U.S. Fish & Wildlife Service

Design and Performance of a Digital Video Monitoring Station Incorporated in a V-Shaped Resistance Board Weir

Alaska Fisheries Technical Report Number 91

King Salmon Fish and Wildlife Field Office
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Jeffry L. Anderson, Nicholas J. Hetrick, Dan Spencer, James P. Larson, and Marlon Santos

Abstract

The King Salmon Fish and Wildlife Field Office operated a fish counting weir on Big Creek to monitor Pacific salmon *Oncorhynchus* spp. escapement from 2000 to 2004. This study was also used as a platform to modify weir designs to minimize impacts to anadromous and resident fish species. A modified resistance board weir was constructed and installed in a V-shaped formation that directs upstream migrant fish to a live trap and video passage chute positioned at the apex of the V. An underwater video monitoring station was incorporated into the weir that used a digital video recorder and motion detection algorithms to record high quality images of fish passage. The ability to replay video files repeatedly in slow motion and to pause on individual frames allows reviewers to accurately identify species, identify individuals within groups, and determine direction of travel. The video system also functions well in turbid water, and has removed much of the variability associated with observation conditions that can affect the accuracy of live counts. Monitoring nighttime migration with our system was problematic, although the use of infrared instead of white light should improve system performance at night.

Introduction

Fisheries managers currently use a variety of techniques and equipment for monitoring Alaska's renowned runs of Pacific salmon *Oncorhynchus* spp., including fish weirs, counting towers, sonar, mark-recapture, aerial surveys, and other methods (Cousens et al. 1982). Although these methods continue to evolve, most require a substantial commitment of personnel and funding and at times, may result in information that lacks the accuracy necessary to make sound management decisions. Difficulty in monitoring salmon populations in Alaska is often compounded by its remoteness. Harsh weather, a lack of reliable electrical power, and logistical and financial constraints all contribute to the challenge of gathering data necessary to conserve wild fish populations.

Fish weirs are one of the most commonly used and widely accepted tools for assessing salmon runs in Alaska (Cousens et al. 1982; Duesterloh 2005). Weirs are considered the most accurate technique for estimating escapement of Pacific salmon when they are feasible to install and operate, and are often used as the benchmark to which other methods are compared (Cousens et al. 1982). Although weirs can provide an accurate means of enumerating annual spawning migrations, these data may be biologically costly. There is a growing concern among fisheries professionals and with the public about potential adverse impacts that weirs may have on fish health, run timing (Ricker and Robertson 1935; Hevlin and Rainey 1993), and spawning success. The physical handling of salmon at weirs to collect length, age, and sex information can increase stress levels and may cause injury to fish (Stickney 1983; Wedemeyer et al. 1990). The potential for disease transmission may also be increased because of crowding (Neish 1977) that is often

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observed downstream of fish weirs (Ricker and Robertson 1935) and inside live traps (Underwood et al. 2004). Crowding can occur during the day as fish may be reluctant to pass through or have difficulty locating the passage chute(s) installed in weirs for counting fish (Sumner 1953). Crowding can be compounded at night as the passage chutes are often closed.

A recent focus of the King Salmon Fish and Wildlife Field Office (KSFO) has been to develop methods for monitoring salmon runs that minimize potential impacts on fish and the environment. We operated a fish counting weir on Big Creek to monitor Pacific salmon escapement from 2000 to 2004, and used this study as a platform to modify weir designs to minimize impacts to anadromous and resident fish species. We initially used a traditional fixed picket weir installed perpendicular to stream flow in 2000 and early 2001 to monitor fish passage. The fixed picket structure did not work well during high water events, which are common during the fall. Also, because the weir was installed perpendicular to stream flow, fish needed to expend time and energy to find the passage area. The fixed picket design was replaced with an angled resistance board weir in late summer 2001. The angled design helped direct fish to the preferred passage area and the floating structure was able to withstand high stream flows in the fall. Whitton (2003) provides details of earlier weir construction at Big Creek.

In 2002, the Big Creek weir was replaced with a resistance board weir modeled after designs reported by Tobin (1994), with modifications so that it could be constructed and installed in a V-shaped formation to direct upstream migrant fish to a live trap and video passage chute positioned at the apex of the V. We also began using underwater video technology in 2002 to assist in monitoring fish passage at the Big Creek weir. This technology was used throughout the 2003 and 2004 seasons to monitor fish movement past the weir. The biological aspects of the Big Creek weir project are detailed in Whitton (2003), Anderson et al. (2004), and Anderson (2005). This report highlights the modification of our weir from Tobin (1994) to a V-shaped design, the design and performance of the underwater video monitoring station at the Big Creek weir, and improvements to the video monitoring system implemented in our 2005 monitoring projects.

Study Area

Big Creek originates in the southern mountains of Katmai National Park and flows northwest about 60 km before joining the Naknek River, 6 km east of King Salmon, Alaska (Figure 1). The drainage is comprised of numerous tributaries, small lakes, and ponds and is almost entirely located within the boundaries of Becharof National Wildlife Refuge. Big Creek is a clear water stream that supports Chinook *Oncorhynchus tshawytscha*, chum *O. keta*, coho *O. kisutch*, pink *O. gorbuscha*, and sockeye *O. nerka* salmon, and spawning populations of rainbow trout *O. mykiss*, Dolly Varden *Salvelinus malma*, Arctic grayling *Thymallus arcticus,* and northern pike *Esox lucius*. Round whitefish *Prosopium cylindraceum*, longnose sucker *Catostomus catostomus*, and lamprey *Lampetra* spp. are also present in Big Creek. The weir site is 35 km upriver from the confluence of Big Creek and the Naknek River. This section of the stream is characterized by glides and riffles flowing over sand, gravel, and small cobble substrate. Willow *Salix* spp., birch *Betula* spp., and grasses dominate the riparian zone. Maximum discharge often occurs during spring breakup, but high discharge also occurs during periods of heavy rainfall between late July and October.

