Weirs

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Background and Objectives

Weirs—which function as porous barriers built across stream—have long been used to capture migrating fish in flowing waters. For example, the Netsilik peoples of northern Canada used V-shaped weirs constructed of river rocks gathered on-site to capture migrating Arctic char *Salvelinus alpinus* (Balikci 1970). Similarly, fences constructed of stakes and a latticework of willow branches or staves were used by Native Americans to capture migrating salmon in streams along the West Coast of North America (Stewart 1994). In modern times, weirs have also been used in terminal fisheries and to capture brood fish for use in fish culture. Weirs have been used to gather data on age structure, condition, sex ratio, spawning escapement, abundance, and migratory patterns of fish in streams.

One of the critical elements of fisheries management and stock assessment of salmonids is a count of adult fish returning to spawn. Weirs are frequently used to capture or count fish to determine status and trends of populations or direct in-season management of fisheries; generally, weirs are the standard against which other techniques are measured.

To evaluate fishery management actions, the number of fish escaping to spawn is often compared to river-specific target spawning requirements (O'Connell and Dempson 1995). A critical factor in these analyses is the determination of total run size (O'Connell 2003). O'Connell compared methods of run-size estimation against absolute counts from a rigid weir and concluded that, given the uncertainty of estimators, the absolute counts obtained at the weir wer significantly better than modeled estimates, which deviated as much as 50–60% from actual counts. The use of weirs is generally restricted to streams and small rivers because of construction expense, formation of navigation barriers, and the tendency of weirs to clog with debris, which can cause flooding and collapse of the structure (Hubert 1996). When feasible, however, weirs are generally regarded as the most accurate technique available to quantify escapement as the result is supposedly an absolute count (Cousens et al. 1982). Weirs also provide the opportunity to capture fish for observation and sampling of biological characteristics and tissues; they may also serve as recapture sites for basin-wide, mark–recapture population estimates. Temporary weirs are useful in monitoring wild populations of salmonids as well as for capturing broodstock for artificial propagation.

FIGURE 1. — A temporary weir constructed of metal tripods, stringers, and galvanized conduit with both an upstream and downstream trap. Ninilchik River, Alaska.

Rationale

Temporary weirs enable field biologists to quantify the escapement of adult salmonids in streams and rivers. In addition to providing absolute counts of fish migrating through the weir, weirs can be used to capture fish, determine sex ratios and species composition, recapture tagged fish, and collect tissue or scale samples. In locations where management relies on escapement goals, weirs can be used to monitor escapement in order to direct in-season management of commercial or subsistence fisheries.

Objectives

This protocol describes the methods used in counting migrating adult salmonids in streams and rivers using weirs and traps. Generally, weirs and traps are temporarily installed across the stream channel and enable monitoring practitioners to estimate or make an absolute count of fish passing that point in the stream.

FIGURE 2. — A resistance board weir featuring a skiff gate to allow boat passage (in the foreground, marked by pylons), a trap to capture fish in middle of weir, and a passage chute (background), where fish are counted as they pass the weir. Pilgrim River, Alaska. (Photo: Karen Dunmall and Tim Kroeker.)

Temporary weirs may be constructed from a range of materials. Rigid weirs generally consist of a fence and support structure; fences may be constructed from netting (Blair 1956; Noltie 1987) or from rigid material such as pipe or metal pickets (Hill and Matter 1991). These weirs are generally easy to dismantle and transport but are sometimes difficult to maintain during high water or in streams with high debris loads. Weirs constructed of screen or wire panels have a tendency to collect debris such as leaves and algae (Clay 1961). Kristofferson et al. (1986) used a weir constructed of polyethylene (Vexar®) and metal t-posts, similar to that described by Noltie (1987), on an Arctic river but found that clogging by algae and debris led to excessive water pressure that eventually caused the weir to collapse. Noltie (1987), however, reported that the same material could easily be cleaned of leaves using a push broom. Because weirs constructed of these materials are relatively inexpensive, they are probably best used for short-term studies in small shallow streams; practitioners choosing these materials need to take into account the time needed to clean these weirs of debris.

