	122,908
Cold Creek	252-331	4,628	10,411	15,039
Horse Marine	257-402	4,132	10,934	15,066
Pink Creek	\d	nd	3,224	3,224
Seven Rivers	258-701	229,098	7,528	236,626
Twin Lakes	253-321	6,400	19,863	26,263
Waterfall \e	251-822	3,365	16,986	20,351

\a escapement data based on peak aerial counts (Swanton, 1992).

\b from appendix tables 1-3,6,10,17, and 18.

\c assumes that mean escapement number equates to full utilization of spawning habitat below barriers; equals mean escapement plus potential escapement above barriers.

\d not currently numbered; tributary to Afognak River (252-342).

\e mean escapement numbers from foot surveys including even years form 1968 - 1980; mean escapement after fish pass installation from 1981 to 1992 is 58,229 with mean escapement above all barriers of 5,962; potential escapement based on corrected spawning area evaluation data; above barrier escapement refers to above third barrier.

nd no data

Table 5. Odd year pink salmon escapements from 1969 to 1989 for Bauman's Creek (253-332).

Year	Peak Count /a	Escapement \b
1969	23,000	42,320
1971	6,000	11,040
1973	3,000	5,520
1975	550	1,012
1977	5,900	10,856
1979	18,100	33,304
1981	44,500	81,880
1983	8,100	14,904
1985	21,000	38,640
1987	15,000	27,600
1989	325,000	598,000
Mean: \c	14,515	26,708

\a aerial survey.

\b escapement number based on 1.84 * peak count from stream life model (Barrett et al, 1990)

\c mean does not include 1989 since overescapement occured as result of the Exxon Valdez oil spill.

Source: Swanton, C.O. and T.J. Dalton. 1992. Pink salmon escapement on egg retention, pre-emerging fry, and adult return to Kodiak and Chignik Management Areas caused by the Exxon Valdez oil spill. NRDA Studies 7B and 8B. Unpublished.

Table 6. Comparison of barrier bypass costs, production value and initial and future cost to benefits (C:B) for Kodiak pink salmon restoration systems.

Creek Name	Fish pass Sect. Needed (m) \a	Initial Cost \b	Potential Production \c	Production Value \d	Initial C:B (C:1)	Post Install. Annual Costs	Years to Cost Effect.	Post Install. C:B (B:1)
Bauman's	300	$980,000	144,300	$43,290	22.6	nd	23	-
Cold	\e	$25,000	15,617	$4,685	5.3	$1,000	5	4.7
Horse Marine	24.4	$100,000	22,599	$6,780	14.7	$14,000	15	0.5
Pink	\e	$26,000	4,835	$1,450	17.9	$1,000	18	1.5
Seven Rivers	42	$137,760	11,292	$3,388	40.7	$26,000	41	0.1
Twin Lakes	nd	nd	29,795	$8,439	nd	nd	nd	nd
Waterfall	9.1 \e	$70,000	28,340	$8,501	8.2	0 \f	8	8,501.0
Cold and Pink	\e	$51,000	20,452	$6,136	8.3	$2,000	8	3.1

\a Denil-type fish pass;based on 7:1 grade.

\b based on $3,280 per meter of fish pass for initial installation (Blackett, personal communication).

\c based on 60% explotation rate; extrapolated from potential escapement above barriers.

\d based on 3 pound pink salmon @ $0.30 per pound;

\e does not require fish pass sections; channel alteration and water diversions recommended.

\f all maintenance costs after initial installation would be paid by Kodiak Regional Aquaculture Association (KRAA) - Perenosa Rehabilitation Project.

nd no data

Table 7. Odd year pink salmon escapements from 1969 to 1989 for Cold Creek (252-331).

Year	Peak Count /a	Escapement \b
1969	600	1,104
1971	nd	nd
1973	200	368
1975	0	0
1977	158	291
1979	3,200	5,888
1981	18,500	34,040
1983	1,096	2,017
1985	200	368
1987	1,200	2,208
1989	2,356	4,335
Mean: \c	2,515	4,628

\a aerial survey.

\b escapement number based on 1.84 * peak count from stream life model (Barrett et al, 1990)

\c mean does not include 1989 since overescapement occured as result of the Exxon Valdez oil spill.

Source: Swanton, C.O. and T.J. Dalton. 1992. Pink salmon escapement on egg retention, pre-emerging fry, and adult return to Kodiak and Chignik Management Areas caused by the Exxon Valdez oil spill. NRDA Studies 7B and 8B. Unpublished.

Table 8. Odd year pink salmon escapements from 1969 to 1989 for Horse Marine Creek (257-402).

Year	Peak Count /a	Escapement \b
1969	25	46
1971	400	736
1973	2,777	5,110
1975	2,000	3,680
1977	7,000	12,880
1979	6,000	11,040
1981	3,000	5,520
1983	1,000	1,840
1985	0	0
1987	2,200	4,048
1989	300	552
Mean:	2,246	4,132

\a aerial survey.