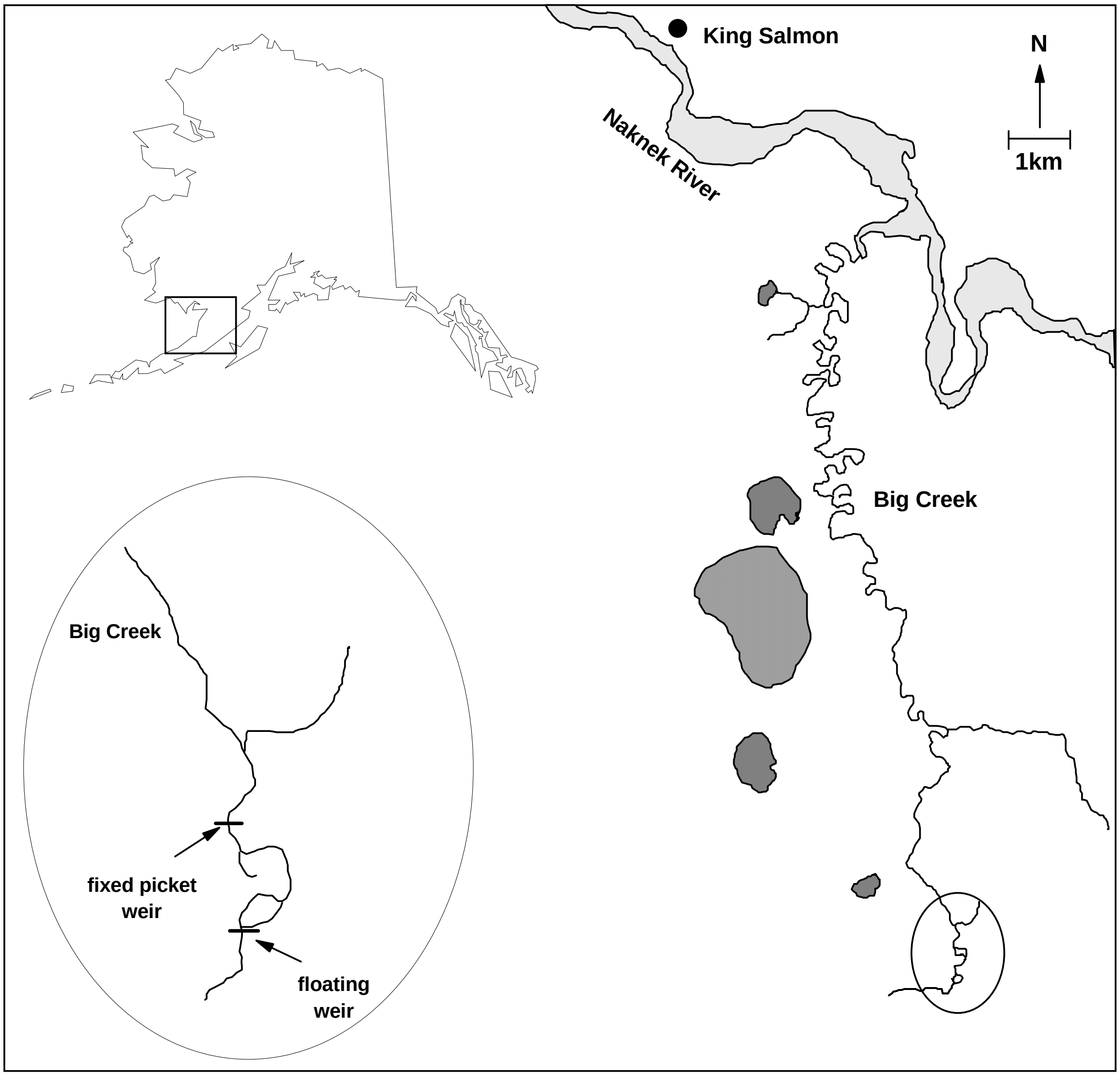


Figure 1. Big Creek study area showing the fixed picket weir site used during 2000 - 2001, and the floating weir site used from September 2001 to September 2004, Becharof National Wildlife Refuge.

System Design and Components

V-Shaped Resistance Board Weir

The Big Creek weir used from 2002 to 2004 was modeled after designs reported by Tobin (1994), with modifications that allowed it to be constructed and installed in a V-shaped formation to direct upstream migrant fish to a video monitoring chute positioned at the apex of the V (Figure 2). We also made several modifications to simplify construction and installation of the weir. The metal substrate rail used by Tobin (1994) was replaced with two 8-mm diameter aircraft cables anchored to the substrate to form the left and right sides of the V. The substrate cables were connected through 25-mm square steel pipe welded to the top of iron H-shaped supports that were anchored to the stream bed using rebar spikes, and through shackles connected to Duckbill anchors (Figure 3). Two pieces of 25-mm square steel pipe were welded to the top of the H-shaped supports, and the substrate cable was run through the top pipe to maintain a small gap between the cable and the streambed (Figure 3). The H-shaped supports and Duckbill anchors were distributed evenly along the length of the cables to prevent bowing. An apron of plastic mesh was anchored to the substrate beneath the substrate cable using rebar spikes instead of the chain link fence described by Tobin (1994). We used rigid weir panels instead of plywood described by Tobin (1994) to form the bulkheads at each end of the floating weir. Rigid weir panels were also used to block off remaining space between the left and right bulkheads and respective stream banks.