Weirs constructed of metal pickets (which are frequently made of aluminum rods or galvanized conduit) are more resistant to buildup of algae, leaves, and other fine material. In some designs, the pickets can be removed for easy cleaning and to reduce pressure from high flows. The length of the conduit will depend on the depth of the stream and should be long enough that salmon should not be expected to jump over the weir. Anderson and McDonald (1978), Kristofferson et al. (1986), and Hill and Matter (1991) describe construction details for such rigid weirs, which generally consist of structures that support panels of pickets. Supports usually consist of tripods constructed of pipe or wood and support stingers that hold the pickets (see Figure 3). By angling the upstream face of the weir at 120° relative to the stream bottom, the water flows slightly up the pickets before passing through; this movement creates a greater area over which water pressure may dissipate (Anderson and McDonald 1978). To further dissipate water pressure, the weir can be constructed so that the wings of the weir terminate in a 90° angle entering the trap box (see Figure 4). This arrangement allows more water to pass through the weir for a given stream width and guides fish into the trap. Mullins et al. (1991) describe a two-way trap that can be constructed in the apex of two weirs that allows for sampling of both upstream and downstream migrants.

FIGURE 3. — Construction details of tripods and weir panels made of metal stringers and pickets of galvanized electrical conduit.

Rigid weirs work best in rivers that have minimal variation in water flow and depth; these conditions will help avoid, to the greatest extent possible, frequency of washout of the trap and/or weir by increased flows or seasonal freshets. Lake outlets, therefore, are particularly suited to the placement of rigid weirs (Clay 1961). Rigid weirs are also susceptible to damage by large floating debris such as logs or ice. Resistance board weirs were designed to accommodate fluctuation in flow and debris and to allow for inclusion of easy-to-use boat passes (Tobin 1994; Stewart 2002) (see figures 2 and 4). Although not impervious to washout, resistance board weirs can be used in rivers that experience debris-laden high water periods (Tobin 1994). During high water, the resistance board weir will temporarily submerge when pressure created by water and debris loading reaches a point that would typically wash a rigid weir downstream (Tobin 1994). This flexibility requires less maintenance and also reduces the frequency of these occasions when fish cannot be counted.

Resistance board weirs consist of three main components: panels made of capped polyvinyl chloride (PVC) pipe, a rail anchored to the substrate that attaches the panels to the river bottom, and a trap box or chute where fish are captured or counted. Detailed construction and installation manuals for resistance board weirs are available in Tobin (1994) and Stewart (2002, 2003). In summary, a rail is installed across the stream. This rail is anchored to the substrate using steel rod and cables attached to duck-bill anchors placed upstream of the weir. The rail anchors and aligns the cable to which panels are attached. The weir panels are constructed of schedule 40 PVC electrical conduit 6.1 m in length. Electrical conduit is used rather than PVC water pipe because it resists breakdown caused by ultraviolet light. Panels consist of multiple pipes supported by 1.2 m-long stringers that are spaced evenly lengthwise along the panels to provide rigidity to the flexible PVC pipe. Pipe spacing is determined by the desired distance between pipes and is adjusted accordingly based on the size of each target species. A resistance board is attached at the downstream end of the panel to deflect water flow downward, which causes lift and holds the downstream end of the panel above the surface of the water (see Figure 5). Panels are attached to one another and span the width of the stream. At either end of the weir, a short section of fixed weir (similar to the rigid weirs described above) seals the end of the floating weir at either bank (Figure 4). Tobin (1994) and Stewart (2003) describe how to incorporate a skiff gate that allows upstream and downstream passage of boats without opening the weir.