\b escapement number based on 1.84 * peak count from stream life model (Barrett et al, 1990)

Source: Swanton, C.O. and T.J. Dalton. 1992. Pink salmon escapement on egg retention, pre-emerging fry, and adult return to Kodiak and Chignik Management Areas caused by the Exxon Valdez oil spill. NRDA Studies 7B and 8B. Unpublished.

Table 9. Odd year pink salmon escapements from 1969 to 1989 for Seven Rivers Creek (258-701).

Year	Peak Count /a	Escapement \b
1969	39,000	71,760
1971	54,000	99,360
1973	24,000	44,160
1975	86,000	158,240
1977	53,000	97,520
1979	100,700	185,288
1981	128,000	235,520
1983	86,000	158,240
1985	60,000	110,400
1987	164,400	302,496
1989	450,000	828,000
Mean: \c	79,510	229,098

\a aerial survey.

\b escapement number based on 1.84 * peak count from stream life model (Barrett et al, 1990)

\c mean does not include 1989 since overescapement occured as result of the Exxon Valdez oil spill.

Source: Swanton, C.O. and T.J. Dalton. 1992. Pink salmon escapement on egg retention, pre-emerging fry, and adult return to Kodiak and Chignik Management Areas caused by the Exxon Valdez oil spill. NRDA Studies 7B and 8B. Unpublished.

Table 10. Odd year pink salmon escapements from 1969 to 1989 for Twin Lakes Creek (253-321).

Year	Peak Count /a	Escapement \b
1969	1,500	2,760
1971	2,500	4,600
1973	3,000	5,520
1975	nd	nd
1977	325	598
1979	4,800	8,832
1981	11,700	21,528
1983	1,400	2,576
1985	nd	nd
1987	2,600	4,784
1989	6,000	11,040
Mean: \c	3,478	6,400

\a aerial survey.

\b escapement number based on 1.84 * peak count from stream life model (Barrett et al, 1990)

\c mean does not include 1989 since overescapement occured as result of the Exxon Valdez oil spill.

Source: Swanton, C.O. and T.J. Dalton. 1992. Pink salmon escapement on egg retention, pre-emerging fry, and adult return to Kodiak and Chignik Management Areas caused by the Exxon Valdez oil spill. NRDA Studies 7B and 8B. Unpublished.

Table 11. Waterfall pink salmon total escapement and spawning numbers above third barrier falls 1980 - 1992.

Year	Total Escapement\a	Escapement Above Third Falls\b	Porportion Above Third Falls (%)
1980	18,000	0	0.0
1981	61,193	1,100	1.8
1982	47,500	0	0.0
1983	21,700	1,600	7.4
1984	40,000	10,400	26.0
1985	119,200	19,800	16.6
1986	48,400	nd	nd
1987	29,100	nd	nd
1988	49,680	nd	nd
1989	117,200	19,500	16.6
1990	47,000	3,100	6.6
1991	115,000	16,000	13.9
1992	43,000	6,000	14.0
Mean:	58,229	5,962	10.2
Mean(89-92):	80,550	11,150	13.8

nd = no data

\a based on fish pass counts.

\b based on foot survey peak spawning counts.

Appendix I

Appendix Table 1. Summary of spawning area parameters, calculations of useable spawning area and pink salmon spawning capacity for 29 September 1972 survey of Bauman's Creek.

Length (m)	Width (m)	Flow (m/s)	Depth (m)	Slope (%)	Useable Area (%) \a	Useable Area (m^2)	Spawning Capacity \b
1,609.3	19.8	nd	nd	nd	50	15,942	15,942
4,023.4	16.8	nd	nd	nd	50	33,724	33,724
1,609.3	15.2	nd	nd	nd	50	12,263	12,263
5,632.7	12.2	nd	nd	nd	50	34,337	34,337
	Above barrier totals:					96,266	96,266

\a survey conducted by Blackett (1972); useable spawning area parameters not defined.

\b based on optimum spawning density of 2.0 m^2 per female and a 50:50 sex ratio (Burgner et al, 1969; Willette 1991).

nd = no data

Appendix Table 2. Summary of spawning area parameters, calculations of useable spawning area and pink salmon spawning capacity for 23 September 1992 survey of Cold Creek.

Length (m)	Width (m)	Depth (m)	Slope (%)	Useable Area (%) \a	Useable Area (m^2)	Spawning Capacity \b
88.4	4.6	0.3	5	60	242	242
73.5	2.4	0.2	-	95	170	170
58.5	3.7	0.2	-	90	193	193
189.6	7.9	0.3	4	75	1,127	1,127
68.9	6.1	0.2	-	80	336	336
155.8	9.1	0.2	7	100	1,424	1,424
81.7	4.6	0.1	-	90	336	336
75.6	7.6	0.5	8	80	461	461
95.4	3.7	0.2	-	65	227	227
127.4	5.5	0.2	-	95	664	664
90.5	6.1	0.5	6	90	497	497
111.3	2.7	0.3	-	90	275	275
77.4	3.7	0.2	4	95	269	269
113.7	2.7	0.2	-	80	250	250
108.2	2.4	0.2	-	100	264	264
52.1	2.4	0.1	-	100	127	127
86.6	2.7	0.1	-	100	237	237
202.7	2.1	0.3	4	90	389	389
192.0	3.4	0.4	-	80	515	515
67.1	1.2	0.1	-	100	82	82
278.0	2.4	0.3	-	75	508	508
285.3	1.8	0.1	-	75	391	391
493.2	1.8	0.2	4	50	451	451
289.6	2.4	0.1	-	80	565	565
133.5	1.8	0.2	4	70	171	171
298.4	1.2	0.2	-	40	146	146
65.2	1.2	0.2	-	35	28	28
218.2	1.2	0.2	-	25	67	67
Above barrier totals:					10,411	10,411