Floating weir panels were constructed from 4.6-m lengths of schedule 40 polyvinyl chloride (PVC) pipe pickets separated by 38-mm lengths of PVC (spacers). The spacers were constructed from 13-mm diameter PVC with ends cut at 30° angles. Aircraft cable (3-mm diameter) was used to string the pickets and PVC spacers together, instead of the polyethylene and wood stringers described by Tobin (1994). Weir panels were constructed at a 30° angle, with the angle of the panels transposed for the left and right side of the apex. Holes to pass the stringer cable through each picket were also drilled to maintain the overall 30° angle of the panels; pickets were not watertight. Aluminum stop sleeves were attached to the ends of the stringer cables to create 1.2-m wide panels. Six stringer cables were installed on each panel to provide rigidity. The downstream (floating) end of each picket was capped, and six evenly spaced hooked end caps were fixed to the upstream ends of pickets on each panel to allow for attachment to the substrate cable. Adjustable resistance boards were constructed of plywood (6 mm) and waterproof foam insulation (38 mm), and were attached to the downstream end of panels to provide flotation as described by Tobin (1994). Panel-to-panel connections were made with polyethylene yokes as described by Tobin (1994). Five floating panels (0.6-m wide) were modified to allow boats to pass the weir. Boat passage pickets were heated and turned downward 45° as described by Tobin (1994). Two floating panels were modified to allow for fish passage into the video monitoring chute and live trap.

Video Monitoring System

A video monitoring system was incorporated into the weir to facilitate fish passage and reduce the number of fish handled. The system included an underwater camera, camera box, video monitoring chute, lights, and a digital video recorder.

Figure 2. Overview of the V-shaped resistance board weir used at Big Creek from 2002 to 2004.

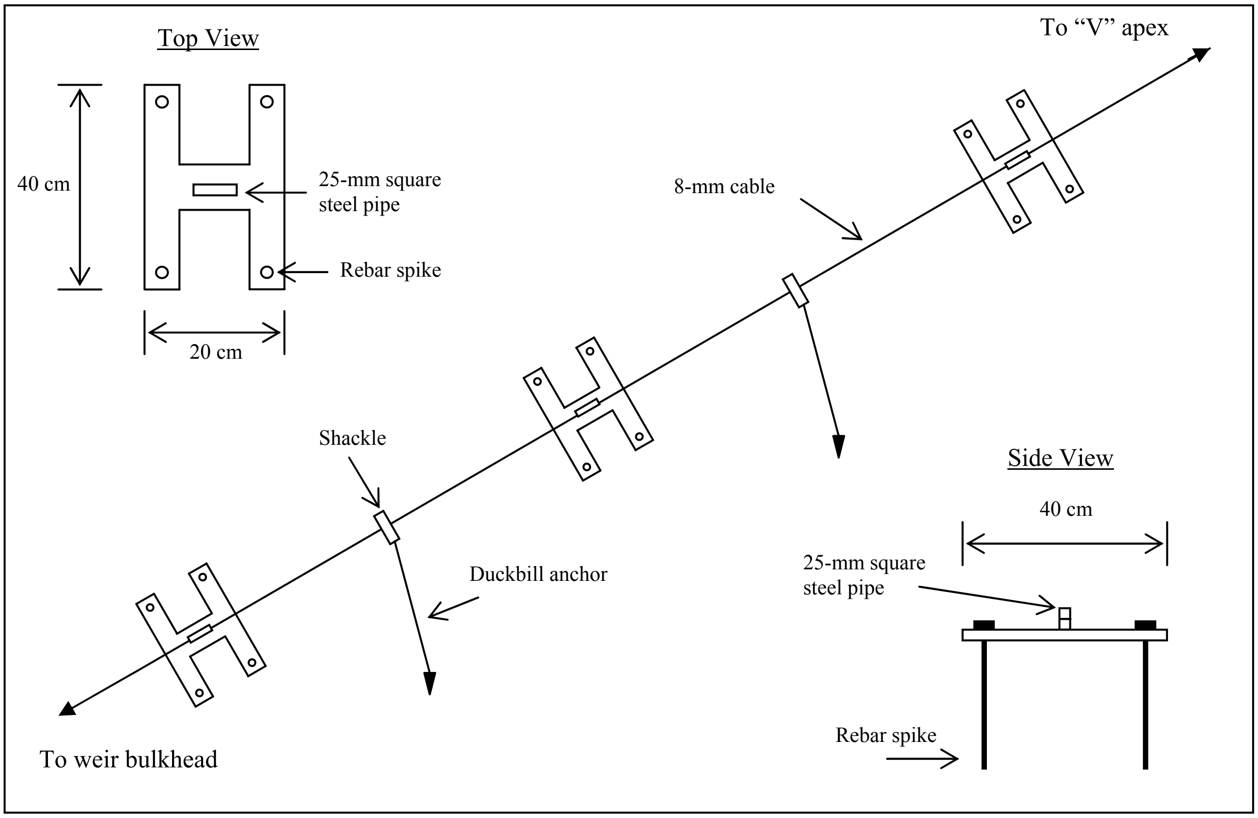


Figure 3. Detail of iron H-shaped supports and a schematic of their use in combination with Duckbill anchors to anchor the substrate cable. Drawings are not to scale.

Camera- In 2003, KSFO used an Applied Microvideo Model 10 underwater video camera system. The Model 10 system included a Sony 410,000 pixel Super hole-accumulation diode (HAD) charge-coupled device (CCD) imager attached to a fixed-focus, auto-iris 3.6-mm wide angle lens. The camera was rated at 480 lines of horizontal resolution. The camera and lens were mounted in a sealed, waterproof aluminum housing. In 2004, we used an Applied Microvideo Model 250 underwater video camera system. The Model 250 system consisted of a Sony 440,000 pixel Super HAD CCD imager attached to a variable focus, auto-iris wide angle 18x-magnification zoom lens mounted in a sealed, waterproof aluminum housing, rated at 470 horizontal lines of resolution. Control of the Model 250 camera was provided with a remote pendant located near the video monitor, or via software loaded on a computer connected with an RS-232 cable. The camera had automatic settings for focus and exposure (iris and shutter speed). Manual controls on the remote pendant included zoom, focus, freeze frame, iris, shutter speed, and backlight compensation. We operated the camera in manual focus mode, and used the automatic exposure features (iris and shutter speed). We did not use the software control after initial testing confirmed that the automatic exposure settings performed better than we could with manual adjustments.