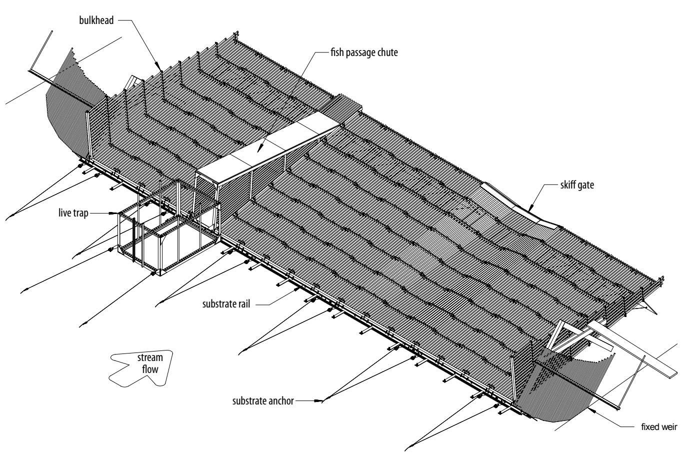

FIGURE 4. — Resistance board weir and major components. (Diagram: Rob Stewart, Alaska Dept. of Fish and Game.)

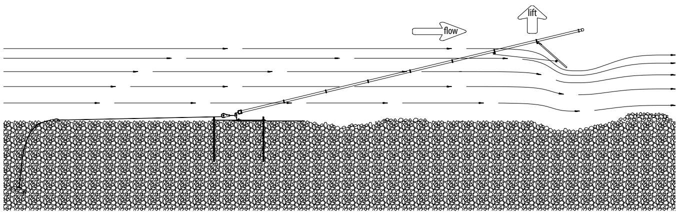

FIGURE 5. — Side view of a resistance board weir panel. The resistance board deflects water at the end of the panel and creates lift to counteract the downward pressure of flow. (Diagram: Rob Stewart, Alaska Dept. of Fish and Game.)

Both rigid and resistance board weirs use fish passage chutes and trap boxes to pass or capture fish. Fish passage chutes allow fish to swim though an opening in the weir and can either attach to a live box for trapping fish or include a counting station where fish are identified and counted. As fish pass through the counting chute they are tallied by observers. In some cases, to minimize personnel costs, automated counters that utilize video technology or resistivity counters are used to quantify fish passing through the fish counting chute (see Figure 6). Trap boxes are used to capture fish for direct examination or for sampling tissues, length, weight, and sex. After having been counted and examined, the fish is passed upstream of the weir. Trap-box designs are presented by Kristofferson et al. (1986), Whelan et al. (1989), and Mullins et al. (1991). In most designs fish enter the trap through a V-shaped passageway (termed a fyke), which inhibits fish from passing back downstream. After fish enter the trap, they either pass through the front gate or counting chute or are trapped for further examination. The trap should be big enough to hold expected numbers of fish comfortably. During the trapping session, the front gate (upstream) is closed and the back gate (downstream) is open to allow fish to enter the trap box. Once the desired number of fish enter the trap, the downstream gate is closed and fish are sampled and released upstream of the weir.

FIGURE 6. — Video monitoring chute, Nikolai Creek, Alaska. Fish passing through the passage chute swim through a video chamber, where they are filmed. Fish can be counted by viewing the video tape in the office.

Sampling design

When creating a sampling design for a weir project, it is important to evaluate the purpose and objectives of each project. In most cases, weirs are used to capture or count all fish passing that point in a stream. For example, if the goal of the project is to determine escapement to a particular river, it is critical that the weir be placed downstream of all spawning habitats and that the weir is operated through the entire migration. In the case of monitoring a stream with small numbers of migrating fish, all fish can be trapped, counted, and passed over the weir without continuous (24-h) counting through the chute. Rather, fish can be examined, counted, and passed at period intervals through the day. A counting chute allows for monitoring larger runs of fish and the counting of each species as they pass uninterrupted through the weir. Counting chutes are fitted with a light-colored floor to facilitate the identification of individual fish; counts are done visually by personnel stationed at the chute, video, or other automated counters. Personnel count fish as long as the counting chute is open to fish passage, which, depending on fish passage rates, may be up to 24 h per day.

Site Selection

Site selection includes two principle considerations. First, the weir must be located at a site that allows sampling and counting of fish to address the objectives of the study. For example, if the objective of the study is to determine escapement of upstream migrating salmonids, the weir must be located downstream of the lowest point of spawning habitat. Second, the location must be conducive to weir construction and maintenance through the range of water flows expected during the operation period.

