Exxon Valdez Oil Spill
Restoration Project Annual Report

Tributary Restoration and Development Project: Port Dick Creek, Lower Cook Inlet, Alaska

Restoration Project 96139A2
Annual Report

This annual report has been prepared for peer review as part of the *Exxon Valdez* Oil Spill Trustee Council restoration program for the purpose of assessing project progress. Peer review comments have not been addressed in this annual report.

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Alaska Department of Fish and Game
Commercial Fisheries Management and Development Division
3298 Douglas Place
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The Port Dick Creek Tributary Restoration and Development Project:
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Study History: The Port Dick Creek tributary restoration and development project was initiated under the restoration surveys (Restoration Study Number 105) in FY/91 and FY/92 which resulted in the selection of Port Dick Creek for further instream restoration work. A tributary restoration feasibility analysis was initiated at this site in 1991 and was continued through the spring of 1993. The tributary restoration project was initially approved for continued funding in FY/94 and FY/95; however, spending was placed on hold pending further review and discussion at the supplemental workshop held in Anchorage in January, 1995. A Detailed Project Description " Proposed Spawning Channel Construction Project Port Dick Creek, Lower Cook Inlet" (Restoration Project 95139), was submitted, and the project was subsequently approved by the Trustee Council in May, 1995. In June, 1996, two tributaries to Port Dick Creek were excavated to create an additional 2,500 m^2 of spawning habitat. A comprehensive study of the newly created spawning tributaries was initiated after the spawning tributaries were excavated. This is the first annual report to be submitted.

Abstract: We completed preliminary monitoring of hydrologic parameters in 1996 in preparation for the subsequent design and construction of two spawning tributaries to Port Dick Creek, which is located in the West Arm of Port Dick, Gulf of Alaska, Alaska. The project continued in 1996 with the design of the spawning tributaries, preliminary surveying, tributary excavation and installation of monitoring equipment. The biologic, hydrologic and sedimentologic monitoring components of the project were initiated in 1996 to support research into creating stable (long-term) spawning habitat in the Gulf of Alaska. Some preliminary results of the monitoring program are available, and data continues to be collected and reduced by the project team. Data analyses in 1997 are expected to initiate a coupled hydrologic and sedimentologic model, while project review will include egg-to-fry survival rates, spawning tributary habitat evaluation and an assessment of the original spawning tributary design.

Key Words: Alluvial, chum salmon, *Exxon Valdez* oil spill, groundwater, habitat, instream, *Oncorhynchus gorbuscha*, *Oncorhynchus keta*, pink salmon, Port Dick, restoration, sedimentation, spawning channel.

Project Data: Data collected to support the spawning tributary design includes water level and temperature data (*format*: text files, *custodian*: Mark Dickson, 3298 Douglas Place, Homer, Alaska 99603-8027, E-Mail; MarkD@fishgame.state.ak.us). Other monitored data initiated late in 1996 will be addressed in the 1997 report.

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INTRODUCTION

In 1991, the Alaska Department of Fish and Game (ADF&G), Commercial Fisheries Management and Development (CFM&D) Division conducted restoration surveys on the outer coast of the Kenai Peninsula to identify pink and chum salmon spawning systems that would benefit from instream habitat restoration. The intent of the subsequent proposed restoration project was to mitigate reduced or lost services to the pink and chum salmon resources and commercial fishery as a result of the *Exxon Valdez* Oil Spill (EVOS). Although several systems were investigated, Port Dick Head End Creek (located within Kachemak Bay State Wilderness Park in the West Arm of Port Dick Bay) was chosen because it is considered one of the more important pink and chum salmon production streams in the Lower Cook Inlet (LCI) area (Figure 1).

The commercial catch of the native Port Dick Bay Pink and Chum Salmon has been declining in recent years (Figure 2). This decrement has been noticed in Island Creek, for example, which has only met the set escapement goal once since 1989 (Port Dick Bay, Figure 3). Port Dick Creek, another spawning stream feeding Port Dick Bay, was moderately to heavily oiled by the EVOS in 1989 (ADF&G, 1993). Although no damage assessment surveys were funded or conducted in the outer Gulf Coastal areas of the Lower Kenai Peninsula, studies in the Prince William Sound area indicated differences in pink salmon egg mortality as well as growth in the early marine life stage (Willette 1994). Port Dick Creek has two intermittent tributaries assigned as the primary tributary and the smaller secondary tributary. Both tributaries enter into Port Dick Creek near the higher high tide zone (Figure 4). The primary tributary selected for restoration had an intermittent surface water flow and intersected Port Dick Creek near the high tide line.

Since 1991, observations by ADF&G personnel reveals that during the frost free season the tributary generally had enough surface water to attract spawning adult salmon. However, during the winter months of November through March the surface water withdrew to 10-80 cm below streambed level.

The water source plays a role in this phenomenon, and the main water source is separate from Port Dick Creek. The source water includes a small lake of less than 4 ha. which is located at the 300 m elevation. Monthly winter surveys since 1991 have shown that the lake outflow is continuous. Prior to the 1964 earthquake, the primary tributary had a stable surface water flow which successfully produced salmon (Personal. Communicataion. Homer resident, Val McLay). Subsequently, the lower 150 m of the primary tributary was uplifted causing a typically dry streambed of rock and cobble to 8.75 cm in diameter. This situation provided an opportunity to restore spawning beds within the primary tributary system.

The nearby secondary tributary branches from the primary tributary approximately 350 m upstream from the confluence with Port Dick Creek, then parallels the primary tributary, connecting to Port Dick Creek near the higher tide level and upstream of the primary tributary (Figure 4). The secondary tributary had intermittent surface water flow due to fluctuations in its groundwater source. During the winter months water at this site withdraws 10-30 cm below the streambed surface as measured near its confluence with Port Dick Creek.

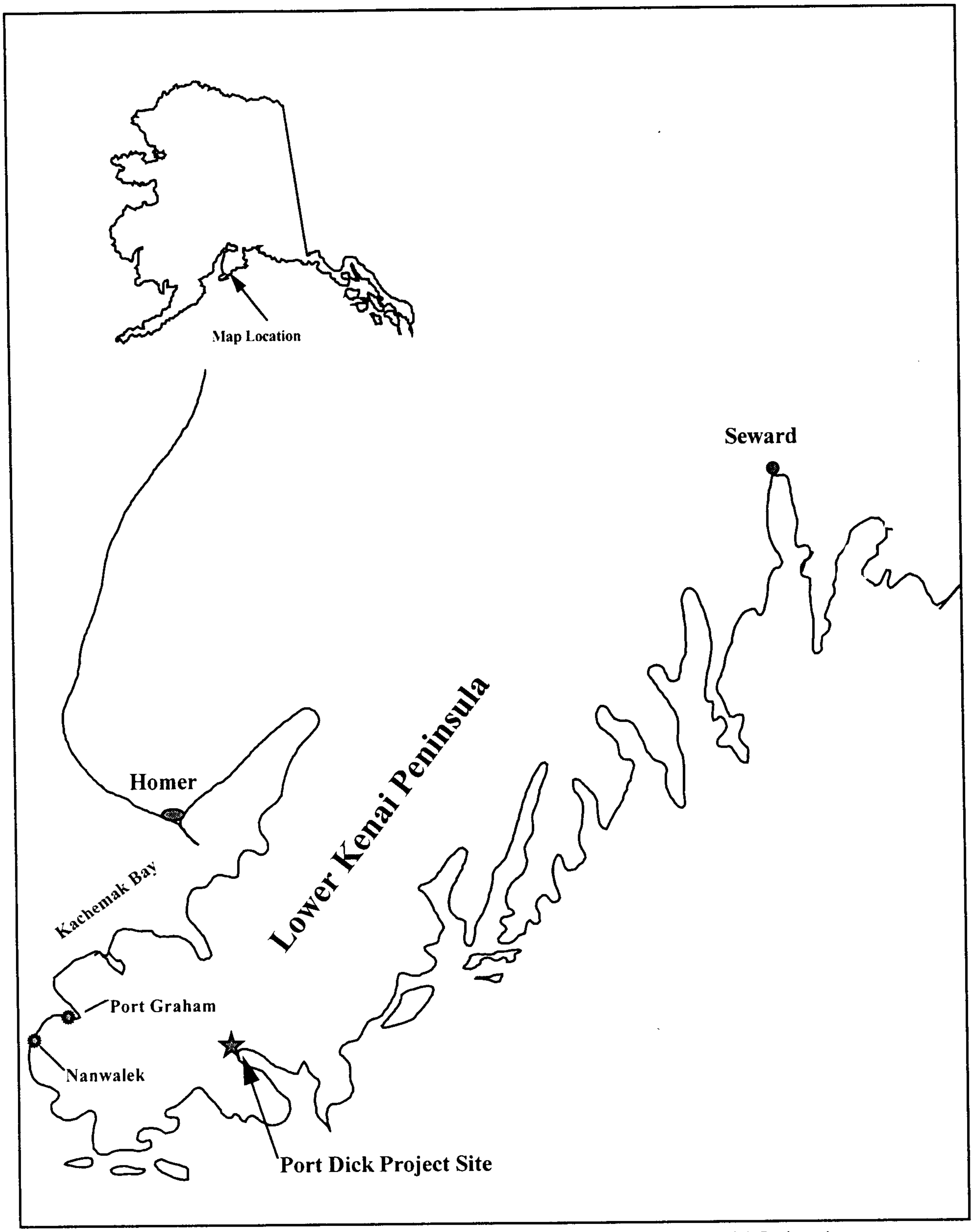


Figure 1 . Map of the outer gulf coast of the Kenai Peniunsula showing the location Port Dick Project site.