Camera box- The underwater video camera was mounted in a sealed aluminum camera box filled with filtered water and treated with an algaecide. The camera box was sized based on camera focal length to maximize the field of view while minimizing overall dimensions. The camera box was constructed of 3-mm aluminum sheet with the sides cut to proper size and welded together (Figures 4 and 5). Images were collected through a clear safety-glass window fixed to the front of the camera box. The distance between the camera and glass was approximately 75 cm, but could be adjusted from 50 to 90 cm by using adjustable rails welded to the camera box interior (Figure 6). This separation between the glass and camera lens was necessary to obtain full frame images of large Chinook salmon. The sealed camera box was developed to allow underwater video equipment to operate in the fall when frequent rains often create turbid water conditions. In turbid water, image quality is maintained as the majority of the distance between fish and the lens is within the filtered clear water contained in the camera box.

Access to the camera box was provided with two aluminum hatches on the top of the box, one near the glass and one directly over the camera and lights (Figures 4 and 5). Permanently mounted bolts were used to secure the hatches and a neoprene gasket was used to form a watertight seal. Video and power cables for the camera and lights were routed through an 18-cm length of 5-cm outside diameter aluminum standpipe welded to the top of the camera access hatch (Figure 5). A watertight seal in the standpipe was achieved using waterproof expanding foam and silicone caulk. An adjustable locking support was fixed to the back of the camera box (Figure 5). The support was constructed of a 7.6-cm length of 5-cm inside diameter aluminum pipe, welded to the back of the camera box. A 1-m length of 4.7-cm outside diameter aluminum pipe with parallel holes drilled through it along its length was then positioned inside the 5-cm inside diameter pipe, and a clevis pin was used to lock the support at the desired height. A submergible electric water pump and an in-line filter were used to clear river water to use inside the camera box. Filtered water was added through two water intake standpipes welded to the top of the camera box (Figure 5). The water intake standpipes were 10-cm lengths of 2.5-cm outside diameter aluminum pipe. Flexible plastic hose was fitted over the water intake standpipes and threaded watertight stoppers were attached to the other end.

Video monitoring chute- The camera box was attached via a track system to a video monitoring chute (Figures 5 and 7) that was connected to the weir with a modified panel at the apex of the V. The chute was constructed from angled aluminum and plywood and functioned as a fish passage chute that isolated the camera from external light. This created a controlled lighting environment that was necessary to allow the motion detection system to function properly. A gate was installed that allowed us to block passage through the video monitoring chute for system maintenance and to capture fish in the live trap for biological sampling. In 2004, a D-shaped baffle was installed at the back of the video monitoring chute forcing fish to pass within 25 cm of the camera box. This improved picture quality and performance of the motion detection processing when stream water was turbid.

Lights- In 2003, the video monitoring chute was lit from above and below by four, 1.2-m long, 12-V DC, 40-W underwater fluorescent light fixtures. The fluorescent lights flooded the video monitoring chute with artificial light, which provided a constant light environment regardless of ambient lighting conditions. In 2004, we used two of the same fluorescent lights, one mounted above and one mounted below the camera box opening. We also added two 12-V DC, 35-W underwater halogen lights mounted near the camera (Figure 6). The halogen lights were positioned to minimize backscatter and disperse lighting to eliminate “hot spots” while still providing enough illumination to identify fish. During normal operation in 2004, only the halogen lights were used; all lights were used during turbid water conditions.