Site selection is an important consideration in determining the success of weir construction and maintenance. When selecting possible weir sites, substrate, river flow, depth, and width, and timing of high water events should all be considered. Suitable sites for both rigid weirs and resistance board weirs are characterized by wide and shallow areas of stable substrate consisting of gravel or small cobble (Clay 1961). Stable substrates of pebbles or small cobbles allow the weir structure to lie flat on the surface of the substrate and also facilitate secure anchoring using pins or duck-bill anchors. If larger boulders are present, they may impede the structure, act as an obstacle, or create gaps that allow fish to get through the weir. At high water, stream energy is equally distributed across the stream in straight reaches of laminar flow, making it easier to maintain the weir through a range of flows. Water depths less than 1 m during normal flows and water velocity that is slow to moderate are preferred for both rigid and resistance board weirs. If the water is too deep and swift to allow an adult person to wade comfortably at normal flow, the site is not suitable for safe weir operations. At the same time, the weir site should have enough current (especially at passage chutes or traps) to ensure efficient fish passage and attraction flows. Stream width may vary, but practitioners should note that wider locations will require more material in weir construction. Near-vertical stream banks are easier to seal against fish passage but should not contain undercut channels because they are difficult to seal.

Another consideration when choosing weir location and design is the position of a trap or traps on the weir. The recommended number and location of traps depends on the size and morphology of the channel at the weir site. Since fish typically travel in the thalweg (the deepest portions of the river channel), the sampling area or trap should be located in this area. If the river has more than one thalweg or channel, it is recommended that the weir have more than one sampling location for fish to travel through. Trap placement on the weir should account for minimum expected depth. If the trap box is located in a site that is too shallow or too deep, it may be difficult to access the trap and handle fish in the trap, and may lead to excessive stress on fish in the trap. If the system is prone to flooding, it is common to have an alternate sampling location for times when normal operations at the main site are not possible. For example, many systems in Alaska experience flood stages during the rainy months of the summer; by installing a second trap in a different location on a given river, practitioners may avoid sampling delays during flood stages.

Sampling frequency and replication

Weirs are usually used to acquire an absolute count of migrating fish; therefore, sampling considerations need to ensure that weir operations begin before fish migration and continue through the end of migration. In the event that logistic considerations or environmental constraints interrupt weir operation, counts will be incomplete. An important consideration in the development of a fish weir project is replication. Depending on the objectives and goals of the study, many years of data may be needed. Practitioners examining run timing of Pacific salmon will need to monitor the entire run over several years to conduct trends analysis. For example, Korman and Higgins (1997) examined the needed replication of escapement estimates to adequately determine the response of salmon populations to habitat alteration, and they determined that posttreatment monitoring needed to be longer than 10 years.

Stratified sampling designs are a common method for estimating total run abundance and determining overall age, sex, and length composition. In most cases the operational period is stratified into weeks, with escapement determined for each week; and total escapement is simply the sum of weekly escapement. In locations where total fish runs are small, each fish may be handled to gather age, sex, and length data. When run size is too great to allow for sampling of all fish passing the weir, a stratified sampling design is used to estimate sex, age, and length distribution of fish passing the weir. This may be achieved by collecting scales and length from every *n*th fish of a species passed through the trap. The number of fish sampled needs to be determined prior to the season and in consultation with a statistician. On weirs that incorporate both a counting chute and trap, fish can be sampled in the trap for stratified periods of time throughout the run. This technique, also known as a pulse sampling design, is conducted over a 1–3-d time period, followed by a period without sampling (trapping and scale collection/length determination). In most cases, a target sample size for each species is sought for each sampling stratum (e.g., week). These samples are calculated as a subset of the entire escapement and expanded to characterize the age, sex, and length composition of the total annual escapement (see Data Handling, Analysis, and Reporting, page 394, for details).