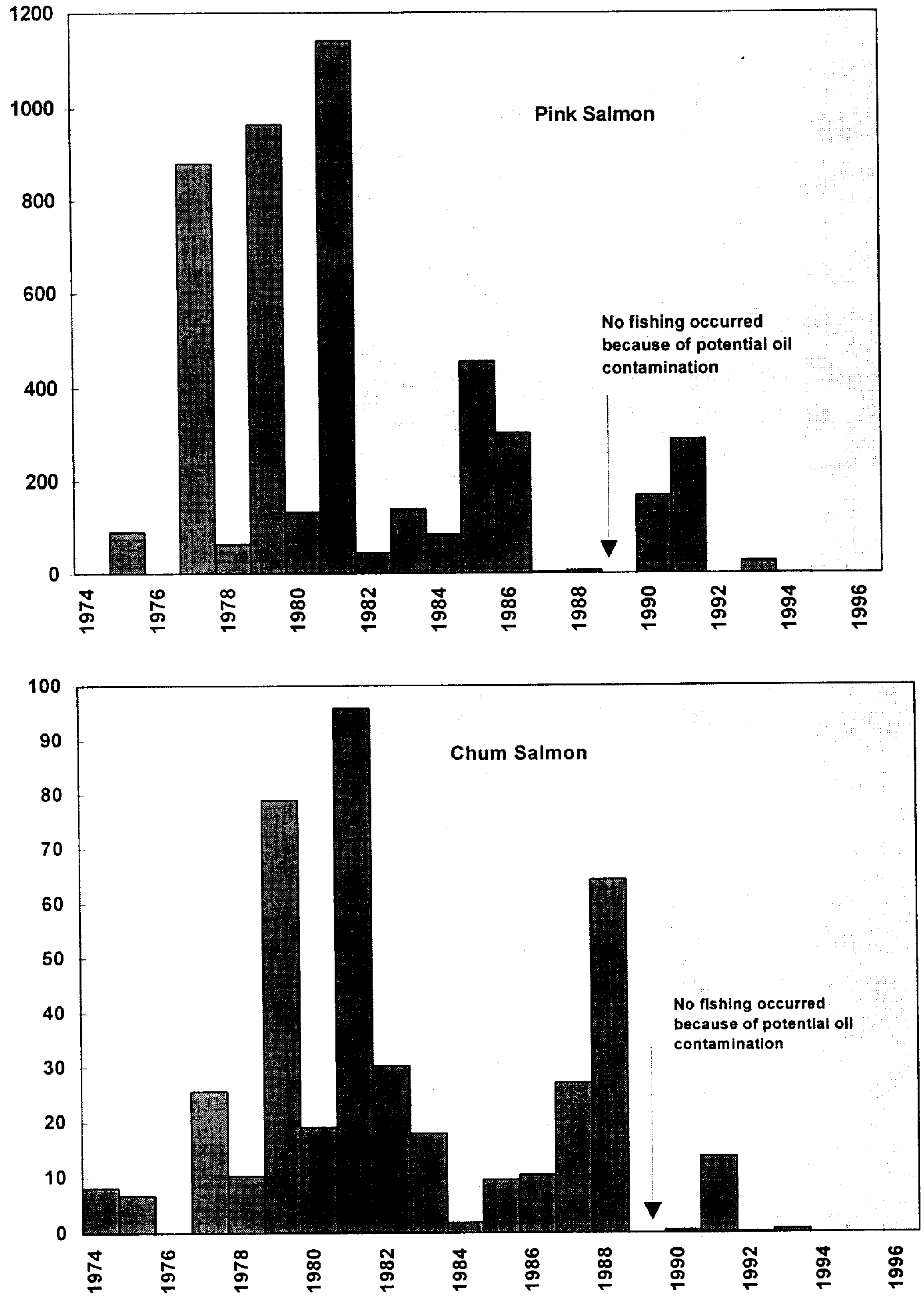


Figure 2. Port Dick Bay Pink and Chum salmon commercial harvest, 1974-1996.

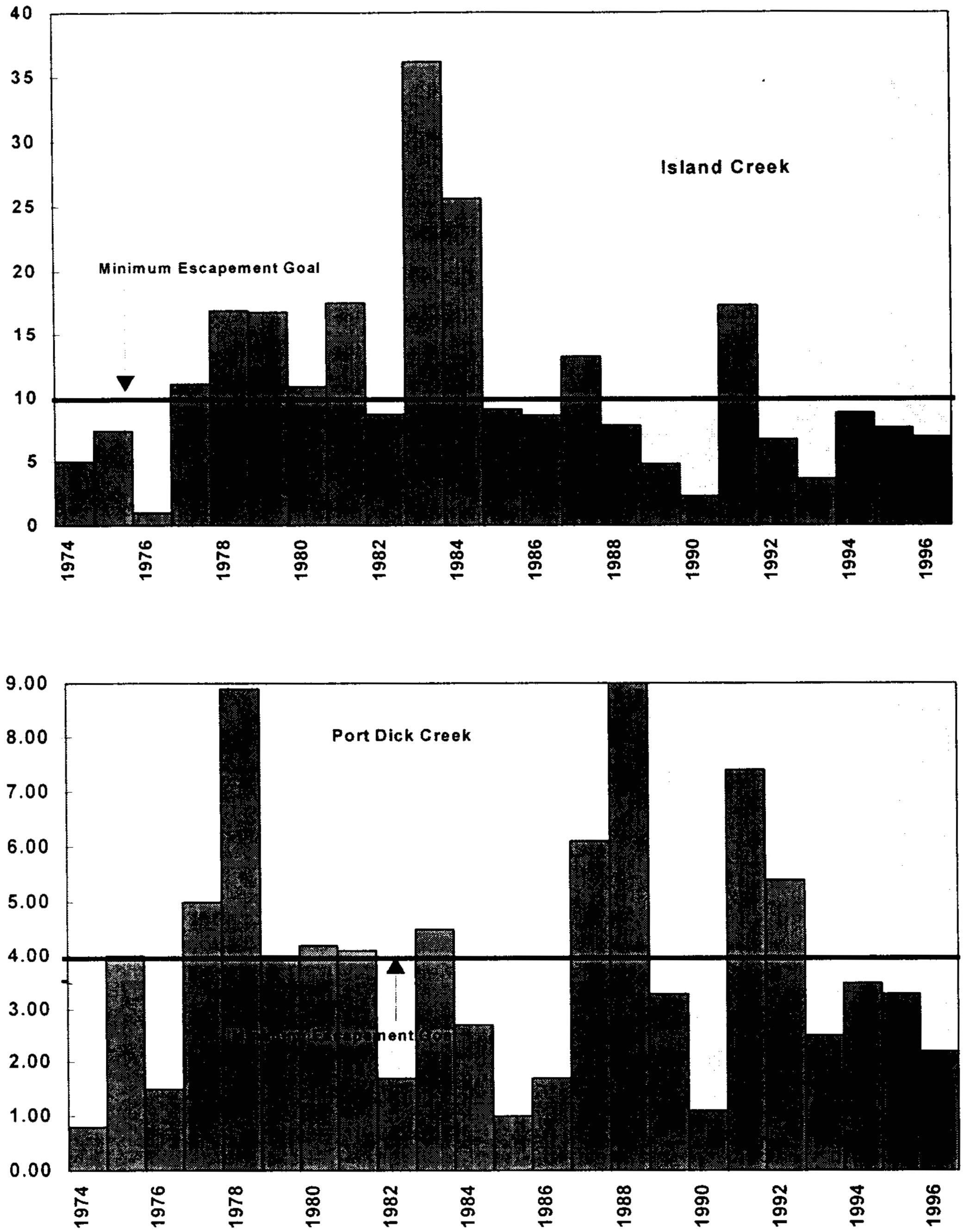


Figure 3. Chum salmon escapements for Port Dick and Island Creek, 1974-1996. Island Creek is located in Port Dick Bay approximately 7 miles SE of Port Dick Creek.

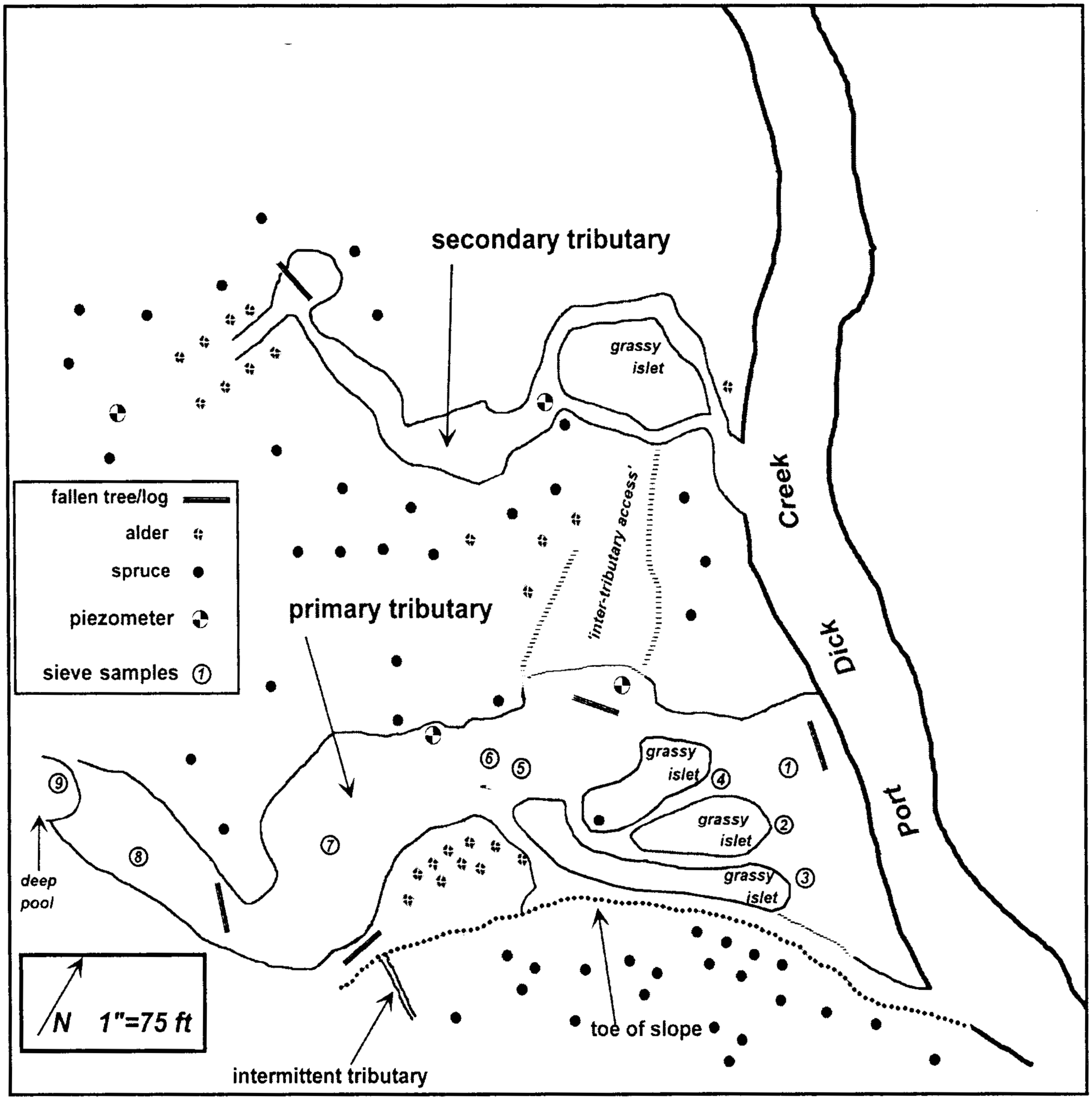


Figure 4. Pre-excavation map,

Unstable spawning habitat conditions are believed to be a limiting factor for poor egg to fry survival in adjacent Port Dick Creek. Such conditions include wide fluctuations in water levels, extreme flooding effects, inadequate water flow and freeze out conditions (ADF&G 1992/1993). Extreme flooding and scouring events occurred at Port Dick Creek in August of 1993 altering up to 150 m of salmon spawning habitat. As a result, the subsequent 1995 adult pink salmon return was estimated below minimum escapement levels (Wes Bucher ADF&G, oral comm).

Feasibility analyses studies were conducted during the winters of 1991-92 through 1995-96 to determine if excavation of the primary and secondary tributaries would increase stable spawning habitat for the pink and chum salmon stocks of Port Dick Creek. If stable prime spawning habitat could be restored within the two tributaries, egg-fry survival rates of up to 55% and 95% could be expected for chum and pink salmon, respectively. This compares to only a 1.3% and 0.2% survival expected in the less stable main stem Port Dick Creek for chum and pink salmon respectively (Lister, Marshall & Hickey, 1980).

A restoration plan and excavation design were developed from collected data and in June, 1996, over 3,000 m^3 of material was removed from the two tributaries that created approximately 2,100 m^2 of additional spawning habitat. In July and August, approximately 572 pink and 300 chum salmon from Port Dick Creek volitionally colonized the tributaries and spawned. This supplemental production calculates to an additional projected adult contribution of over 11,600 adults beginning in 1998. Juvenile and adult Dolly Varden trout and juvenile coho salmon have also been observed utilizing the restored habitat as rearing habitat.