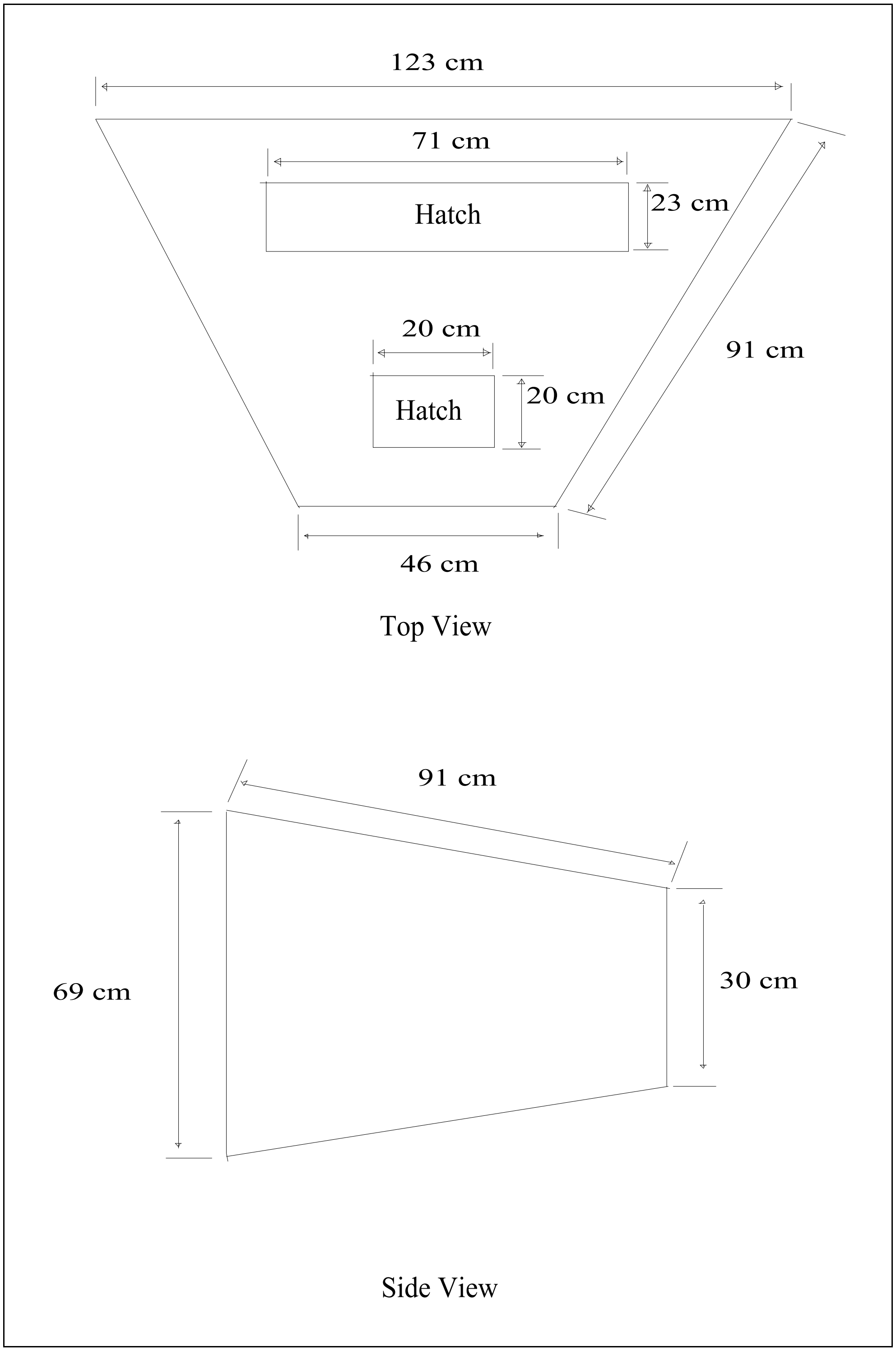


Figure 4. Dimensions and schematic for the camera box used at the Big Creek video monitoring project, 2003 and 2004. Drawings are not to scale.

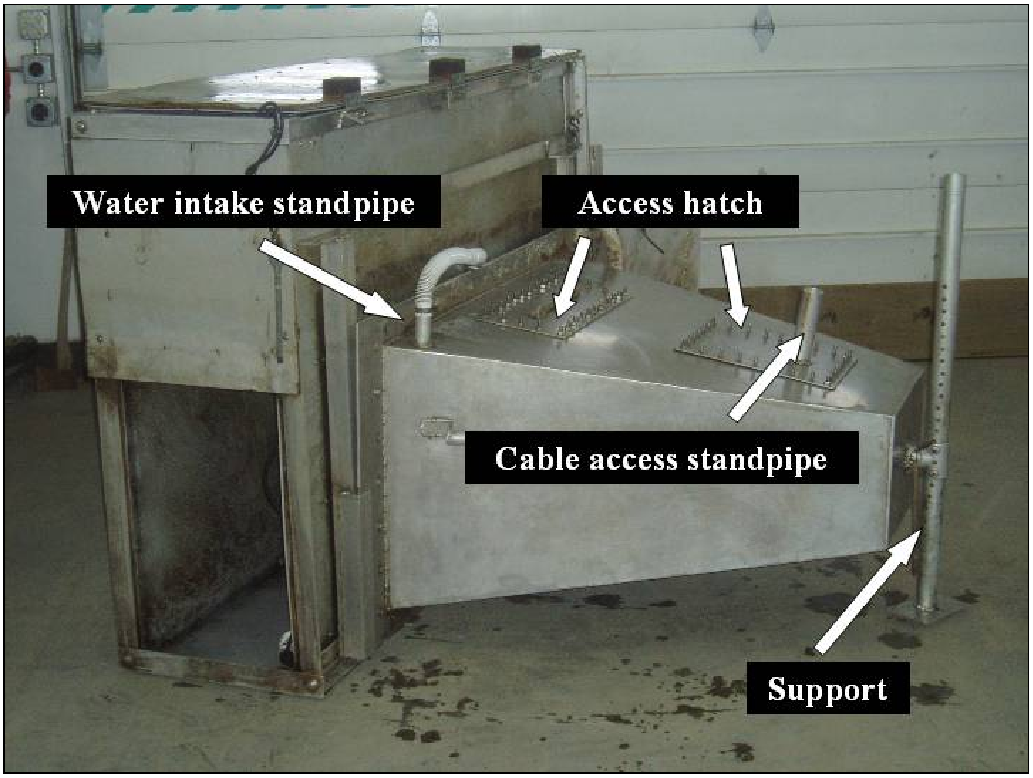


Figure 5. Camera box (top) and connection to video monitoring chute (bottom) used at the Big Creek weir, 2003 and 2004.