Field/Office Methods

Setup

Before trapping can begin, all weir components need to be purchased, assembled, and constructed. For larger weirs, fabrication can take several weeks and requires use of a workshop with necessary tools and staff expertise. Commercially produced traps are available but can be very expensive. After construction the weir components need to be shipped to the weir location. For remote locations, this may involve the use of helicopters or other means of transportation. Once on-site, the weir can be installed in the stream. In Alaska weirs are frequently installed in early spring when water flow is low. Final panels or trap boxes are installed when trapping begins later in the season. In remote locations a camp must be constructed at the weir site to provide sleeping and eating quarters for all personnel required to maintain the weir. Once the crew is on-site, personnel in the office will need to facilitate grocery shipments and safety of the field crew.

Safety and operational training is an important step in preparing for a field season. Safety training should include first aid appropriate for the location, as remote field locations will require higher proficiency in dealing with injuries while waiting for transportation or medical aid. This training is frequently referred to as wilderness first-aid. Training in operation around water is required, and boat training is needed if the weir will be accessed by boat. Similarly, if helicopters or fixed-wing aircraft are used to access the weir site, training may be needed for proper conduct around aircraft. In remote locations in Alaska, training regarding bear encounters and gun handling is needed. Most agencies have established safety programs and requirements, and weir project planners should check with agency safety personnel when starting a weir project to determine what safety training will be needed and where such training can be acquired. Operational training is also important, and all weir personnel should receive training in weir operation, construction, and project implementation (as well as safety training). Personnel who fully understand the protocol and objectives of the project will be in a better position to make day-to-day decisions concerning project implementation.

Events sequence

Although weir projects may have a field season of a few weeks to months, preparation, analysis, reporting, and maintenance usually require year-round activity. Field crews need to be hired early enough to allow for preseason deployment and training. Creating a preseason task checklist is recommended. Appendix A details the preseason checklist used by the U.S. Fish and Wildlife Service on the Kwethluk River weir project. It includes all tasks that must be completed to initiate the Kwethluk River weir project, including scheduling, hiring, training, shipping, travel, and crew gear distribution. This checklist can be modified for use by other projects.

Another pertinent item to include when preparing for field season is an equipment checklist or inventory list. This should include all the equipment needed to complete the project with associated quantities, quality (i.e., used or new), and storage location. If the field project is located on private, state, or federal land, a land-use agreement or lease will be necessary to occupy and use the land,

and permits may be required. Scientific collecting permits may also be required from state fish and game agencies. Before beginning any project, local fish and wildlife managers should be consulted concerning permit requirements. When preparing for the field season it is important to create a timeline that is associated with the preseason checklist. The timeline should outline deadlines for the preparation, installation, operations, and takeout process.

Measurement details and sample processing

During weir operation, a range of data needs to be collected. These data include the number of fish passing the weir (usually recorded on an hourly basis), length, weight, and scale samples collected, water temperature, and flow (stage height or discharge). Data forms printed on weatherproof paper or notebooks should be developed to organize data gathering and ensure that all data are collected at the appropriate time. All data forms should be easy to understand, with proper headings and space provided to include all the data necessary. Fish passage should be monitored continuously, and fish passage should not be hindered. When operating a weir, it is important to ensure that the weir does not delay fish migration. Fleming and Reynolds (1991) found that Arctic grayling *Thymallus arcticus* delayed at a weir did not migrate as far as control fish and suggested that such delays could cause fish to spawn in suboptimal locations. Fish collected in traps should be sampled as quickly as possible to minimize holding stress and migration delay.

There are two different approaches for weir operation: one utilizes the trap to capture fish and release manually, and the other utilizes the trap as a counting station allowing fish to pass uninterrupted. Typically, the size of the escapement or objectives of the study will determine which technique is suitable for each system. The first method involves trapping fish as they pass through the weir, sampling them for genetics, age, sex, or length information, and releasing them by hand above the weir. This method works well on smaller systems. For larger systems, trap operation may be round-the-clock, and the design would include a counting chute that allows fish to pass uninterrupted. An observer or a video camera would then count each fish as it passes upstream through the weir. In this method, a counting session commences as the counting chute is open, and fish are identified and counted as they pass through the weir. Fish can also be examined by simply allowing the counting chute to remain closed and the downstream gate of the trap to remain open, essentially allowing fish to move into the trap, where they are retained until examined and then released upstream of the weir.