OBJECTIVES

The following objectives represent work accomplished in fiscal year 1996:

1. Measure groundwater level, temperature and other tributary design parameters prior to design phase.
2. Complete permit requirements and Environmental Assessment.
3. Develop design of salmon spawning channels for tributary restoration.
4. Install pre-excavation survey monuments to support the streambed stability study.
4. Excavate and build the spawning tributaries.
5. Install post excavation monitoring materials, equipment and instruments.
5. Monitor adult salmon colonization into the restored tributaries.
6. Initiate project evaluation phase by estimating adult colonization into the restored tributaries. Initiate egg-fry survival and streambed stability evaluations.

METHODS

Permit Requirements, Environmental Assessment and Public Involvement

Several state and Federal permits are required before a project of this type and size can be undertaken. A state required Coastal Management Project Questionnaire and Certification Statement was completed in July of 1995 for project consistency with the Alaska Coastal Management Program. Refer to appendix A for required permits and issuing agencies.

Scoping Meeting

A meeting was held in Anchorage at the ADF&G Office, 333 Raspberry Road on June 19, 1995 to determine the scope of the project. ADF&G (Commercial Fisheries Management and Development Division) communicated with the U.S. Forest Service and ADF&G (Habitat and Restoration Division). The scoping meeting was held to present the proposed project to the appropriate agencies and to propose methods to publicize the project. The following are important results of the meeting:

The project was reviewed by the EVOS Trustee Council (TC) in April 1995 which included members from the State of Alaska (Attorney General, Commissioners of ADF&G and Alaska Department of Environmental Conservation), Federal members of Departments of the Interior, Agriculture and the National Oceanographic and Atmospheric Administration (NOAA). As part of the review process, the EVOS Trustee Council Public Advisory Group (PAG) reviewed this salmon instream habitat and restoration project in 1994 and 1995 prior to preparing recommendations to the Trustee Council.

Alaska statute Sec 41.21.142 allows the Department of Fish and Game to engage in stream rehabilitation, enhancement and development activities within Kachemak Bay State Wilderness Park (ADNR 1994).

Environmental Assessment

An Environmental Assessment (EA) was required under the, National Environmental Protection Act (NEPA), before the restoration project would be approved. The U.S. Forest Service is the lead federal agency assigned to review the EA and to and to issue a "Finding Of No Significant Impact" based on the analysis. The ADF&G was the cooperating state agency writing the EA.

The EA listed two alternatives, the proposed action (excavate up to 1,200 m^3 of material in two tributaries to create additional stable spawning habitat) and alternative B, no action. In addition to the proposed action, 8 key issues were identified which required mitigating efforts: Refer to Appendix B for key issues verses the alternatives.

Design of Salmon Spawning Channels

The tributary system consisted of coarse gravel at the base of a small watershed. The tributary excavation would create a free water surface and additional spawning grounds for Pink and

Chum Salmon. The flood-scoured dry streambed surface was mapped prior to excavation shown in (Figure 4) to begin the process of designing the spawning tributaries.

The principal data collected to support the spawning tributary design phase included streambed elevations, streambed sediment samples, water level hydrographs, groundwater temperature measurements, streambed morphology measurements, and angle of repose data of streambed sediments. Some effects of flooding were observed, and the positions of vegetation vital for increasing bank stability and providing shade were also noted.

Determination of Alluvial Slope and Discharge Capacity

The alluvial slope for the primary tributary area was determined initially by ADF&G using a direct surface water measurement (Oct., 1994). Many elevation measurements had confirmed that 0.007 was a good approximate value for maximum slope of the primary tributary channel prior to excavation, as well as for Port Dick Creek at the base of the tributaries. The secondary tributary had a more gradual slope estimated to be approximately 0.005.

Surface water discharge entering the tributary system played a key role in the spawning tributary design. Discharge data included direct measurements by ADF&G using a current meter (0.7 m^3/s, below bankfull discharge) and a calculation based on measurements of bankfull ice formation and stream cross section. It was estimated that the bankfull discharge entering the gravel alluvium provided groundwater to both the primary and secondary tributaries at approximately 1.1 m^3/s.

The groundwater system is also fed by water from Port Dick Creek during low tributary flows, which has a larger effect on the secondary tributary due to its closer proximity to Port Dick Creek. One half of the design bankfull discharge for the secondary tributary was assumed to come from this additional source, since the secondary tributary is fed exclusively by groundwater most of the time.

Braided Versus Meandering Stream Systems

One of the initial concerns in restoring the tributaries was to determine whether the stream system would be braided or meandering, given the alluvium was excavated with no change in slope. Because the slope is more gradual in the secondary tributary, the primary tributary was examined for this determination.

Preliminary measurements of the primary tributary were taken to determine distances between gravel depressions (or pools during high water) imprinted in the surface gravel. Estimates of the radius of curvature of bends in the dry gravel streambed were also obtained. An empirical relationship had been developed with this type of data based on many alluvial stream and river systems that related the median streambed gravel size and discharge to braided or meandering systems (Henderson, 1963);

$$S = 0.06\left[\frac{d}{3.3}\right]^{1.14}\left[\frac{Q}{0.028}\right]^{-0.44},$$

where d is the median gravel size in m and Q is the discharge in m^3/s. Table 1 shows the average median diameter from the grain size analyses for samples 1 to 8 (Figure 4) is approximately 11 mm.

Table 1. Grain Size Analyses Results

Sample #	Description	Median Size	D_{75}
1	Mouth, Primary Trib.	14.0 mm	6.9 mm
2	(")	0.8	0.5
3	(")	25-50+	25-50+
4	(")	12.4	7.7
5	35 m upstream of 4	12.6	11.0
6	5 m upstream of 5	4.5	2.4
7	27 m upstream of 6	2.3	1.1
8	27 m upstream of 7	27.0	15.0
9	22 m upstream of 8	22.0	13.8
*10	16 m upstream of 9	5.3	2.2
*11	14 m upstream of 10	1.6	1.2
12	34 m upstream of 11	9.0	5.0
13	60 m upstream of 12	25-50+	25-50+
14	(", channel middle)	24.5	17.5

*pool sediments, i.e. lower energy setting

Using a discharge of 1.1 m^3/s a value of 0.003 was obtained, indicating that since the actual slope is 0.007 there may be a tendency for braided conditions (Henderson, 1966). This means the formation of bars or islets would be probable by simply excavating a straight channel with no change in slope.

Therefore efforts at reducing the slope were desirable for the tributaries. Introducing a meander to decrease the channel slope and the use of drop structures such as a riffle or rapids area were both used in the tributary design.

Determination of River Geometry.

Many researchers have noted relationships between meander curvature, bankfull width, discharge, slope and meander distances. These empirical relationships help determine various tributary design limitations.

For example, stream width B has been found to be a function of the wavelength L of stream meanders expressed as the ratio $\frac{L}{B} = 7$ to 11 (Costa et al., 1995). This relation has been found to be broadly applicable to streams and rivers of varying widths and streambed sediment character.

Approximate values of meander wavelength measured in the dry streambeds were 40 m and 60 m for the secondary and primary tributaries, respectively. A good range of streambed widths was then calculated based on the wavelengths. The stream tributary width ranges were B= 5 to 9 m wide for the Primary Tributary, and B= 3 to 6 m wide for the Secondary Tributary.

Another parameter that affects streambed slope and stream energy slope is the radius of curvature (r_c) of a stream meander. The distance r_c defines how tight or stretched out the meanders are in a meandering stream system. The following empirical relationship has been found to be true across the same data set used for the previous relationship:

$\frac{r_c}{B} = 2$ to 3 (Costa et al., 1995). Using the range of stream widths calculated previously, the primary tributary would be expected to have an r_c of 11 to 25 m, and the secondary tributary 7 to 18 m.

Figure 4, confirms the general geometry for the secondary tributary, in that the secondary tributary has an r_c of approximately 18 m for both possible measurements. This was difficult to verify in the primary tributary, however, due to a lack of similar surface features.

Tributary Design

One of the most important data sets used in the tributary design were groundwater level measurements. Initial groundwater measurements were taken in the winter of 1991/92 from peizometers inserted into the streambed at locations shown in Figure 4. Field trips were scheduled approximately every 4-6 weeks to measure the water level. Results from standpipes 1&2 are nearly identical and are shown in (Figure 5a). Budget restraints limited the measurements to a simple dipstick and standpipe device. Results from the winter of 1992/93 of the primary tributary, which were recorded with a remote data logger, is shown in Figure 5b. More detailed groundwater level data was collected in 1995-1996 at the head of the secondary tributary (Figure 6).

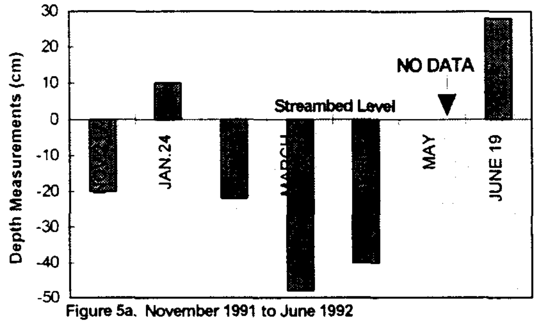


Figure 5a. November 1991 to June 1992

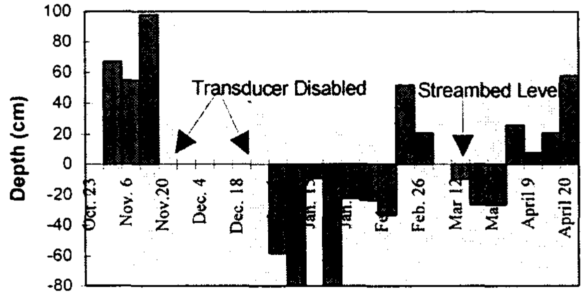


Figure 5b. October 1992- April 1993

Figure 5. Initial groundwater fluctuation results from the Port Dick Creek primary tributary site. The measurements for the Nov. 91-June 1992 were taken with a ruled dipstick during site visits. The measurements taken during the Oct. 92- April 1993 period were recorded with a battery operated remote data logger equipped with a pressure sensitive transducer.

It was noted that chum salmon prefer spawning gravel water depths of 0.2 to 0.5 m, whereas Pink salmon prefer to spawn in water depths of 0.3 to 1.0 m (Groot and Margolis, 1991). Assuming the gravel aquifer to have a high transmissivity, this dictated that the primary tributary be excavated to a depth of approximately 1.2 m at the upper piezometer and approximately 0.9 m below sediments at the pool represented by the lower piezometer. Surface water was always observed exiting the Primary Tributary at the terminal end, so that the excavation depth at that location was dictated by the streambed level of Port Dick Creek. The secondary tributary would then require approximately 0.8 m of excavation at the lower piezometer location, and approximately 1.1 m of excavation at the upper piezometer.

Another important factor taken into consideration was groundwater temperature. Groundwater temperature was monitored during a very cold period in 1995-1996 with little snow cover (Figure 7), which showed that at a given level beneath the bare streambed there was flowing groundwater during these periods. The temperature record also differentiates the surface water and groundwater sources to the piezometer, as evidenced by the high correlation between Figures 6 and 7.

Finally, water velocity must be considered in the design. Chum salmon prefer between 0.2 and 0.8 m/s for spawning (80%), although spawning has been observed in water velocities between 0 and 1.67 m/s (Groot and Margolis, 1991). The preferred spawning velocities for Pinks range from 0.30 to 1.4 m/s, with an average water velocity over the redds of 0.70 m/s (Groot and Margolis,1991). Pink salmon prefer more intragravel oxygen than Chum salmon, which is consistent with a higher velocity preference, whereas Chum salmon prefer spawning grounds with upwelling water, i.e. gaining streams (as is the case here).