\a useable spawning area was defined as flows of ~0.5 m/sec, water depth of 0.3-0.5m, gravel size of 6-150mm with <25% by volume of the gravel ≤6mm, and minimal compactness (Chambers et al, 1955).

\b based on optimum spawning density of 2.0 m^2 per female and a 50:50 sex ratio (Burgner et al, 1969; Willette 1991).

Appendix Table 3. Summary of spawning area parameters, calculations of useable spawning area and pink salmon spawning capacity for 16 September 1978 survey of Horse Marine Creek.

Length (m)	Width (m)	Flow (m/s)	Depth (m)	Slope (%)	Useable Area (%) \a	Useable Area (m^2)	Spawning Capacity \b
160.9	12.8	nd	nd	nd	70	1,442	1,442
160.9	16.8	nd	nd	nd	80	2,158	2,158
160.9	21.3	nd	nd	nd	80	2,747	2,747
160.9	16.8	nd	nd	nd	80	2,158	2,158
160.9	16.8	nd	nd	nd	90	2,428	2,428
	Above barrier totals:					10,934	10,934

\a survey conducted by Blackett (1978); useable spawning area parameters not defined.

\b based on optimum spawning density of 2.0 m^2 per female and a 50:50 sex ratio (Burgner et al, 1969; Willette 1991).

nd = no data

Appendix Table 4. Flows measured at transect 1 below falls for the 07 January 1992 survey of Pink Creek.

dist. (m)	depth (m)	vel. (m/s)	flow (m^2/s)
0.30	0.06	0.00	0.00
0.30	0.08	0.20	0.00
0.30	0.12	0.26	0.01
0.30	0.15	0.06	0.00
0.30	0.15	0.18	0.01
0.30	0.20	0.00	0.00
0.30	0.27	0.37	0.03
0.30	0.24	0.43	0.03
0.30	0.21	0.30	0.02
0.30	0.21	0.21	0.01
0.30	0.15	0.11	0.00
0.30	0.12	0.18	0.01
0.30	0.15	0.12	0.01
0.30	0.15	0.20	0.01
0.30	0.14	0.15	0.01
0.30	0.09	0.34	0.01
0.30	0.09	0.21	0.01
0.30	0.02	0.00	0.00
		Total m^2/s	0.17

Appendix Table 5. Flows measured at transect 2 above falls for the 07 January 1992 survey of Pink Creek.

dist. (m)	depth (m)	vel. (m/s)	flow (m^2/s)
0.30	0.29	0.12	0.01
0.30	0.17	0.02	0.00
0.30	0.24	0.02	0.00
0.30	0.24	0.05	0.00
0.30	0.24	0.06	0.00
0.30	0.27	0.11	0.01
0.30	0.24	0.20	0.01
0.30	0.24	0.21	0.02
0.30	0.24	0.15	0.01
0.30	0.24	0.15	0.01
0.30	0.23	0.11	0.01
0.30	0.21	0.09	0.01
0.30	0.23	0.15	0.01
0.30	0.18	0.15	0.01
0.30	0.24	0.03	0.00
0.30	0.14	0.76	0.03
		Total m^2/s	0.15

Appendix Table 6. Summary of spawning area parameters and calculations of of useable spawning area and pink salmon spawning capacity for 07 January 1992 survey of Pink Creek.

Length (m)	Width (m)	Slope (%)	Useable Area (%) \a	Useable Area (m^2)	Spawning Capacity \b
18.9	3.0	7	35	20	20
26.8	3.0	4	45	37	37
61.0	2.4	4	85	126	126
45.7	2.4	6	95	106	106
67.1	2.4	-	90	147	147
46.6	2.7	-	95	122	122
40.2	3.0	4	95	117	117
33.8	2.4	-	85	70	70
47.9	3.0	5	80	117	117
42.7	4.6	6	60	117	117
53.9	5.5	4	75	222	222
53.6	4.6	-	75	184	184
32.9	3.0	4	90	90	90
53.0	3.7	-	85	165	165
24.4	3.7	-	50	45	45
84.7	4.6	4	90	349	349
64.6	4.6	-	95	281	281
128.9	5.5	3	90	637	637
39.3	5.5	6	90	194	194
49.4	4.6	-	35	79	79
	Above barrier totals:			3,223	3,223
35.1	9.1	-	90	288	288
76.2	4.6	-	85	296	296
61.0	4.6	-	60	167	167
	Below barrier totals:			752	752

\a useable spawning area was defined as flows of ~0.5 m/sec, water depth of 0.3-0.5m, gravel size of 6-150mm with <25% by volume of the gravel ≤6mm, and minimal compactness (Chambers et al. 1955).