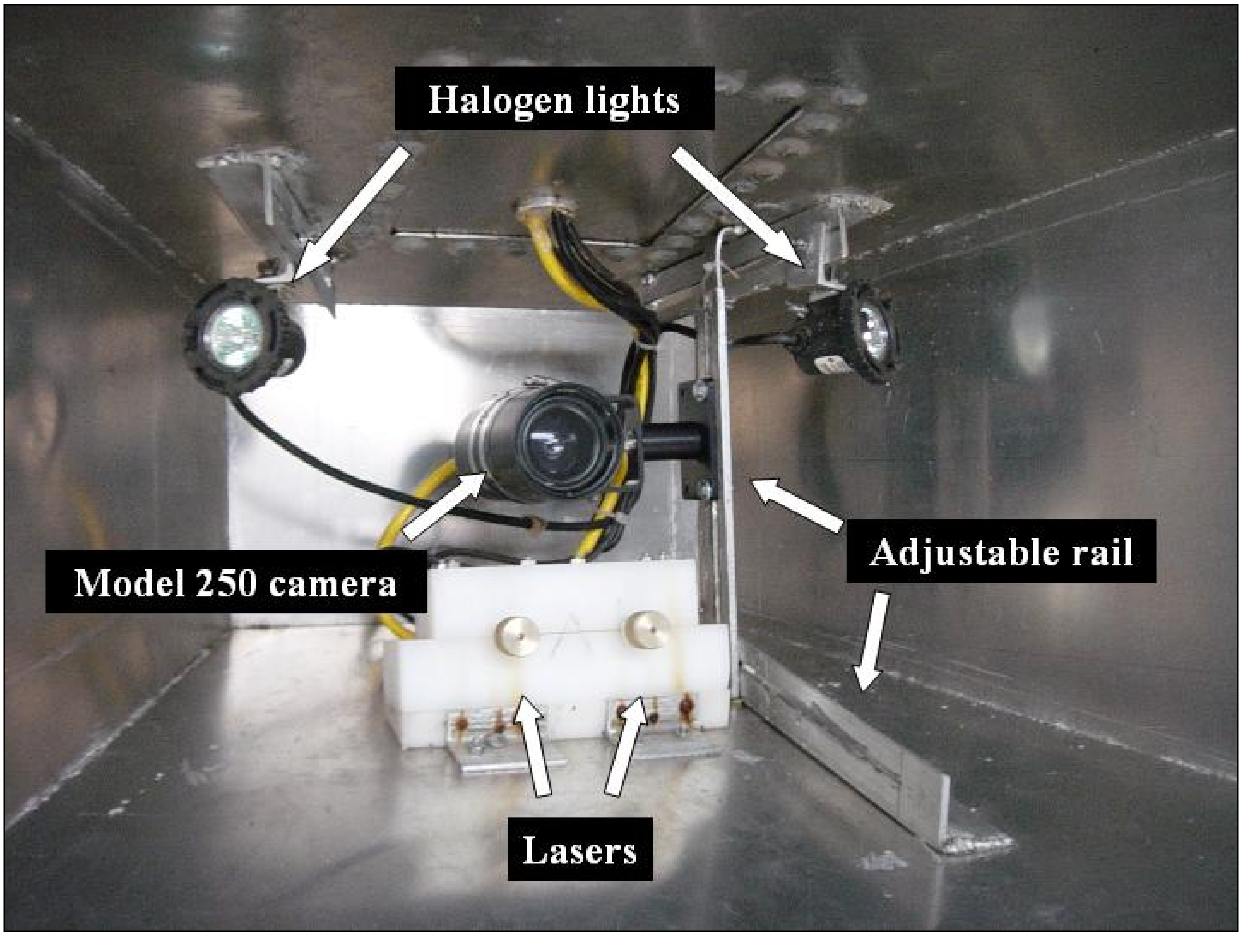


Figure 6. View of camera box interior showing equipment used in 2004.

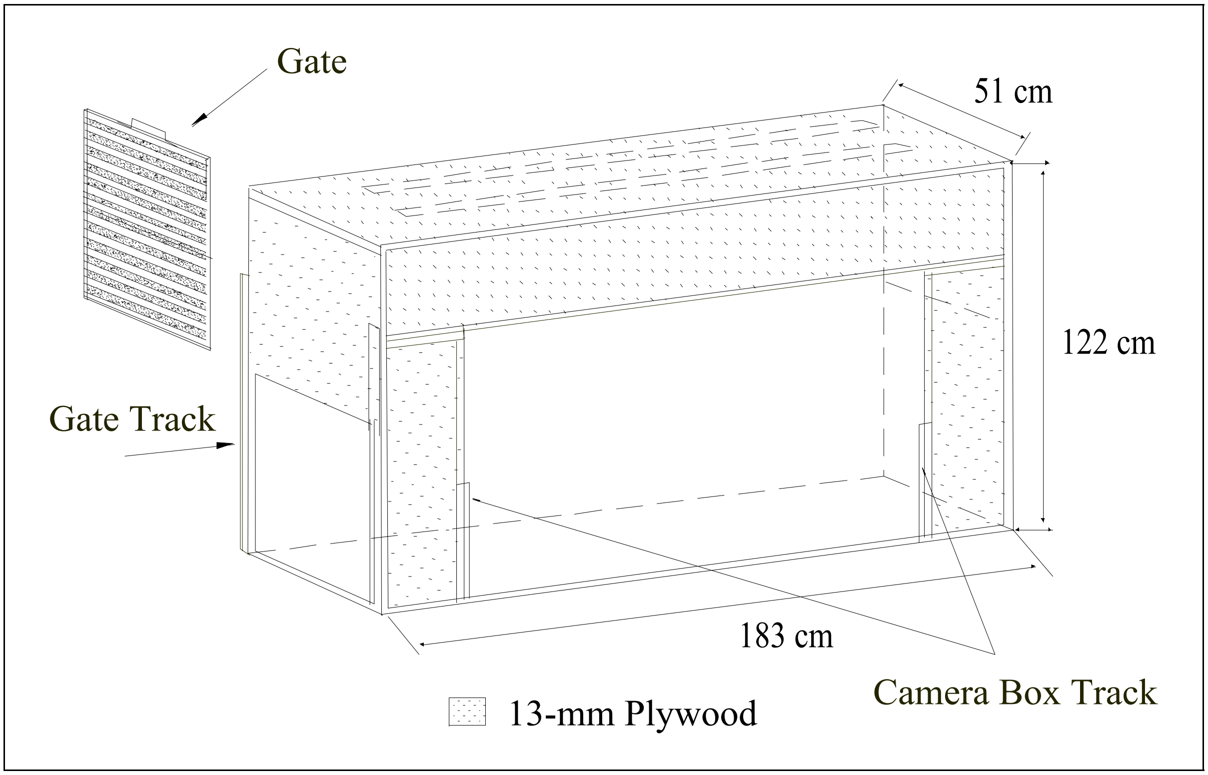


Figure 7. Dimensions and schematic for the video monitoring chute used at the Big Creek video monitoring project, 2003 and 2004. Drawing is not to scale.

Digital video recorder- The underwater video camera was connected to a Sanyo DSR-3000 digital video recorder using a shielded coaxial cable. The unit was connected to power and left on 24 h/day to avoid potential condensation issues associated with a field environment noted by Hetrick et al. (2004). Video images were recorded digitally on the hard disk using a proprietary motion JPEG (Joint Photographic Experts Group) compression-decompression algorithm (CODEC). The digital data streams were then processed using motion detection algorithms. Photographic motion detection processing was used to eliminate blank or “fishless” video footage, thereby limiting recorded footage to files that included fish passage. When functioning properly, motion detection processing minimizes time required to review stored video files to identify and count passing fish (Hatch et al. 1998; Hetrick et al. 2004; Anderson 2005). Motion detection recording was activated in response to a moving object causing a change in the brightness in user-defined detection zones with user-defined trigger sensitivity. This required background light levels to be fairly constant, and provide a contrast with images of fish.