There are several reasons for designing the tributaries using a maximum radius of curvature for both the primary and secondary tributaries. A maximum meander curvature minimized groundwater drainage during low flow periods, maximized spawning area, maximized secondary currents that tend to keep the tributaries clear of debris and minimized the slope to allow the groundwater time to recharge the surface water and maintain a desirable depth during low flows (and also to protect from damage due to heavy discharge). The main disadvantage was that a larger amount of excavated material would be generated.

The primary tributary could have a meander with a radius of curvature of approximately 25 m, which reduced the slope of the surface water to 0.005.

Calculations for bank stability and head loss from a riffle structure are presented in Appendix C. The calculations assumed a shear stress produced by clear, flowing water and a trapezoidal channel cross section. While these assumptions are certainly adequate for most of the year, flood conditions are another matter. Every effort was be made to incorporate bedrock outcrops or boulders into the primary tributary during construction at the most erosive areas of the tributary. Calculations of stable side slope that incorporate sediment transport would have required considerably more site-specific data, for example bed-load transport rates during significant discharge events to justify much improvement in the results.

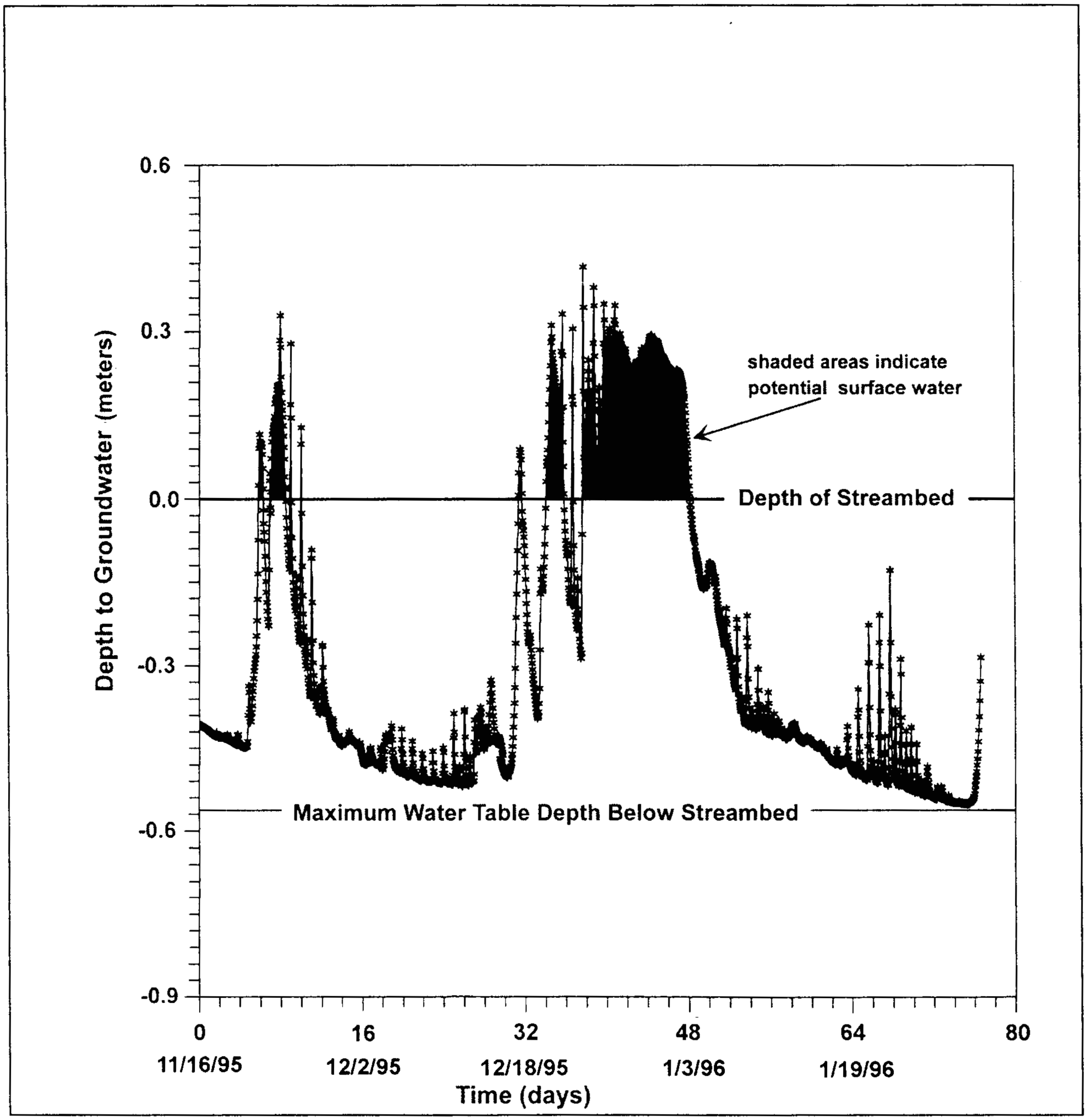


Figure 6. Secondary tributary water level hydrograph, upstream well.

Many practical design considerations were also identified. For example, cohesive sediments were used to help minimize the excavated area in the secondary tributary. The final decision of placement of the primary tributary ultimately accounted for the many vegetation features that were mapped with regard to resisting erosion and salmon habitat. In addition, the sloping tributary sides above bankfull discharge were adjusted to utilize existing root systems, boulders and bedrock to help stabilize the tributaries during flood stage.

Finally, a large seepage face boundary was needed at the upstream end of the primary tributary to help dissipate flood energy and stabilize the large amount of sediment upgradient of the site. A large chevron-shaped drop structure created from the largest boulders and underlain by approximately 10 feet of log footers is the upstream, or first riffle of this multiple-riffle drop structure. This first riffle was installed at the existing uplifted streambed level, whereas the last riffle in this seepage face was installed at the approximate pre-earthquake levels creating a 1.5 m seepage face over a horizontal distance of 10 m.

Broodstock Development and Adult Colonization

Methods to seed the newly restored spawning habitat with pink and chum salmon eggs have been developed. Three methods to fully seed the tributaries were available: 1) both tributaries could be colonized naturally or 2) natural colonization could be supplemented with fish cultural techniques such as egg-takes and green and eyed-egg plants and 3) the tributaries could be seeded fully through fish cultural techniques if no volitional colonization occurred.

If the tributaries were naturally colonized to maximum density, the only task required would be to develop an estimate of spawner abundance. If the tributaries needed to be fully or partially seeded through supplementation, then established fish cultural methods will be used. ADF&G technicians will capture adult pink and chum salmon in Port Dick Creek with seine and dip nets. The salmon will then be held in holding pens until sexually mature when the eggs would be striped and fertilized. When the fertilized eggs become water hardened, they will be planted into the streambed of the two tributaries with a water pump injection method. The number of eggs needed to supplement colonization would depend on the number of returning adults relative to established escapement goals. If Port Dick Creek pink and chum salmon escapement goals are not met then ADF&G management biologists would develop a salmon and egg removal schedule from Port Dick Creek. The removal schedule will be the maximum number of adults and eggs that can be removed from Port Dick Creek without jeopardizing native stock integrity. If escapement goals are met and there are adequate number of adults excess to the escapement goal, then the tributaries can be seeded to a density of 1 female per m^2, approximately 2,200 eggs/ m.

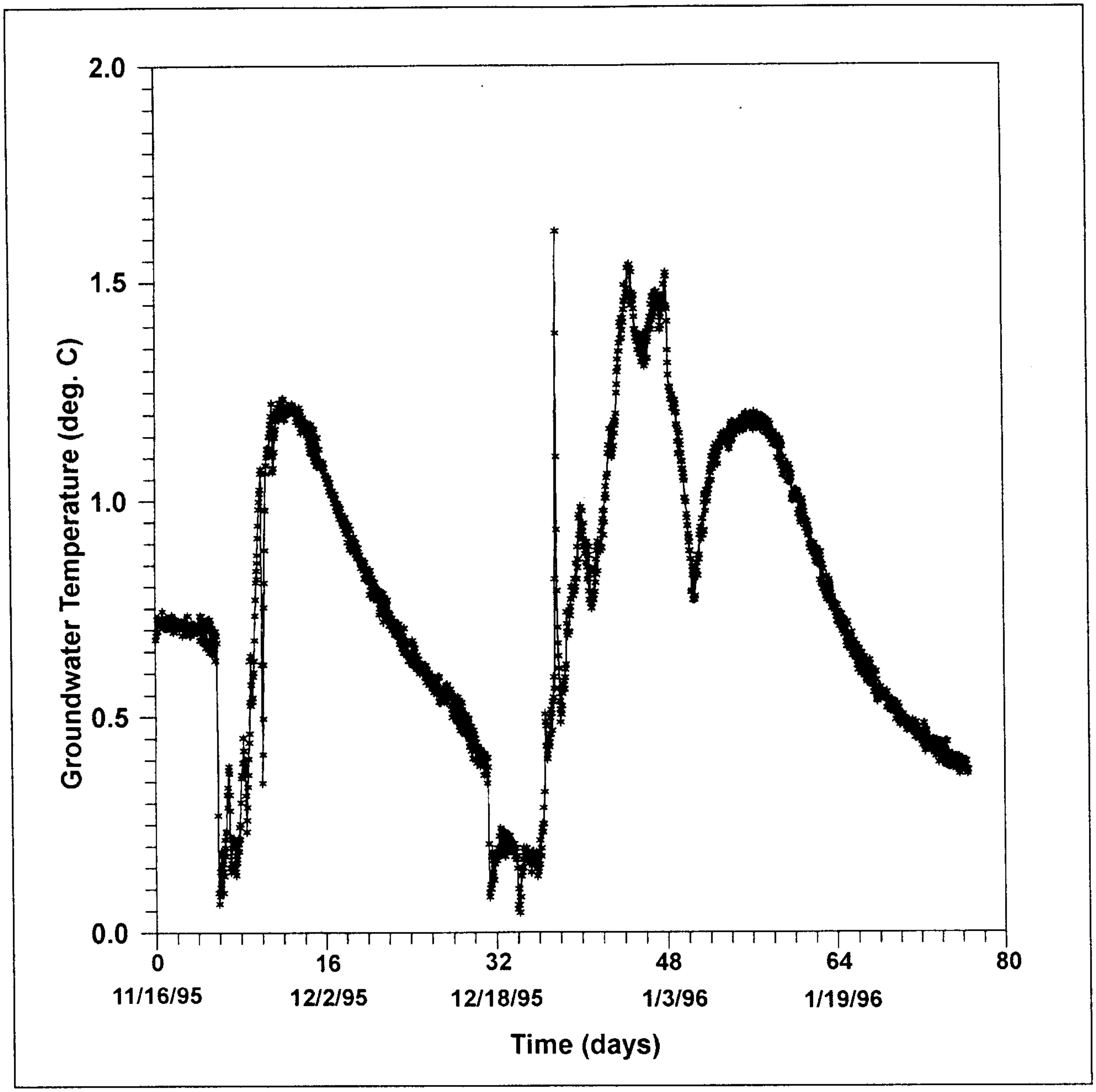


Figure 7. Secondary tributary channel groundwater temperature (depth~ 1.2 m).

Project Evaluation

Successful instream habitat restoration projects, like the Port Dick project, requires cautious planning and competent scientific evaluation. It is essential that all such projects be thoroughly documented and objectively evaluated so that we can learn from project performance to improve future efforts (Kondorf 1995 in G. Mathias Kondorf, Jennifer C. Vick and Timothy M. Ramirez. 1996).

Fisheries and Hydrologic Evaluation.