\b based on optimum spawning density of 2.0 m^2 per female and a 50:50 sex ratio (Burgner et al, 1969; Willette 1991).

Appendix Table 7. Pink and chum salmon escapement and carcass counts by day at Pink Creek, 1990.

Date	Pink				Chum			
	Live		Carcass		Live		Carcass	
	daily	cum	daily	cum	daily	cum	daily	cum
25-Jul	0	0	0	0	0	0	0	0
26-Jul	0	0	0	0	0	0	0	0
27-Jul	0	0	0	0	0	0	0	0
28-Jul	0	0	0	0	0	0	0	0
29-Jul	0	0	0	0	0	0	0	0
30-Jul	0	0	0	0	0	0	0	0
31-Jul	0	0	0	0	0	0	0	0
01-Aug	3	3	0	0	0	0	0	0
02-Aug	0	3	0	0	0	0	0	0
03-Aug	0	3	0	0	0	0	0	0
04-Aug	14	17	0	0	0	0	0	0
05-Aug	28	45	0	0	0	0	0	0
06-Aug	31	76	0	0	0	0	0	0
07-Aug a	94	170	0	0	0	0	0	0
07-Aug b	0	170	0	0	0	0	0	0
08-Aug	283	453	0	0	0	0	0	0
09-Aug	17	470	0	0	0	0	0	0
10-Aug	4	474	0	0	0	0	0	0
11-Aug **	996	1,470	2	2	0	0	0	0
12-Aug	156	1,626	3	5	0	0	0	0
13-Aug a	0	1,626	0	5	0	0	0	0
13-Aug b	113	1,739	0	5	0	0	0	0
14-Aug	30	1,769	3	8	0	0	0	0
15-Aug a	172	1,941	1	9	0	0	0	0
15-Aug b	0	1,941	0	9	0	0	0	0
16-Aug	192	2,133	3	12	0	0	0	0
17-Aug	26	2,159	5	17	0	0	0	0
18-Aug a	0	2,159	6	23	0	0	0	0
18-Aug b	54	2,213	0	23	0	0	0	0
19-Aug	163	2,376	8	31	0	0	0	0
20-Aug	131	2,507	14	45	0	0	0	0
21-Aug a	0	2,507	0	45	0	0	0	0
21-Aug b	29	2,536	12	57	0	0	0	0
22-Aug	61	2,597	33	90	0	0	0	0
23-Aug	27	2,624	51	141	0	0	0	0
24-Aug a	2	2,626	42	183	0	0	0	0
24-Aug b	2	2,628	19	202	0	0	0	0
25-Aug	90	2,718	57	259	2	2	0	0
26-Aug	266	2,984	65	324	0	2	0	0
27-Aug a	0	2,984	37	361	0	2	0	0
27-Aug b	44	3,028	32	393	0	2	0	0
28-Aug	40	3,068	33	426	0	2	0	0
29-Aug	1	3,069	72	498	0	2	0	0
30-Aug a	0	3,069	35	533	0	2	0	0

Appendix Table 7. continued. Pink and chum salmon escapement and carcass counts by day at Pink Creek, 1990.

Date	Pink Live daily	Pink Live cum	Pink Carcass daily	Pink Carcass cum	Chum Live daily	Chum Live cum	Chum Carcass daily	Chum Carcass cum
30-Aug b	3	3,072	366	899	0	2	0	0
31-Aug	10	3,082	49	948	0	2	0	0
01-Sep	1	3,083	35	983	0	2	0	0
02-Sep a	3	3,086	17	1,000	0	2	0	0
02-Sep b	111	3,197	261	1,261	0	2	0	0
03-Sep	997	4,194	20	1,281	0	2	0	0
04-Sep	13	4,207	57	1,338	0	2	0	0
05-Sep a	2	4,209	17	1,355	0	2	0	0
05-Sep b	0	4,209	0	1,355	0	2	0	0
06-Sep	13	4,222	31	1,386	0	2	0	0
07-Sep	27	4,249	34	1,420	0	2	0	0
08-Sep a	0	4,249	0	1,420	0	2	0	0
08-Sep b	10	4,259	194	1,614	0	2	0	0
09-Sep	1	4,260	18	1,632	0	2	0	0
10-Sep	1	4,261	25	1,657	0	2	0	0
11-Sep a	0	4,261	158	1,815	0	2	0	0
11-Sep b	31	4,292	58	1,873	0	2	0	0
12-Sep	2	4,294	53	1,926	0	2	0	0
13-Sep	0	4,294	34	1,960	0	2	0	0
14-Sep	8	4,302	155	2,115	0	2	0	0
15-Sep a	0	4,302	114	2,229	0	2	0	0
15-Sep b	0	4,302	20	2,249	0	2	0	0
16-Sep	0	4,302	75	2,324	0	2	0	0