Effectiveness of motion detection was assessed by comparing fish counts taken from motion-triggered video files to counts tallied in real-time by observers monitoring the live video display. Observers recorded numbers and species of fish passing through the video monitoring chute for 60 min and noted whether every fish that passed through the field of view caused a motion-triggered video file to record. We then reviewed the recorded motion-triggered video files and compared counts of each species to the live observations. We also noted the number of video files recorded, time required to review the footage, and the number of false triggers for each trial.

A false trigger was defined as a motion-triggered video file that was triggered by anything other than a fish, such as debris or drastically changing light conditions. Motion detection efficacy was checked periodically during the field season.

After the motion detection was verified to be functional, fish counts were made by reviewing motion-triggered video files. We used the time/date search function of the DSR-3000 to retrieve the first file to review. The "Play" button was pressed and the recorded file would play back on the monitor. The DSR-3000 had numerous file review features that assisted in identification and counting of passing fish. The image could be played forwards or backwards at various speeds, or paused and zoomed to assist in counting or species identification. Once all fish in a file were identified and counted, the next file was reviewed. Video files were reviewed sequentially until all fish passing through the video monitoring chute were identified and counted.

The digital video recorder was configured to record a 3-s pre-event in a memory buffer so the recorder could access and record the video that preceded each motion-triggered event. Motion-triggered video files were set to record for 10 s, but video footage would continue to record as long as fish were activating the motion detection. For a single fish passing directly through the video monitoring chute, 13 s of video were recorded (3-s pre-event plus 10-s motion-triggered event). The date, time, file number, and percent of remaining hard disk space were digitally encoded as a date-time stamp on each video file.

Most video was recorded on the digital video recorder at 10 frames/s, at the highest image quality setting ("superfine", 720 x 486 pixels, 50 kB per frame; Sanyo 2004). The hard disk capacity of the DSR-3000 was 160 GB. With the settings described above, the DSR-3000 was able to record 37 h of video before hard disk space was exceeded. During normal operations at Big Creek in 2003 and 2004, we reviewed recorded fish passage the same day it occurred, and hard disk capacity was not a limitation to system performance.

Microwave Link

SeeMore Wildlife Systems installed a microwave system at the Big Creek weir in 2004 that allowed us to broadcast live images from the underwater camera at Big Creek to receivers at the U. S. Fish and Wildlife Service Visitor Center in King Salmon and KSFO (Figure 8). We used this system to demonstrate the utility of the equipment for remote monitoring of fish passage projects. The microwave system allowed for full bandwidth transmission of the video signal, providing a television-quality picture to both receiver sites in King Salmon. A pan-tilt-zoom (PTZ) camera was also installed on a 5-m tall tripod tower at the weir site that was remotely controlled at the Visitor Center. Visitors could switch between views from the underwater and overhead cameras and viewed the video signal on an 81-cm diagonal flat panel monitor mounted on a wall. Switching between cameras and control of the PTZ camera at the Big Creek weir was provided by SeeMore Wildlife Systems camera control software on a computer located at the Visitor Center. Video and audio connections were also available, enabling visitors to record video from the system to a personal camcorder. A second microwave receiver was installed at KSFO, but we did not have the ability to switch between camera views; we received the video signal from whichever camera was selected on the computer at the Visitor Center. Because the Big Creek weir site is located in a depression that precludes sending a direct line-of-sight signal to receivers in King Salmon, a repeater was used to pass the microwave video signal back to King Salmon, and to pass the ultra high frequency (UHF) camera control signal to the weir (Figure 8). The repeater was set up on a hilltop near the Big Creek weir such that line-of-sight

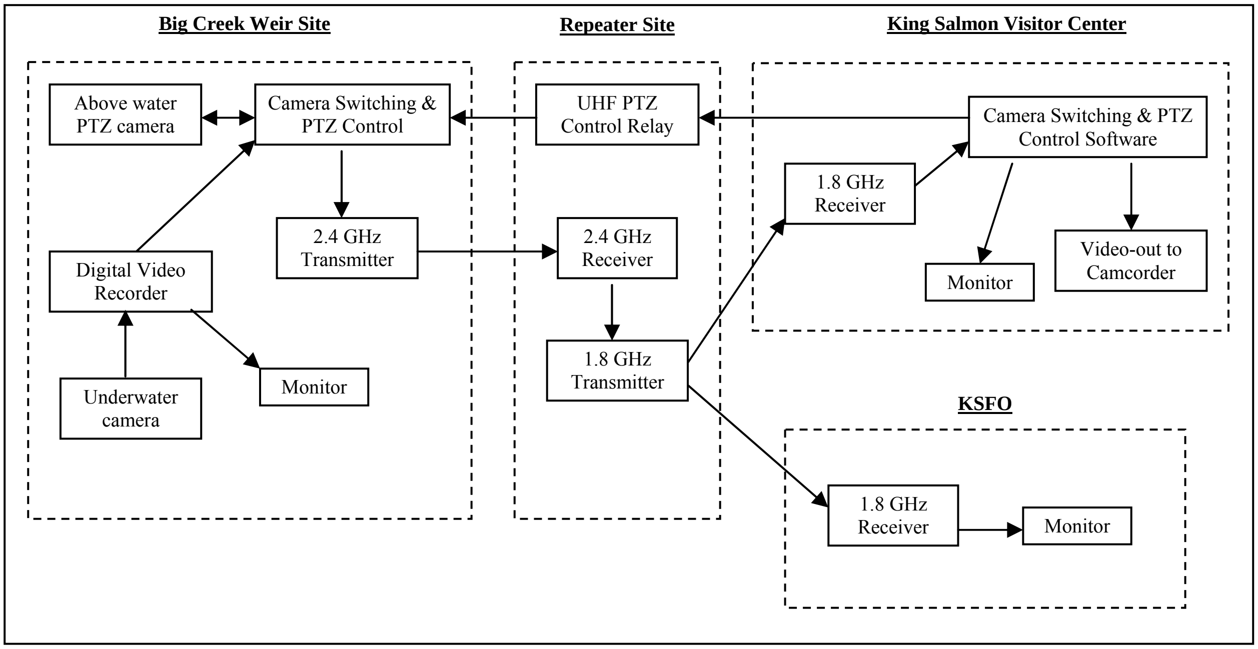


Figure 8. Schematic of video and control signal flow for the Big Creek video monitoring project, 2004.

signals were possible between the weir site and repeater (1 km), and between the repeater and King Salmon (20 km).