Adult spawning density, number of females, potential egg deposition and egg to fry survival rates will be calculated after the initial adult return and colonization.

Spawner abundance and density will be enumerated from periodic ground surveys. To standardize the escapement estimates, ground survey data from the tributaries will be generated into daily escapement estimates using stream life (number of days), live and dead count, the number of surveys and the time between surveys Yuen and Bucher (1993) Generally the return of chum salmon to Port Dick Creek occurs during the month of July, and the pink return occurs during the month of August.

To estimate egg to fry survival, seaward bound pink and chum fry will be trapped using an intertidal fry trap modeled after a systems developed by Quimby and Dudiak (1983). Fry traps will be installed at the downstream end of each tributary and all fry counted If the numbers are to great, however, a sub-sampling procedure will be used following methods developed by ADF&G biometricians and biologists. The sub-sampling method will include enumerating all fry during three 2-minute samples, and then multiplying by 10: (3) 2-minute samples x 10 = 60 minutes). Egg to fry survival will be estimated as the number of fry trapped divided by the average fecundity. Fecundities were obtained from fish culture work with pink and chum salmon during previous work at Port Dick Creek in 1979. A 2-person crew will travel to Port Dick Creek in early April, 1997 to establish living quaraters and the intertidal fry trap operations to enumerate emigrating salmon fry.

Influences of physical hydrologic parameters on spawning success will also be evaluated using long term hydrologic monitoring in addition to bedload transport monitoring. Figure 9 shows the general measurement locations and field arrangement of the hydrologic monitoring equipment.

The changing channel geometry after construction and sensitivity of salmon eggs to water level necessitated monitoring water levels after the spawning tributaries were excavated. This data is being collected using pressure transducers accurate to 0.01 ft of water within the pressure range expected at the site. The transducers measure pressure relative to atmospheric pressure so that atmospheric pressure effects need not be taken into account.

Water depth is a particularly important parameter during winter freezing conditions, though not easy to measure. A novel water level monitoring design is used in each tributary, which allows for an extended period of surface water level measurement (Figure 8). The pressure transducer cables were secured in such a way that their movement does not affect the depth of the transducer. Also, the elevation of the casing shown in Figure 8, must be periodically monitored as this will change throughout the year, and is a necessary component of determining the elevation of water levels measured with the transducers. This has been done using the total station.

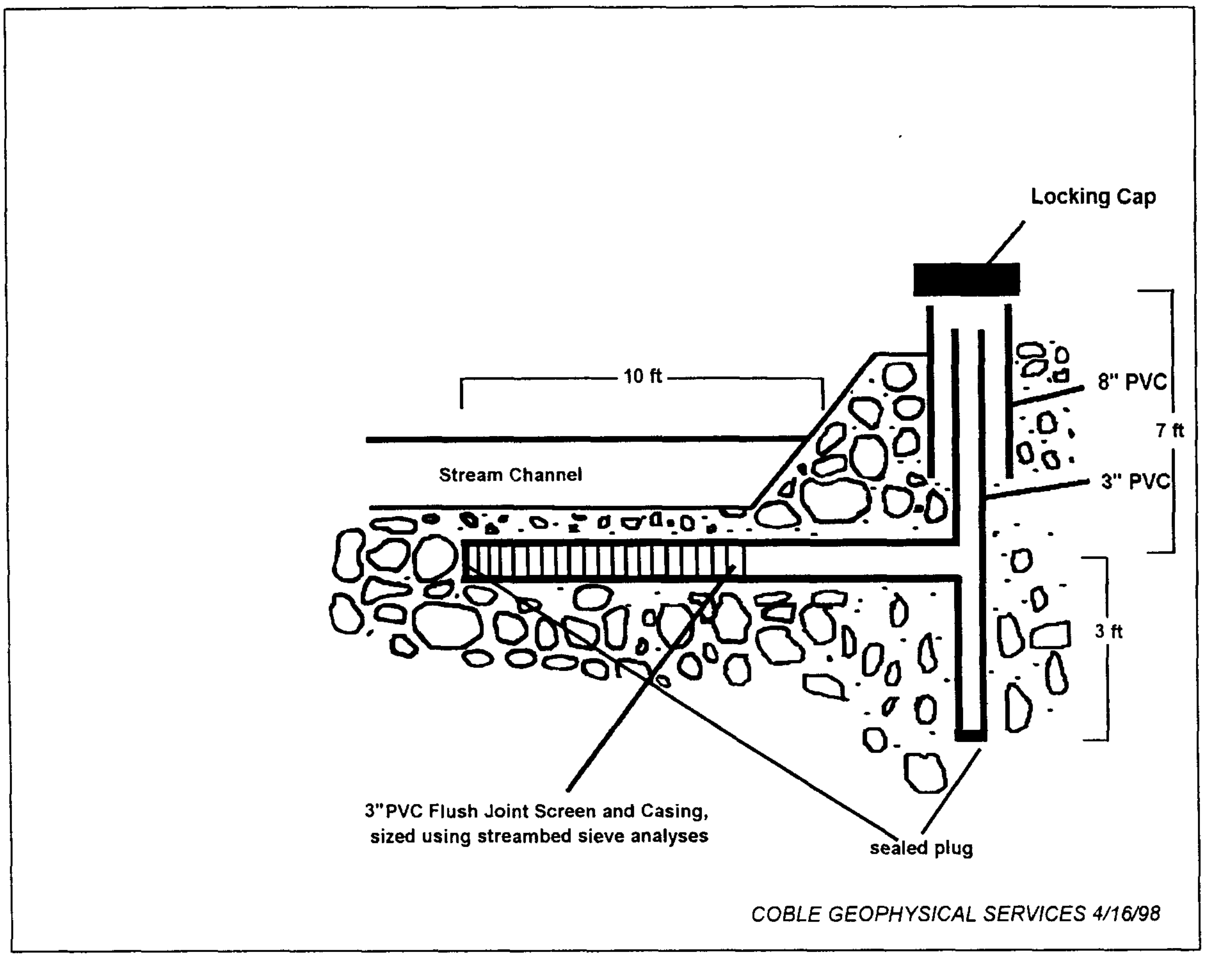


Figure 8. Water level monitoring station design.

Temperature is measured to an accuracy of 0.4 C. Temperature effects on salmon cited in the literature (e.g. Pauley, 1988; Wangaard, 1983) correlate fry survival rates to temperature using similar accuracy.

Temperature monitoring locations are shown in Figure 9. There are expected to be some temperature differences between the lower reaches of the spawning tributary and the upper reaches, particularly in summer and fall months. The variation of temperature with depth in the spawning tributary is not thought to be significant due to the turbulence of the water. The temperature probes are secured within the top 10 cm of substrate to facilitate comparisons of temperature to egg-fry survival rates and to protect the sensors. An additional temperature monitoring point in Port Dick Creek is be used to provide a comparison to the known chum and wild pink salmon runs in that reach as shown in Figure 9.

Water velocity measurements are needed because low and high stream velocities can both adversely affect chum salmon. Spawning adult chum salmon use water with velocities varying between 46 and 101 cm/sec (Pauley, 1988). Streamflow therefore regulates the amount of spawning area available: increased flow covers more gravel, thus making more suitable spawning substrate available. Higher stream velocities erode the substrate and suitable spawning is decreased. It is especially critical when constructing a spawning channel to monitor the stream velocities.

In addition, salmon eggs require sufficient water velocities to keep the stream well-oxygenated, protect the streambed from freezing temperatures, and to remove waste metabolites (CO_2). Siltation is a major cause of egg and alevin mortality as mentioned previously, which is directly correlated to stream velocity. The current meter used is be compatible with the USGS Type AA (Price-type) meter, which has an accurate window of measurement between 0.03 and 5.5 meters per second.

Salinity can interfere with fertilization of the eggs of chum salmon spawning in or near the intertidal zone. After absorption of the yolk sac, however, chum salmon can tolerate full-strength sea water. Salinity will be correlated to conductivity which is the parameter proposed for measurement. Sea water has a conductivity of approximately 40 to 50 msiemens, which requires an electrode spacing much greater than conductivity sensors for fresh water. The conductivity meter used will be calibrated from fresh water to full strength sea water, however the electrode spacing are be designed for discerning salinity changes in the spawning tributary. The conductivity sensors are attached to the temperature sensors in the substrate at approximate locations shown in Figure 9.

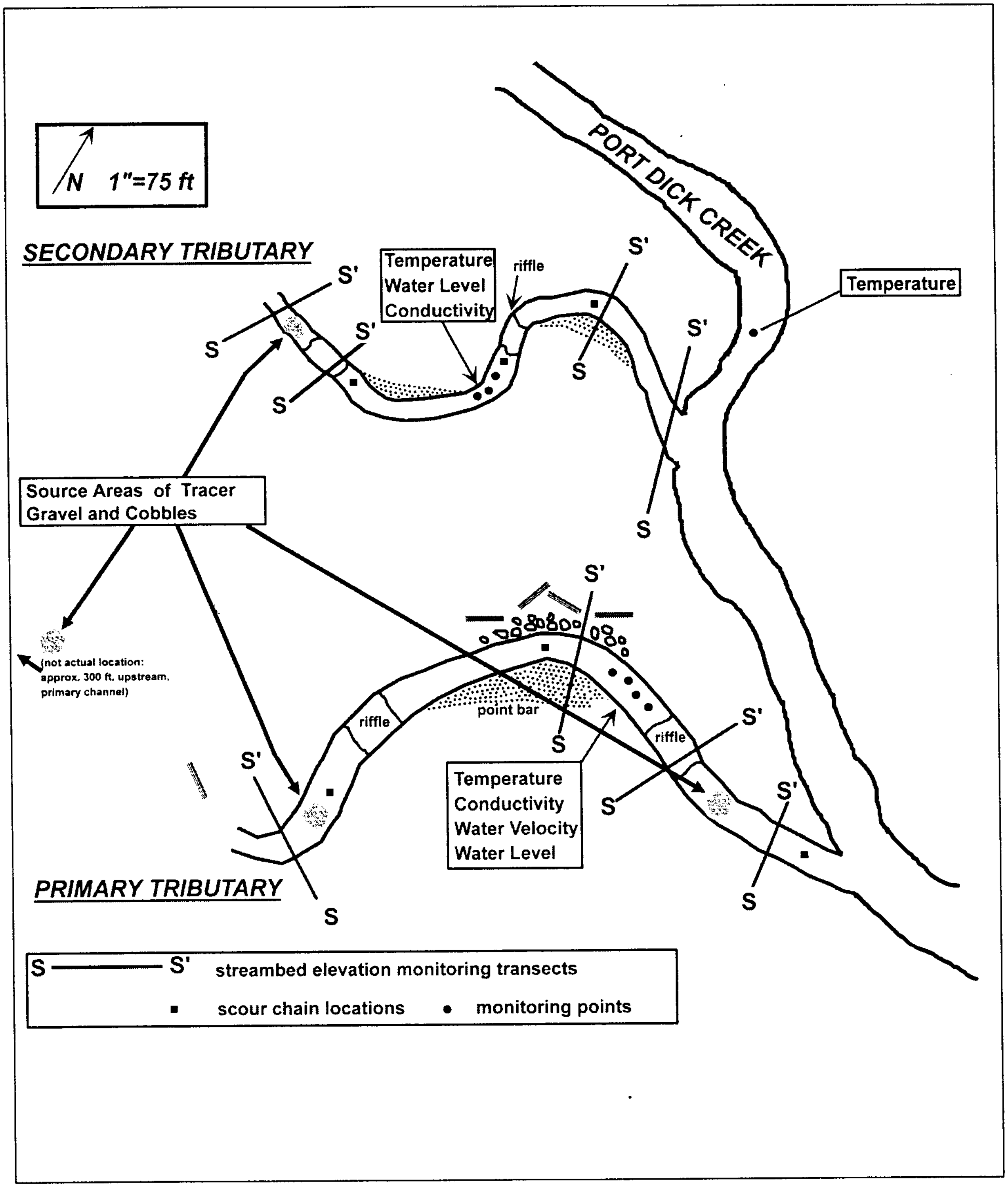


Figure 9. Physical parameter monitoring locations for post-construction Primary and Secondary tributary spawning channels, Port Dick Creek.