1/ a = presurvey
b = postsurvey
** weir is totally submerged, not fish tight

Appendix Table 8. Flows measured at transect 1 below falls for the 09 April 1992 survey of Seven Rivers Creek.

dist. (m)	depth (m)	vel. (m/s)	flow (m^2/s)
0.30	0.00	0.00	0.00
0.30	0.06	0.02	0.00
0.30	0.06	0.12	0.00
0.30	0.09	0.15	0.00
0.30	0.11	0.20	0.01
0.30	0.12	0.14	0.01
0.30	0.20	0.11	0.01
0.30	0.24	0.21	0.02
0.30	0.30	0.34	0.03
0.30	0.34	0.27	0.03
0.30	0.30	0.70	0.07
0.30	0.27	0.52	0.04
0.30	0.24	0.46	0.03
0.30	0.21	0.40	0.03
0.30	0.18	0.37	0.02
0.30	0.14	0.18	0.01
0.30	0.15	0.09	0.00
		Total m^2/s	0.30

Appendix Table 9. Flows measured at transect 2 above falls for the 09 April 1992 survey of Seven Rivers Creek.

dist. (m)	depth (m)	vel. (m/s)	flow (m^2/s)
0.30	0.12	0.09	0.00
0.30	0.21	0.09	0.01
0.30	0.15	0.21	0.01
0.30	0.15	0.43	0.02
0.30	0.24	0.34	0.02
0.30	0.24	0.40	0.03
0.30	0.26	0.46	0.04
0.30	0.20	0.38	0.02
0.30	0.18	0.52	0.03
0.30	0.15	0.34	0.02
0.30	0.12	0.20	0.01
0.30	0.11	0.15	0.00
0.30	0.08	0.34	0.01
0.30	0.12	0.03	0.00
0.30	0.09	0.02	0.00
0.30	0.09	0.30	0.01
		Total m^2/s	0.23

Appendix Table 10. Summary of spawning area parameters, calculations of useable spawning area and pink salmon spawning capacity for 09 April 1992 survey of Seven Rivers Creek.

Length (m)	Width (m)	Flow (m/s)	Depth (m)	Slope (%)	Useable Area (%) \a	Useable Area (m^2)	Spawning Capacity \b
121.6	4.6	0.1	0.1	6.0	45	250	250
108.8	6.4	0.3	0.1	5.5	85	592	592
100.9	5.5	0.2	0.1	4.5	60	332	332
107.6	4.6	0.2	0.2	5.0	70	344	344
81.7	4.6	0.4	0.2	5.5	75	280	280
122.5	7.6	0.3	0.1	5.5	60	560	560
81.4	5.5	0.6	0.2	3.0	85	380	380
91.1	4.6	0.8	0.1	6.5	85	354	354
121.0	4.6	0.5	0.2	4.5	90	498	498
99.4	4.3	0.2	0.1	5.0	70	297	297
62.2	4.6	0.2	0.3	6.0	55	156	156
82.0	4.6	0.7	0.2	6.0	30	112	112
86.6	4.0	0.6	0.2	6.0	35	120	120
133.2	2.7	0.6	0.2	6.0	40	146	146
180.4	2.1	0.5	0.2	-	55	212	212
101.2	2.4	0.8	0.2	-	55	136	136
89.6	2.1	0.7	0.1	4.5	95	182	182
120.1	3.7	0.4	0.5	4.5	60	264	264
158.2	3.0	0.5	0.2	4.5	40	193	193
139.0	2.4	0.6	0.2	2.5	40	136	136
121.0	3.0	0.2	0.3	2.0	80	295	295
125.0	1.8	0.4	0.2	6.0	70	160	160
117.7	2.1	0.6	0.2	9.0	20	50	50
189.3	1.5	0.4	0.2	-	40	115	115
141.7	1.8	0.2	0.2	6.0	60	156	156
168.2	1.8	0.4	0.2	-	60	185	185
142.6	1.5	0.5	0.2	-	65	141	141
300.8	1.8	0.3	0.2	4.0	80	440	440
210.6	1.8	0.2	0.2	5.0	80	308	308
146.6	1.8	0.6	0.1	-	50	134	134
	Above barrier totals:					7,528	7,528

\a useable spawning area was defined as flows of ~0.5 m/sec, water depth of 0.3-0.5m, gravel size of 6-150mm with <25% by volume of the gravel ≤6mm, and minimal compactness (Chambers et al, 1955).