Sample processing may take place in-season or, in most cases, will occur postseason. In-season samples, such as daily escapement estimates, scale samples, or genetic samples, may need to be transported for immediate consideration by fishery managers. In this case, it is important that sampling procedures include a detailed component for quality control. If this element occurs in the field, proper steps should be taken to ensure accurate data collection and proper crew training; one individual needs to be responsible for the oversight and handling of samples.

Data Handling, Analysis, and Reporting

To determine total escapement past the weir, the total number of fish passing the weir each day is summed. In the case of weirs that incorporate a fish counting chute that is open to passage at all times, if fish are only counted during a portion of the day, then the count is expanded to estimate the full day's passage (assuming that passage rates are constant throughout the day). For full days missed because of high water or other events that prevent fish counting, linear interpolation of the counts before and after the missed day(s) can be used to estimate passage for that time period. In cases where fish are passed through a fish trap or where all fish are counted (24-h per day), the resulting number is the absolute number of fish passing the weir.

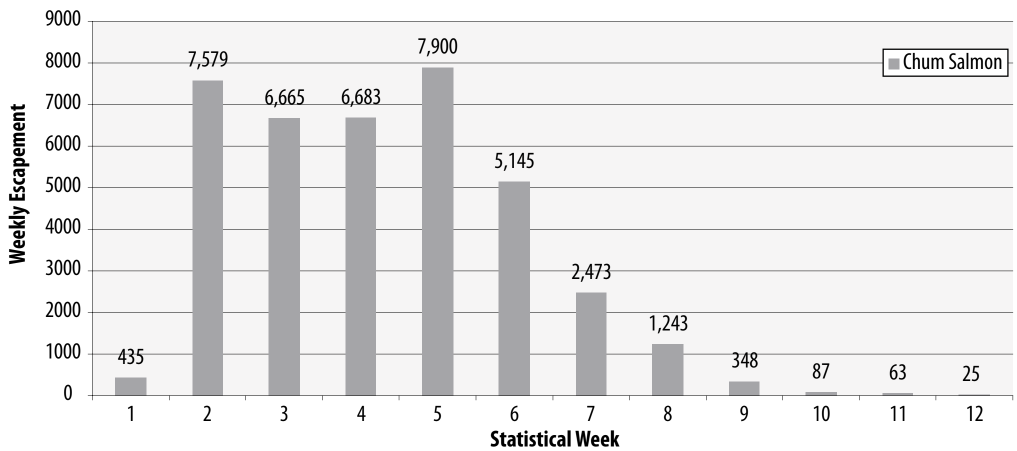

FIGURE 7. — Weekly passage (escapement) of chum salmon *Oncorhynchus keta* at the Kwethluk River weir, 2004 (data from Roettiger et al. [2005]).

When analyzing data from weirs, the sampling period is usually stratified into weekly periods (see Figure 7). Within each stratum (or week), the proportion of fish of a given sex or age (p_{ij}) is calculated as

$$\hat{p}_{ij} = \frac{n_{ij}}{n_j} \qquad \text{(eq 1)}$$

where n_{ij} is the number of fish of sex i or age i sampled in week j, and n_j is the total number of fish sampled in week j. Sex or age composition (p_i) for the total run of a species of sex i or age i is calculated as

$$\hat{p}_{ij} = \sum \left(\frac{N_j}{N} \right) \hat{p}_{ij} \qquad \text{(eq 2)}$$

where N_j equals the total number of fish of a given age or sex passing through the weir during week j, and N is the total number of fish of a given species during the run.

Personnel and Operational Requirements

A successful weir project requires a dedicated and professional staff. Typically, projects will be staffed by a crew leader who is a fishery biologist. The crew leader is responsible for the day-to-day operation of the weir, including determination of crew schedules and daily tasks, quality control of data, and overall project performance. Crew members are responsible for following crew leader's instructions of the and ensuring that tasks are completed in a safe manner that is consistent with project objectives. When possible, project personnel should be hired locally from surrounding communities. Locally hired personnel are likely to have personal experience in the area; such practices are an important step in establishing community support for the project.