The datalogging equipment used by the sensors can easily retain measurements every 30 minutes for 2 months, and without power constraints for the sensors. The datalogging equipment is rugged, and can operate under conditions ranging from -55 to +80 degrees centigrade. Dataloggers and power supplies are housed in fiberglass reinforced and humidity controlled field enclosures for long term monitoring.

Streambed Stability Evaluation.

The stability of stream channels and banks substantially affects the quality of riparian and aquatic habitats. Stream stability is affected by channel morphology and channel material (Myers et al., 1992), both factors which are changed during spawning channel excavation. The benefits of characterization of sediment transport in the gravel-bedded channels can range from moderately helpful to extremely important.

Sediment and bedload transport in gravel-bedded rivers has received far less attention in the published literature compared to stream channels of finer grained sediments. There has even been controversy in the recent past about the effect of high discharge events on the sediment transport and bed armor of natural gravel-bedded streams and rivers (Ikeda et al., 1990). Discerning the effects of altering a gravel-bedded stream channel on sediment transport and deposition would be a side benefit of this study useful for future spawning habitat rehabilitation projects.

Salmon spawning channel construction provides a unique opportunity to study these effects, in addition to providing needed information on channel stability. Four methods used in detailed sediment transport studies of gravel-bedded streams are proposed to take advantage of the pre- and post construction phase of this project, and designed for inexpensive long term monitoring in conjunction with the hydrologic parameter monitoring. The four methods include bedload sampling using the Helley-Smith sampler, measurement and comparison of changes in surveyed stream transects, use of tracer cobbles and gravel, and measurement of changes in scour chain orientations. The implementation and justification of each technique is described below.

Bedload sampling can be used to determine the relationship between streambed material size (channel bottom armor) and bedload transport rate (Dietrich et al., 1989). This relationship can be used to determine the short-term stability of spawning gravel. Other factors that affect streambed stability are dependent on variables that will be measured and observed, including the average size of the bedload, meander geometry, the amount of bedload and upstream erosion.

Surveyed channel transects are the second method used to address short and long term streambed stability. Surveyed markers and marked trees are used to locate stream transect sections. A surveyor tape is stretched between the markers for horizontal reference. Streambed elevations are then measured to ~0.01 ft elevation using a total station at approximately 2 foot intervals across the transect. This is a standard method for monitoring changes in streambed morphology with time, compatible with other detailed studies of stream sediment transport in gravel-bedded streams (e.g. Jacobson, 1995). Eight such transects are proposed with approximate locations shown in Figure 9.

Seven brass survey monuments were installed onsite as reference points for the surveyed transects. The monuments are mounted in iron pipe driven into the ground, however they are referenced to a monument mounted in bedrock above the primary channel.

Surveyed transects are made as close in time as possible. Subsequent transects will show how much the stream channel adjusts to the designed spawning channel, particularly after high discharge events.

Tracer gravel and cobbles are being used to help determine rates of transport, of particular concern for the post construction phase of the spawning channels. Port Dick Creek Tributary gravel and cobbles were constructed into tracer material, some of which is in the range useful in salmon spawning grounds. The cobbles and gravel were marked using holes drilled in the material and filled with clear epoxy and numbered sheet copper (the tracers must be unobtrusive, yet easy to find). The shape of the tracer material was chosen to be as rounded as possible in order to reduce shape-induced uncertainties in the course of their movement (Cavazza, 1981).

Each of the 700 tracers were weighed, measured for orthogonal dimensions and specific gravity, then placed along the marked stream source areas shown in Figure 9 (e.g. tracer #223 weighs 148 gm, has orthogonal dimensions of x=64.43 cm, y=49.77 cm, z=33.98 cm and specific gravity 2.7 gm). The tracers are relocated periodically with a metal detector to determine the amount of movement from the source area for the specific tracer material during periods of high discharge. Each tracer will be re-weighed periodically throughout the long-term monitoring, and re-deployed to the source area if found near the mouth of either tributary.

Results from tracer tests are also of fundamental value in characterizing the size and rate of bedload transport averaged between monitored periods. The tracer data will be used to calculate accurate rates of bedload transport by comparison to the continuously monitored water level and stream velocity parameters. Such direct measurements of gravel and cobble transport would be very useful to discussions of construction techniques for future spawning channel projects in gravel-bedded streams.

Use of scour chains is the final method for addressing streambed stability. Scour chains are an inexpensive method for determining the thickness of bed mobility (depth of scour and depth of fill) following high discharge events. The scour chains consist of vertically oriented and weighted stainless steel link chain (2.5 cm links).

The chains will be periodically located and unburied. The length of horizontal chain and depth to the chain will be recorded, and the chain reoriented vertically for the next high discharge event. This allows the evaluation of scour events such as the depth of bedload scour and subsequent sediment burial thickness. Such maximum-event data helps determine the mobility of sediment during high discharge (Gordon et al., 1992). The amount of bedload transport from a flood event can be estimated with scour chains in combination with stream elevation cross sections, tracer gravel and cobbles.

RESULTS

Project Logistics and Tributary Excavation

Three pieces of heavy equipment (D-8 type caterpillar, one large backhoe (excavator) and one articulating front-end loader) were transported by landing craft vessel to Port Dick Creek on June 1, 1996 and off loaded during the following low tide. The front-end loader was not unloaded due to unstable substrate in the off-loading area. It was determined prior to transport time that a rock hopper/grader would not be necessary. Actual excavation of both tributaries took 3 days when the landing craft returned and transported the equipment back to Homer.

Approximately 2,500 m^3 of material was excavated from both tributaries with the two pieces of equipment that created approximately 2,500 m^2 of additional spawning habitat (Figure 10). Excavated material that was not incorporated into streambank or spawning bed structures was side-casted in two areas near the primary tributary. The side-casted material, or spoil piles, were groomed to match the existing topography and re-seeded with native grass species. Other plant species such as alder, willow and Devils Club were transplanted to the spoil piles from adjacent areas.

Broodstock Development and Adult Colonization

A total of 282 chums and 422 pink salmon colonized both tributaries (Figure 11). Only 2,200 chum salmon returned to Port Dick Creek in 1996, well below the minimum escapement goal of 4,000 fish. Colonization of the primary and secondary tributaries by pink and chum salmon occurred naturally. Regardless of the overall low escapement number, chum and pink salmon volitionally invaded the tributaries and spawned.

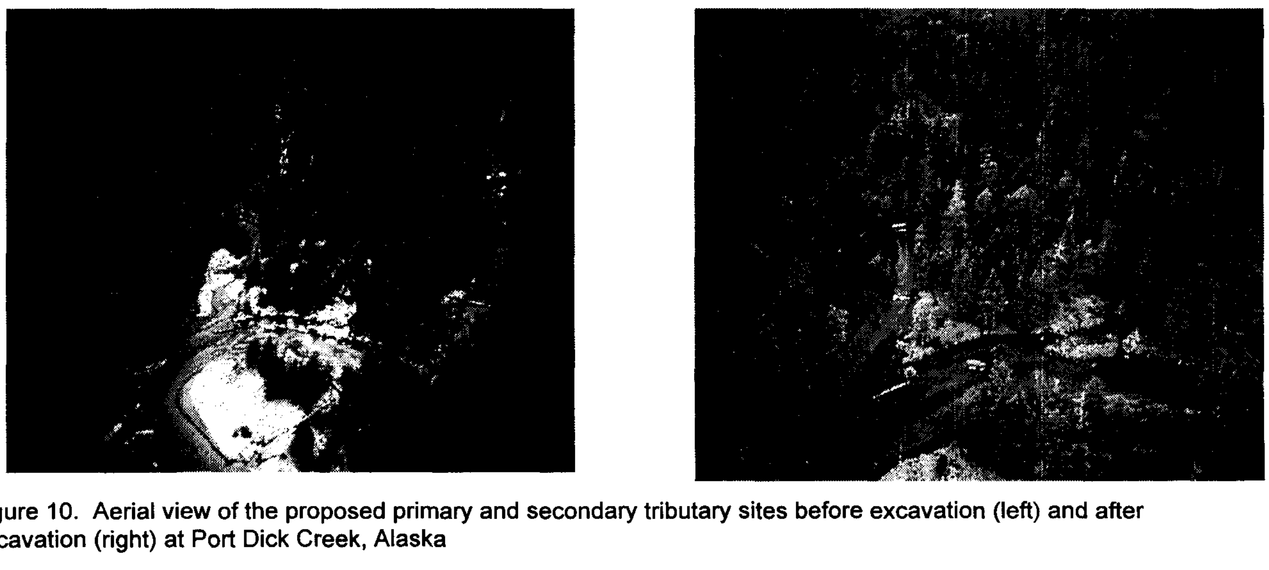


Figure 10. Aerial view of the proposed primary and secondary tributary sites before excavation (left) and after excavation (right) at Port Dick Creek, Alaska

The 1996 pink salmon escapement to Port Dick Creek totaled 23,200 fish only slightly higher than the 20,000 fish escapement goal set for Port Dick Creek. Results of the periodic ground surveys conducted at Port Dick Creek and the tributaries are shown in table 2.

Figure 11. Native adult chum salmon colonizing the primary tributary (above) on Port Dick Creek. Extreme low precipitation levels for 1996 in south central Alaska, resulted in low lake and stream levels which restricted the usable spawning habitat of both tributaries to approximately 85%.

Project Evaluation

The Port Dick Project is divided into two parts with respect to project success evaluation: fisheries and hydrologic evaluation and the evaluation of the physical stability of the restored tributaries.

Fisheries and Hydrologic Evaluation

Project success will be measured by estimating egg to fry survivals. Potential egg deposition was estimated by multiplying the number of spawning females by the potential fecundity. The escapement/colonization estimate for each tributary was then generated using the ground survey data (Table 2) and a FORTRAN program developed by Yuen & Bucher (1993). An estimated 282 chums and 422 pinks colonized the primary tributary; and 8 chums and 149 pink salmon colonized the secondary tributary. The number of females was estimated at 50% of the total estimated spawner abundance and a fecundity of 2,200 for chum and 1,660 eggs for pink salmon was assumed at 2,200 and 1,600 for pink salmon.

Table 2. Initial colonization of pink and chum salmon into the primary & secondary tributaries

	Primary Tributary		Secondary Tribuary	
	Live	Dead	Live	Dead
DATE		Chum salmon		
15-Jul	75	0	0	0
16-Jul	85	0	0	0
17-Jul	95	0	0	0
22-Jul	110	14	6	0
23-Jul	109	14	0	0
30-Aug	20	9	0	0
5-Sep	5	11	0	2
		Pink salmon		
30-Aug	306	31	94	45
5-Sep	218	80	68	81

Total potential egg deposition for the **primary tributary**:

Chum salmon 2,200 x 141 females = 310,200 eggs.

Pink salmon 1,600 x 211 females = 337,600 eggs.

Subtotal...647.800 eggs

Total potential egg deposition for the **secondary tributary**:

Chum salmon 2,200 x 4 females = 8,800 eggs.