\b based on optimum spawning density of 2.0 m^2 per female and a 50:50 sex ratio (Burgner et al, 1969; Willette, 1991)

Appendix Table 11. Flows measured at transect 1 below falls for the 30 January 1992 survey of Twin Lakes Creek.

dist. (m)	depth (m)	vel. (m/s)	flow (m^2/s)
0.30	0.00	0.00	0.00
0.30	0.23	0.00	0.00
0.30	0.27	0.00	0.00
0.30	0.30	0.00	0.00
0.30	0.44	0.00	0.00
0.30	0.41	0.00	0.00
0.30	0.50	0.00	0.00
0.30	0.58	0.00	0.00
0.30	0.56	0.00	0.00
0.30	0.62	0.00	0.00
0.30	0.69	0.00	0.00
0.30	0.73	0.00	0.00
0.30	0.73	0.00	0.00
0.30	0.76	0.00	0.00
0.30	0.76	0.00	0.00
0.30	0.82	0.00	0.00
0.30	0.79	0.03	0.01
0.30	0.85	0.05	0.01
0.30	0.82	0.08	0.02
0.30	0.73	0.20	0.04
0.30	0.67	0.09	0.02
0.30	1.01	0.20	0.06
0.30	0.88	0.18	0.05
0.30	0.85	0.34	0.09
0.30	0.88	0.37	0.10
0.30	0.85	0.55	0.14
0.30	0.76	0.61	0.14
0.30	0.73	0.44	0.10
0.30	0.64	0.46	0.09
0.30	0.55	0.37	0.06
0.30	0.46	0.30	0.04
0.30	0.38	0.23	0.03
0.30	0.32	0.18	0.02
0.30	0.26	0.20	0.02
0.30	0.27	0.12	0.01
0.30	0.23	0.05	0.00
		Total m^2/s	1.05

Appendix Table 12. Flows measured at transect 2 above falls for the 30 January 1992 survey of Twin Lakes Creek.

dist. (m)	depth (m)	vel. (m/s)	flow (m^2/s)
0.30	0.00	0.00	0.00
0.30	0.30	0.21	0.02
0.30	0.27	0.09	0.01
0.30	0.27	0.00	0.00
0.30	0.40	0.27	0.03
0.30	0.49	0.34	0.05
0.30	0.58	0.27	0.05
0.30	0.55	0.40	0.07
0.30	0.70	0.49	0.10
0.30	0.70	0.49	0.10
0.30	0.67	0.49	0.10
0.30	0.58	0.55	0.10
0.30	0.52	0.58	0.09
0.30	0.41	0.55	0.07
0.30	0.41	0.46	0.06
0.30	0.37	0.34	0.04
0.30	0.43	0.27	0.04
		Total m^2/s	0.92

Appendix Table 13. Flows measured at transect 3 above falls for the 30 January 1992 survey of Twin Lakes Creek.

dist. (m)	depth (m)	vel. (m/s)	flow (m^2/s)
0.30	0.15	0.09	0.00
0.30	0.15	0.15	0.01
0.30	0.18	0.27	0.02
0.30	0.18	0.30	0.02
0.30	0.21	0.30	0.02
0.30	0.15	0.46	0.02
0.30	0.15	0.49	0.02
0.30	0.21	0.46	0.03
0.30	0.24	0.52	0.04
0.30	0.30	0.40	0.04
0.30	0.27	0.40	0.03
0.30	0.24	0.49	0.04
0.30	0.24	0.55	0.04
0.30	0.27	0.55	0.05
0.30	0.32	0.30	0.03
0.30	0.40	0.37	0.04
		Total m^2/s	0.44

Appendix Table 14. Flows measured at transect 4 above falls for the 07 April 1992 survey of Twin Lakes Creek.

dist. (m)	depth (m)	vel. (m/s)	flow (m^2/s)
0.30	0.06	0.00	0.00
0.30	0.12	0.12	0.00
0.30	0.15	0.30	0.01
0.30	0.17	0.27	0.01
0.30	0.18	0.49	0.03
0.30	0.15	0.52	0.02
0.30	0.18	0.52	0.03
0.30	0.18	0.67	0.04
0.30	0.23	0.70	0.05
0.30	0.21	0.94	0.06
0.30	0.18	1.04	0.06
0.30	0.15	0.91	0.04
0.30	0.12	0.91	0.03
0.30	0.21	0.64	0.04
0.30	0.18	0.61	0.03
0.30	0.21	0.12	0.01
0.30	0.34	0.11	0.01
0.30	0.40	0.15	0.02
0.30	0.41	0.18	0.02
0.30	0.43	0.61	0.08
0.30	0.38	0.02	0.00
0.30	0.30	0.00	0.00
0.30	0.24	0.03	0.00
0.30	0.15	0.18	0.01
0.30	0.15	0.34	0.02
0.30	0.12	0.18	0.01
0.30	0.08	0.06	0.00
0.30	0.06	0.00	0.00
0.30	0.00	0.00	0.00
		Total m^2/s	0.65

Appendix Table 15. Flows measured at transect 5 above falls for the 07 April 1992 survey of Twin Lakes Creek.