The number of personnel required to operate a weir depends on the project. Crew members should always work in pairs to ensure safety. If few fish are encountered, a two- or three-person crew may be sufficient to sample fish and maintain the weir. Projects intended to count large numbers of salmon around the clock may require up to eight people.

Equipment

- Weir and traps
- Boats (if needed to reach weir site)
- Dip nets for collecting fish from trap
- Scales and measuring boards
- Sample containers or cards for scale and genetic samples
- Floodlights (for night work)
- Tools and equipment for maintaining or repairing weir
- Camp equipment, including tents and cooking gear
- Safety equipment (fire extinguishers, personal flotation devices, medical kits, etc.)
- Radio, satellite phone, or other means of communication
- Brooms or rakes for cleaning front of weir

Budget Considerations

Estimated costs

Generally there is a positive correlation between project cost and remoteness of the site. Approximate amounts for two differing kinds of weirs (a picket weir and a floating weir) are shown in the following budget breakdown; costs are in U.S. dollars as of 2005.

Item	Quantity	Cost per weir (USD)
Picket weir with one trap	30 m length	$ 65,000
Floating weir with one trap	60 m length	$100,000
Lighting system for river and camp	Varies by project design	$100–2,000
Field gear for remote site (e.g., tents, sleeping bags, stove, water system)	Per person	$1,000

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Appendix A: Pre-season checklist used to prepare the Kwethluk River weir project, U.S. Fish and Wildlife Service, Kenai, Alaska\

- ❑ Determine Field Schedule ____________
- ❑ Set-up Contract Funding ____________
- ❑ Build New & Replacement Parts ____________
- ❑ Hire Local Crew (see below) ____________
- ❑ Hire USFWS Crew (see below) ____________
- ❑ Coordinate Short-Term Volunteers (see below) ____________
- ❑ Train Crew ____________
- ❑ Issue gear to Crew ____________
- ❑ Crew Schedules to Kwethluk ____________
- ❑ Update Supplies According to Inventory List ____________
- ❑ Initiate Satellite Phone Account ____________
- ❑ Initiate grocery Accounts ____________
- ❑ Initiate Fuel Account ____________
- ❑ Ship Supplies (Consider HazMat Lead-Time) ____________
- ❑ Update Field Procedures ____________
- ❑ Update Emergency Procedures & Acquire Signatures ____________
- ❑ Brief Crew on Emergency Procedures ____________
- ❑ Set-Up Field Computer ____________
- ❑ Make Travel Arrangements ____________
- ❑ Refuge for Bunkhouse arrangements ____________
- ❑ Ship Vehicle, ____________
- ❑ Ship Boat ____________
- ❑ Vehicle Key ____________

Hire Local Crew:	Position	Contact #
❑ 1. ____________	____________	____________
❑ 2. ____________	____________	____________
❑ 3. ____________	____________	____________

Hire USFWS Crew:		
❑ 1. ____________	____________	____________
❑ 2. ____________	____________	____________

Coordinate Short-Term Volunteers:		
❑ 1. ____________	____________	____________
❑ 2. ____________	____________	____________
❑ 3. ____________	____________	____________
❑ 4. ____________	____________	____________

Train Crew:	1st Aid/CPR	Watercraft	Bear/Firearms
❑ 1. ____________	______	______	______
❑ 2. ____________	______	______	______
❑ 3. ____________	______	______	______
❑ 4. ____________	______	______	______
❑ 5. ____________	______	______	______
❑ 6. ____________	______	______	______
❑ 7. ____________	______	______	______

Issue Gear to Crew:	Hip Waders	Chest Waders	Rain Gear	Sleeping Bag	Other
❑ 1. ____________	❑	❑	❑	❑	______
❑ 2. ____________	❑	❑	❑	❑	______
❑ 3. ____________	❑	❑	❑	❑	______
❑ 4. ____________	❑	❑	❑	❑	______
❑ 5. ____________	❑	❑	❑	❑	______
❑ 6. ____________	❑	❑	❑	❑	______