Pink salmon 1,600 x 75 females = 119,200 eggs.

Subtotal...128,000 eggs.

The estimated total egg deposition for pink and chum salmon was calculated at 775,800 eggs for both tributaries.

Comparison of biological parameters with physical hydrologic parameters will add meaning to the egg to fry survival rates. One of the most important parameters for this type of analysis would be streambed temperature, and preliminary results from monitoring of temperature are shown in Figure 12 for both tributaries.

Streambed Stability Evaluation

One of the preliminary results for the streambed cross-sections is shown in Figure 13. More interesting from the streambed stability standpoint is the change of each cross section with time, and this will be available for the 1997 annual report.

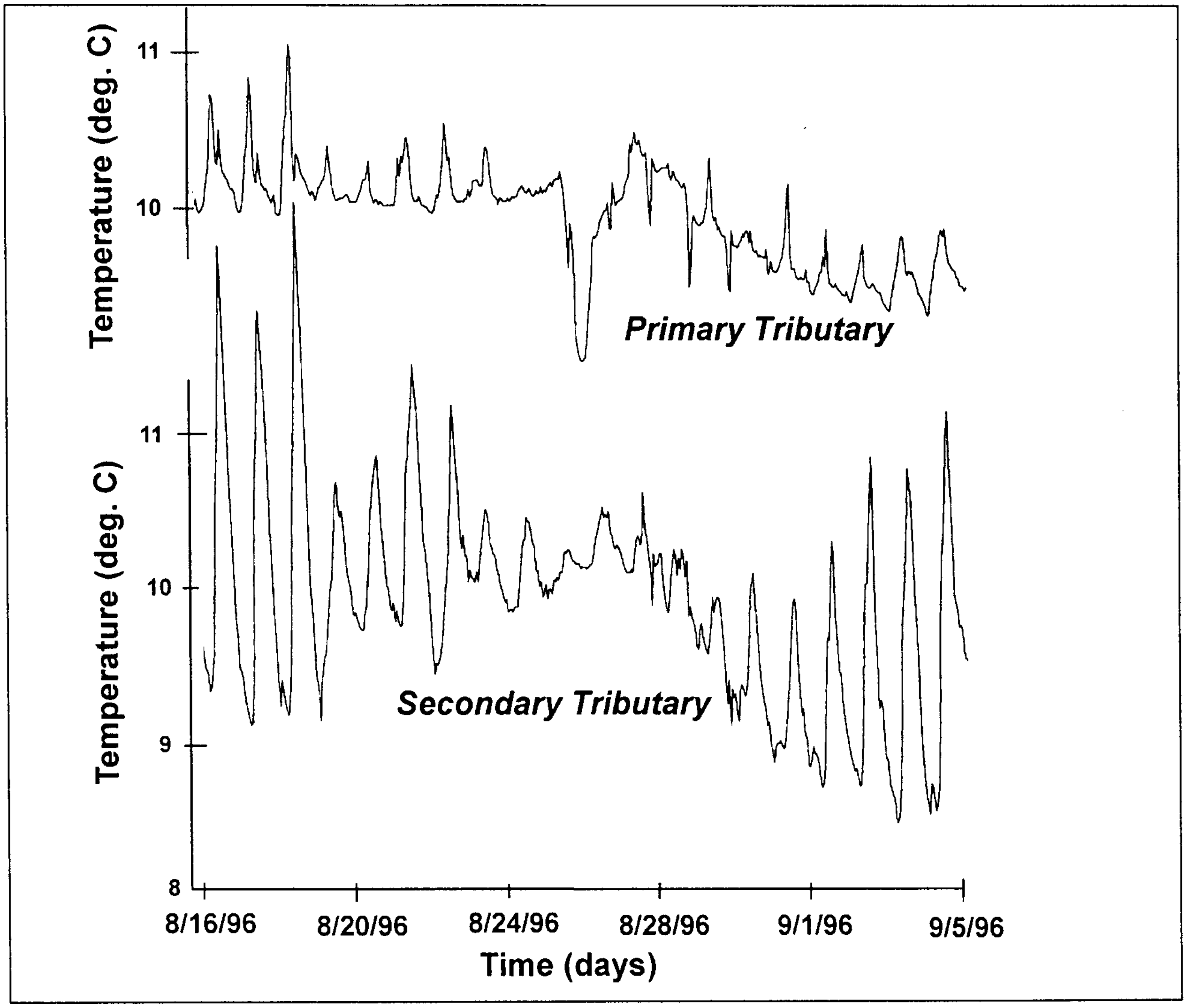


Figure 12. Tributary temperature comparison, August 1996.

Finally, timing has proved to be very important at this site in collecting sediment samples using the Helley-Smith technique. Because of the difficulty in being onsite precisely when the tributaries are in flooding conditions (when significant bedload transport is occurring), a cumulative sediment sampling method will be experimented with in 1997.

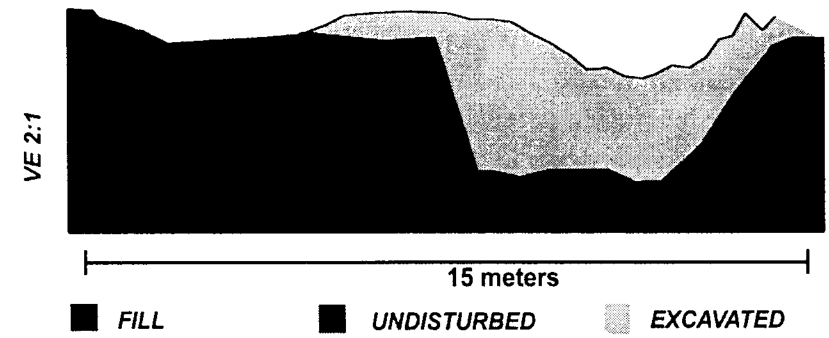
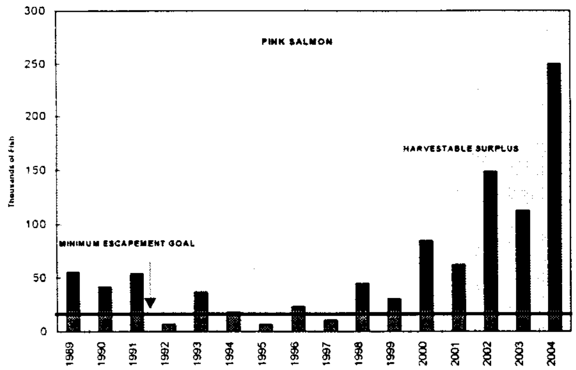


Figure 13. Pre- and post construction cross section comparison (6/1/96 and 6/30/96, respectively), Cross Section #3, Primary Tributary

DISCUSSION

Biologic and Hydrologic Evaluation

The results of the spring 1997 pink and chum salmon fry outmigration study will be used to estimate the spawning success of initial colonization. Future potential pink and chum salmon production from the restoration efforts at Port Dick Creek were calculated. An assumed egg to fry survival rate of 54.7% for pink and 55% for chum salmon was used to estimate future production from the restoration activities (Lister, Marshall and Hickey 1980; and Heard, 1978). Figure 14 displays the projected adult return contribution from the restoration activities for pink and chum salmon. The chum and pink salmon projection assumes that the escapement level for 1997 through 1999 will be at least the average of the previous 5 years, and for graphic representation the commercial harvest will be zero.



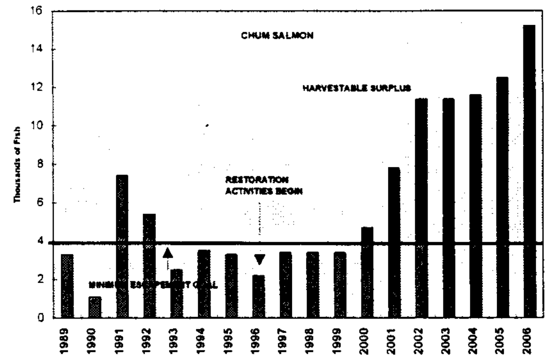


Figure 14. Projected estimated adult return contribution from instream habitat restoration efforts, Port Dick Creek, Alaska. The estimated escapements for pink and chum salmon, 1997-1999 are an average of the previous five years escapements. The projection assumes there is zero commercial harvest.

Factors that could influence fry survival estimates are variability in spawner densities, degree of egg retention, variations in fecundity, predation and problems associated with fry trapping (Bonnel, 1991). Colonization rates were estimated at 85% of saturation for the primary and secondary tributaries. Low precipitation levels on the Kenai Peninsula during the 1996 spawning run resulted in reduced stream levels which restricted available habitat and may have reduced the colonization level.

The results from the Port Dick Project (i.e. tributary excavation, egg to fry survival within the restored tributaries and tributary stability research) can be applied to other systems experiencing instream survival problems due to deteriorating spawning habitat. Local habitat such as Island Creek in Port Dick and the Windy and Rocky Rivers (located approximately 12 miles SW of Port Dick) are also experiencing low salmon survival rates that may be due to instream habitat problems.

Several parameters must be monitored to evaluate a link of the fisheries data to EVOS, not to mention the success of the project. In addition, the spawning tributaries themselves are being evaluated using the hydrologic parameters. The tributaries undergo changes in vegetation and streambed characteristics over different time scales, which become a factor in salmon spawning success. Such factors enter into the design features of future projects of this kind.

In most cases success of the project with regards to hydrologic monitoring is determined by comparing results and analyses of the hydrologic parameter monitoring to fisheries data such as egg mortality. The monitoring objectives may improve upon the results received from monitoring, so it is useful to discuss further considerations for each measured parameter.

Water depth was a critical parameter in many streams in the Gulf of Alaska following the 1964 earthquake, when streams experienced the effect of low water depths. This caused the atypically widespread formation of ice frozen to the streambed (termed anchor ice) as well as frozen spawning gravel. In itself anchor ice is not a problem in a mild winter, as intra-gravel flow can still provide oxygenated water to the spawn, while ice and surface water provide insulation to the spawning bed. McNeil et al. (1968) found many spawning tributaries in the Prince William Sound area experience high mortality rates due to low streamflow in winter.

Another problem possibly relevant to this site occurs when anchor ice is lifted off the streambed when the tide comes in; eggs, alevins and all. McNeil (1968) has observed piles of gravel on the side of a spawning tributary from this effect. This effect is of possible concern in upper areas of the Port Dick Creek Spawning Tributaries.

Finally, it is desirable to determine the energy slope of each tributary at various stream stages and water levels. This is possible only with accurate surveying combined with the transducers. It may be possible to install an additional transducer to obtain the energy slope continuously with time. This information is very useful in sediment transport modeling.

Temperature is a very sensitive parameter for determining pink and chum salmon survival rates. Beacham et al. (1988) found a rearing temperature variation of just 3^0 C caused a 34% change in survival rates under artificial rearing conditions. Because of the differences between intra-gravel temperatures (which effect the eggs and alevins most directly) and surface water temperatures, it is desirable to monitor both in the new spawning tributaries. Surface water temperature is useful for evaluating the spawning tributaries, such as growth of vegetation and variations in tributary depth caused by sediment scour and deposition. Water temperature is a relatively inexpensive parameter to monitor accurately, so more thermistors do not significantly add to project cost.

Salinity can be an important factor in egg mortality. Topographic maps as well as site observations show that large fluctuations in salinity are possible in the tributaries at high tides. These conditions are a factor to consider, though this is more of a problem at sites where earthquake subsidence has occurred (Groot and Margolis, 1991). Natural variations in salinity have been shown to cause differences in pink salmon gamete variability (Werthemeier, 1981) however he mentions the effect was small for estuarine conditions. A side benefit of salinity monitoring is that it is useful for determining the tidal influences on sediment transport during complex hydrologic events, and can help to calibrate a tidal component to surface water models of the site.