dist. (m)	depth (m)	vel. (m/s)	flow (m^2/s)
0.30	0.09	0.03	0.00
0.30	0.23	0.06	0.00
0.30	0.21	0.06	0.00
0.30	0.18	0.06	0.00
0.30	0.21	0.14	0.01
0.30	0.30	0.03	0.00
0.30	0.34	0.00	0.00
0.30	0.40	0.00	0.00
0.30	0.43	0.09	0.01
0.30	0.52	0.05	0.01
0.30	0.55	0.24	0.04
0.30	0.55	0.27	0.05
0.30	0.55	0.46	0.08
0.30	0.49	0.43	0.06
0.30	0.46	0.46	0.06
0.30	0.35	0.40	0.04
0.30	0.27	0.44	0.04
0.30	0.24	0.37	0.03
0.30	0.20	0.27	0.02
0.30	0.23	0.23	0.02
0.30	0.20	0.23	0.01
0.30	0.15	0.14	0.01
0.30	0.11	0.06	0.00
0.30	0.02	0.00	0.00
		Total m^2/s	0.49

Appendix Table 16. Flows measured at transect 6 above falls for the 07 April 1992 survey of Twin Lakes Creek.

dist. (m)	depth (m)	vel. (m/s)	flow (m^2/s)
0.30	0.02	0.00	0.00
0.30	0.06	0.21	0.00
0.30	0.12	0.32	0.01
0.30	0.12	0.27	0.01
0.30	0.15	0.15	0.01
0.30	0.21	0.34	0.02
0.30	0.24	0.37	0.03
0.30	0.30	0.43	0.04
0.30	0.30	0.52	0.05
0.30	0.30	0.58	0.05
0.30	0.27	0.58	0.05
0.30	0.23	0.52	0.04
0.30	0.21	0.46	0.03
0.30	0.15	0.46	0.02
0.30	0.12	0.32	0.01
0.30	0.12	0.12	0.00
0.30	0.06	0.03	0.00
0.30	0.00	0.00	0.00
		Total m^2/s	0.38

Appendix Table 17. **Summary of spawning area parameters, calculations of useable spawning area and pink salmon spawning capacity for 30 January, 07 April 1992 surveys of Twin Lakes Creek.**

Length (m)	Width (m)	Flow (m/s)	Depth (m)	Slope (%)	Useable Area (%) \a	Useable Area (m^2)	Spawning Capacity \b
36.0	6.1	0.7	0.3	-	60	132	132
28.7	6.1	0.6	0.6	5	60	105	105
20.4	4.6	0.8	0.3	-	40	37	37
31.7	4.6	0.5	0.5	4	25	36	36
46.6	5.5	0.8	0.3	5	35	90	90
39.6	5.5	0.7	0.2	-	25	54	54
40.8	6.1	0.7	0.3	-	30	75	75
81.7	5.5	1.0	0.3	-	40	179	179
67.7	6.7	0.5	0.5	-	70	318	318
72.2	5.5	0.9	0.3	3.5	90	357	357
106.1	6.7	0.2	0.3	4	90	640	640
41.8	4.6	0.3	0.2	-	95	181	181
116.4	3.0	0.6	0.3	-	95	337	337
42.4	7.3	0.5	2.3	-	90	279	279
57.6	8.5	0.6	0.8	3.5	100	492	492
89.6	5.2	0.2	0.3	3	90	418	418
77.7	5.2	0.5	0.2	-	80	322	322
89.3	9.1	0.3	0.2	3	70	572	572
75.6	9.1	0.7	0.2	-	75	518	518
93.0	9.1	0.7	0.2	2.5	50	425	425
247.2	6.7	1.1	0.3	4	40	663	663
67.4	4.3	0.3	0.5	-	65	187	187
75.6	7.9	0.9	0.2	-	75	449	449
79.6	3.7	1.0	0.2	4	85	247	247
131.7	9.1	0.5	0.2	-	80	963	963
132.0	7.0	0.4	0.5	-	80	740	740
67.4	11.3	0.4	0.3	-	65	494	494
70.4	9.1	0.3	0.3	3.5	80	515	515
173.7	4.6	0.9	0.3	-	70	556	556
109.1	4.6	1.1	0.1	-	50	249	249
109.1	5.5	0.9	0.2	1	15	90	90
171.9	6.4	0.4	0.2	1.5	60	660	660
56.4	3.0	1.2	0.3	4	10	17	17
45.4	9.1	0.3	0.2	4	65	270	270
79.9	10.7	0.2	0.2	2.5	80	682	682
93.6	7.6	0.8	0.2	2	60	428	428
40.5	4.0	0.2	0.2	3.5	50	80	80
71.0	6.1	0.3	0.2	-	5	22	22
42.4	4.3	0.0	ERR	-	65	118	118
146.0	1.5	0.1	0.1	4	45	100	100
103.3	4.6	0.3	0.2	-	60	283	283
102.1	7.0	0.2	0.3	4	65	465	465
71.3	4.6	0.4	0.2	-	70	228	228
98.5	4.6	0.3	0.2	5	60	270	270
87.5	4.6	0.2	0.5	4.5	90	360	360
94.5	5.8	0.2	0.2	-	90	492	492
36.6	4.6	0.3	0.3	4.5	80	134	134
195.1	7.6	0.3	0.2	2.5	90	1,338	1,338
61.0	3.7	0.2	0.2	4.5	90	201	201
141.4	5.5	0.1	0.2	-	85	660	660
44.5	4.6	0.3	0.2	6	90	183	183
91.4	4.6	0.2	0.2	-	90	376	376
34.1	4.9	0.4	0.1	4.5	10	17	17
81.4	4.9	0.2	0.1	4.5	70	278	278
129.8	7.6	0.2	0.2	-	90	890	890
161.5	4.6	0.0	0.0	-	80	591	591
Above barrier totals:						19,863	19,863