Streambed Stability Evaluation

Many aspects of research into solving problems associated with critical discharge and streambed stability in gravel-bedded streams are topics of recent research. Some of the areas of analyses and research that can help solve problems in the tributaries include studying shear stresses during flood stage, stream channel shape factors, and numerical modeling of the stream channels that includes meanders, stream channel widening and groundwater-surface water interaction.

The main purpose of streambed sediment monitoring and analyses at this site is to study the long term success of the spawning tributary project in terms of streambed stability, and to disseminate the project findings to the public and scientific community. The results will be useful for any adjustments needed to assist the current project.

Discussion of streambed parameters

Measuring the variation of elevation across a section of a stream channel with time as depicted in Figure 4, is a very useful way to monitor streambed stability. Numerous studies have used this technique successfully, e.g. Jacobsen (1995 in AGU Monograph 89) and Dietrich and Whiting (1989). Transects are also useful in the hydrologic parameter objectives for this project for determining estimates of egg mortality due to erosion (McNeil, 1965). This is of particular interest in the few years following excavation of a spawning channel. Therefore monitoring stream transects is an important parameter to consider for all objectives of this project.

Many studies find streambed elevation changes useful over the very long term by monitoring waves of sediment as they flow by a station (Jacobsen, 1995). In this case the study will be useful in determining relatively short-term changes (a few years) that may be reversed or enhanced by small alterations in the spawning tributary geometry.

The bed shear velocity, a parameter important in gravel-bedded stream sediment transport models, may be estimated using near bed velocity (Wilcock, 1996) monitored at this site. This can also be done with the local shear stress parameter. These parameters are important in calculating scour or deposition rates and other tributary changes.

Tracer gravel is a traditional way to study gravel transport in gravel-bedded streams, but continues to be a very valuable research tool. The movement of bed load is complex, intermittent and yet very important to the understanding of problems this project poses.

Gravel morphology and density play an important role in the entrainment of gravel, so use of onsite gravel is a good choice for tracer material as mentioned in the RFP, particularly since the data is to be published. Different sized gravel can be used for comparisons to a size-selective tracer study such as Ashworth et al. (1989). Bridge et al. (1992) show why tracer densities and tracer dimensions are important for studying the results of tracer transport, so it is recommended to measure the lengths of the orthogonal gravel axes for completeness. Hassan et al. (1991) have had success recently using tracer gravel in gravel-bedded streams to calculate gravel transport rates.

Scour chains can be useful in estimating the amount of bed material eroded as a measure of salmon egg mortality. McNeil (1965) used ping pong balls buried vertically for this purpose, but had problems estimating scour depth when losing all of them in one location. The advantage of scour chains is they can be straightened and re-buried vertically quickly, and they can be relocated using a metal detector. Scour chains are useful in conjunction with stream elevation transects to understand the history of sediment transport between site visits. Stream bank erosion pins can also be used in the same way as scour chains to study bank erosion should this become an issue.

Streambed Analyses

There are many concerns that can be addressed by streambed analyses that benefit the spawning tributary project both directly and indirectly.

Perhaps most important are concerns over the long term stability and viability of the spawning tributaries. The best way to approach this concern is to use onsite data from the sediment transport monitoring to calculate basic sediment transport. These sediment transport parameters can then be used in surface water models to help answer questions concerning the long term streambed stability, the short term ability for the tributaries to maintain its water depth and to determine what changes in the tributary geometry could be made to improve the streambed stability. In addition, comparison studies can be made with other gravel-bedded stream studies in the literature.

The 'flushing flow' discharge from hydroelectric projects is a current matter of intensive research. This 'flushing flow' is on a small scale directly related to the critical discharge necessary for bedload transport in gravel-bedded streams (e.g. Kondolf, 1996). Other basic parameters that must be derived from onsite data have been discussed previously (shear stress, sedimentologic characteristics, stream width, stream depth profile, variations in discharge etc.). Calculation of parameters as basic as discharge in gravel bedded streams are a matter of current research (e.g. Bridge, 1992), particularly where there are many obstructions as is the case upgradient of the spawning tributaries.

Models that use the parameters for gravel-bedded streams are continually being refined, researched and published. For example, (Bridge and Bennet, 1992) recently published a basic sediment transport model for gravel-bedded streams that includes the critical discharge parameter, Hassan et al. (1991 and 1994) proposed a model for gravel movement using tracer data and a model for the mixing of bedload downgradient from a source area Dietrich and Whiting (1993) have worked with models that include meanders in gravel bedded rivers, an important component at this site, and Pizzuto (1991) published an important model concerning gravel channel widening predictions. In addition there are valuable published data sets for comparison studies available for gravel bedded flow, for example from laboratory flume studies (e.g. Pizzuto, 1990).

A final subject that is of interest to the site is studying the influence of drop structures and their effect on gravel sediment transport. This topic often appears in the context of bridge construction, since bridges frequently must be founded on erodible material. The scour of a gravel-bedded stream is different at the location of a drop structure, so a variety of studies (e.g. Laursen et al., 1984) indicate the stable sediment size at sloping sills and erosion depth directly below drop structures.

Laursen et al. (1984) proposed a model for the size of riprap needed on the face of a sloping sill similar to the seepage face at the head of the primary tributary spawning tributary. Elements of more specific papers on drop structures can also be useful in deriving models that describe sediment transport at drop structures (e.g. Humpherys, 1986; Fiuzat, 1987; Christodoulou, 1985). A related topic is streambank stability analyses (e.g. Chang, 1990). These topics are useful to keep in mind should future tributary changes be deemed necessary.

CONCLUSIONS

The restoration phase of the project was successfully finished while operating within the environmental constraints identified through the Environmental Assessment process. Both tributaries were colonized to approximately the 85% level during the first year. Volitional colonization of both tributaries restricted the need for supplemental procedures to artificially seed the restored spawning habitat. Initial egg to fry survival rates will be related to hydrologic data and sediment transport data as it becomes available. The sediment transport data set has been initiated, with some adjustments to the data collected that have been identified, and the program is proceeding towards the sediment transport modeling and research priorities. Major research priorities for the sediment transport data set include using the data to address effects of gravel tributary widening, flood conditions on sediment transport and determining an effective discharge for both tributaries.

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APPENDIX A. List of Permits, Licenses, Authorizations Necessary to Implement the Project.

List of Permits, Licenses & Authorizations Necessary to Implement the Project, based on completion of the Coastal Project Questionnaire and Certification Statement

Regulated Activity	Permit Required	Governing Agency	Next Renewal
Instream excavation	U.S. Corps of Engineers	U.S. Corps of Engineers	Pending: Submitted 8/31/95; assigned project # 4-950786
Work on State Park Land	Special use Permit	ADNR	Pending: Submitted 8/18/95
Fish egg transport	Fish Transport Permit	ADF&G	Annual
Waterway Activities	General Waterway/Waterbody Permit	ADF&G	Annual: Submitted 8/1/95

ADF&G---Department of Fish and Game

ADNR---- Alaska Department of Natural Resources

ADEC---- Alaska Department of Environmental Conservation

U.S.COE- United States Corps of Engineers

APPENDIX B. Key Issues Verses the Alternatives.

Key Issues Verses Alternatives

	Alternative A	**Alternative B**
Wilderness/Noise	Short term duration: 14 day limit	No impact.
Wilderness/ Wildlife	All excavation activities within tributary boundary. Schedule would limit disruption to wildlife.	No impact, but no benefits from increased number of spawning salmon.
Archaeological Concerns	Cultural resource survey on Sept. 1, 1995, no impact within tributary boundary. Sensitive areas near cabin.	No impact
Siltation Concerns	Excavation activities within lower reaches of spawning system, limited siltation expected with silt filtering berm	No impact
Visual Concerns	Short term impacts: All excavation activities restricted to tributary boundary. No evidence of activity after 12-14 months	No impacts.
Spoil Disposal/Loss of Uplands	676 m^2 disposal site identified: spoil would measure up to 40 cm high.	No impacts.
Genetic Risks	No impacts: same genetic stocks used	No impacts.
Mixed Stock Fishery	Additional salmon can be managed effectively with time and fishing area manipulation.	Pink and Chum stocks will continue to suffer from unstable spawning habitat.
Number of Eggs Needed	No impacts. Egg removal schedule developed to prevent over harvest	No impact
Recreational Users	Excavation schedule does not coincide with sport fishermen. Bear hunters in area earlier & hikers use area later.	No impact, but no benefit from increased fish production.

APPENDIX C: Calculation of a Stable Trapezoidal Channel

The fluid shear stress needed to move a grain, τ_o, is less than the fluid stress that is required to move a grain of the streambed bottom τ_c, because both shear and side slope are combining to dislodge the grain. This relationship is embodied in the following equation:

$\frac{\tau_o}{\tau_c} = \sqrt{1 - \frac{\sin^2\theta}{\sin^2\phi}}$, where ϕ is the angle of repose of the streambed armor (gravel) and θ is the angle of the streambed to the unconsolidated bank gravel. Since much of the forces depend on the depth of water (y) and slope (S) of the channel, the further relation $\tau_o = 0.75\gamma yS$ is needed, where γ is the specific weight of water.

Angle of repose data were measured in the field at several locations in the primary tributary where steep banks were found in the alluvium (30 to 35 degrees) and in the lab using the sediment samples (37 degrees). The secondary tributary banks contain 1-2 feet or more of cohesive sediments, which were almost vertical to the tributary. Below this topsoil is similar alluvial gravel to that found on the secondary tributary streambed (somewhat smaller in diameter to that of the primary tributary).

The angle θ must be chosen such that it is less than the angle of repose, in this case 35 degrees. While a slope of 1.5H:1V is acceptable (34 degrees) it is safer to use 1.75H:1V, or θ=30 degrees. Therefore $\frac{\tau_o}{\tau_c} \leq 0.49$.

The following are possible stream depths for different stream slopes (different stream slopes as caused by a riffle or rapids structure) for a D_{75} grain size of 15 mm (a reasonable distribution to achieve by sieving based on Table 1):

Slope	**Water Depth**	**Requirements of riffle**
S=0.005	y≤0.6 ft	0.0 ft head loss over 300 feet
S=0.004	y≤0.8 ft	0.3 ft head loss over 300 feet
S=0.003	y≤1.0 ft	0.6 ft head loss over 300 feet
*S=0.002	y≤1.5 ft	0.9 ft head loss over 300 feet
S=0.001	y≤3.0 ft	1.2 ft head loss over 300 feet

*acceptable riffle water depth for salmon spawning channel

Primary Tributary: (using S=0.002, y=1.5 ft)

b	A	P	R=A/P	v	Q=v/A
18 ft	30.95 ft^2	24.05 ft	1.89 ft	1.12 ft/sec	34 cfs

(cont.)

Secondary Tributary: (using S=0.002, y = 1 ft)

b	A	P	R=A/P	v	Q=v/A
12 ft	13.75 ft2	16.03 ft	0.86 ft	0.85 ft/sec	11.7 cfs

(from Henderson, 1963) where y is the depth of water at a riffle or rapids area, S is the slope that accounts for the elevation of the riffles, b is the base width of the trapezoidal channel, A is the area of the channel cross-section, P is the wetted perimeter of the flow cross section, R is the hydraulic mean radius, v is the mean stream velocity across the channel, and Q is the mean discharge of the stream.