\a useable spawning area was defined as flows of ~0.5 m/sec, water depth of 0.3-0.5m, gravel size of 6-150mm with <25% by volume of the gravel ≤6mm, and minimal compactness (Chambers et al. 1955).

\b based on optimum spawning density of 2.0 m^2 per female and a 50:50 sex ratio (Burgner et al, 1969; Willette 1991).

Appendix Table 18. Summary of spawning area parameters, calculations of useable spawning area and pink salmon spawning capacity for 30 July 1978 and 14 July 1991 surveys of Waterfall Creek.

Length (m)	Width (m)	Flow (m/s)	Depth (m)	Slope (%)	Useable Area (%) \a	Useable Area (m^2)	Spawning Capacity \b
91.4	7.6	nd	nd	nd	0	0	0
19.8	4.9	nd	nd	nd	100	97	97
152.4	9.1	nd	nd	nd	0	0	0
91.4	10.7	nd	nd	nd	0	0	0
155.4	15.2	nd	nd	nd	90	2,132	2,132
155.4	16.8	nd	nd	nd	96	2,502	2,502
155.4	15.8	nd	nd	nd	100	2,464	2,464
155.4	14.3	nd	nd	nd	100	2,227	2,227
76.2	19.8	nd	nd	nd	100	1,510	1,510
45.7	6.1	nd	nd	nd	100	279	279
45.7	7.9	nd	nd	nd	100	362	362
155.4	21.0	nd	nd	nd	80	2,615	2,615
91.4	17.7	nd	nd	nd	95	1,536	1,536
310.9	12.2	nd	nd	nd	0	0	0
121.9	10.4	nd	nd	nd	100	1,263	1,263
277.4	16.8	nd	nd	nd	0	0	0
Above 7.9m barrier totals:						16,986	16,986
106.7	10.7	nd	nd	nd	0	0	0
45.7	14.9	nd	nd	nd	100	683	683
121.9	9.1	nd	nd	nd	98	1,093	1,093
61.0	7.9	nd	nd	nd	10	48	48
114.3	7.3	nd	nd	nd	10	84	84
53.3	7.3	nd	nd	nd	0	0	0
Above 1.5m barrier, below 7.9m barrier totals:						1,907	1,907
Total above all barriers:						18,894	18,894
46.9	14.3	nd	nd	nd	20	134	134
38.7	18.3	nd	nd	nd	60	425	425
30.5	21.9	nd	nd	nd	70	468	468
30.5	14.9	nd	nd	nd	35	159	159
30.5	5.5	nd	nd	nd	10	17	17
30.5	14.3	nd	nd	nd	20	87	87
30.5	15.2	nd	nd	nd	55	255	255
Below 1.5m barrier totals (all barriers):						1,546	1,546
Below third barrier totals:						3,454	3,454

\a survey conducted by Blackett (1980); useable spawning area parameters not defined except, useable spawning area for survey below 1.5m barrier was defined as water depth of 0.3-0.5m, gravel size of 6-150mm with <25% by volume of the gravel≤6mm, and minimal compactness.

\b based on optimum spawning density of 2.0 m^2 per female and a 50:50 sex ratio (Burgner et al, 1969; Willette 1991).

Appendix Table 19. Escapement counts for Waterfall Creek 1968 - 1992.

	Year	Count \a	Above Third Barrier	Type Survey
	1968	500	0	foot
	1969	nd	0	foot
	1970	2,000	0	aerial
	1971	nd	0	foot
	1972	nd	0	aerial
	1973	nd	0	foot
	1974	6	0	foot
	1975	7,000	0	foot
	1976	5,003	0	foot
	1977	nd	0	nd
	1978	3,580	0	nd
	1979	7,650	0	nd
	1980	18,000	0	nd
	1981	61,193	1,100	foot
	1982	47,500	0	weir
	1983	21,700	1,600	weir
	1984	40,000	10,400	weir
	1985	119,200	19,800	weir
	1986	48,400	nd	weir
	1987	29,100	nd	weir
	1988	49,680	nd	aerial
	1989	117,200	19,500	weir
	1990	47,000	3,100	weir
	1991	115,000	16,000	weir
	1992	43,000	6,000	weir
Mean:		39,136	3,523	
Mean (68-80):		5,467	0	
Mean (81-92):		61,581	8,611	

\a First two barriers bypassed with fish passes in 1979; third barrier bypassed in 1980.