Remote Power Generation

Primary power at the Big Creek video monitoring station was provided by two photovoltaic (PV) arrays and a 12-V DC battery bank (Figure 9). Each PV array consisted of four 90-W solar panels connected in parallel, producing a maximum output of 360 W (720 W for the two arrays). Each array was wired through a separate solar charge controller so that solar energy would be provided to the battery bank regardless of a failure in either array circuit. We used eight 12-V DC sealed lead acid absorbed glass mat (AGM) deep-cycle batteries, rated at 100 ampere-hours (Ah) each, and connected them in parallel to form a bank with a total storage capacity of 800 Ah. The PV arrays charged the battery bank, which provided power to our DC loads (lights, microwave equipment, PTZ camera) and to a 1,000-W DC to AC pure sine wave power inverter that provided power to the AC loads (monitor, digital video recorder, underwater camera transformer). A 175-A DC disconnect breaker isolated the battery bank from the DC loads and power inverter. A 3,000-W gasoline-powered generator and 75-A battery charger were also used as a backup power source when solar energy did not meet our needs. Power at the microwave repeater site was provided by a system comprised of two 80-W solar panels connected in parallel, a 15-A solar charge controller, and two 12-V DC, 55-Ah deep-cycle AGM batteries connected in parallel.

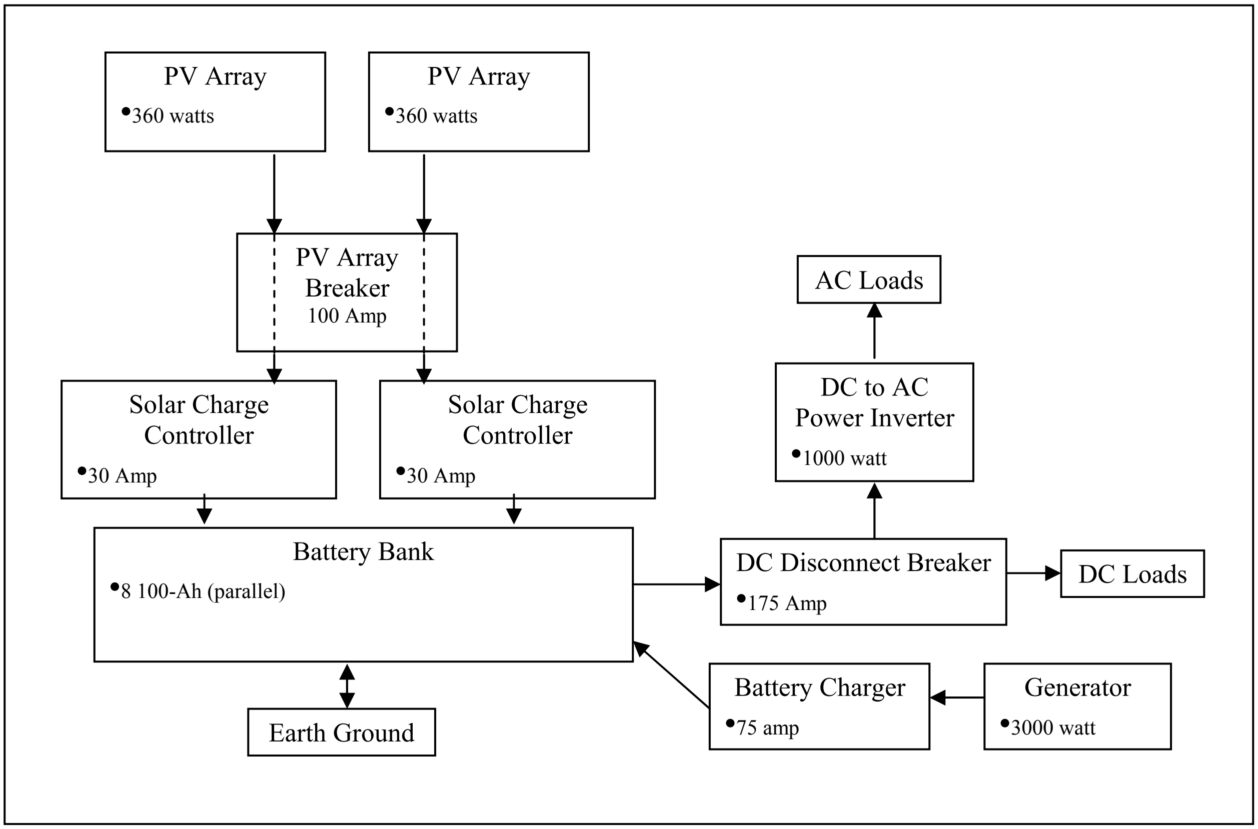


Figure 9. Power schematic for the Big Creek video monitoring project, 2003 and 2004.

Performance

V-Shaped Resistance Board Weir

The V-shaped resistance board weir functioned well from its initial installation in June 2002 until the project was completed following the 2004 field season. We installed the weir panels each year in late June and removed them in the fall; the substrate cables remained in place for the duration of the project. Although high stream flows would overcome the floatation provided by the resistance boards and cause the structure to submerge, the weir would float itself again as soon as the flood waters subsided. We did not collect enough stream discharge data to determine the stream flow threshold that caused the weir to fail. From late June 2002 until its final removal in September 2004, the Big Creek weir was operational and fish tight for 257.5 out of 270 days (95% effectiveness). The weir was operated from 29 June until it was submerged by high water on 7 September 2002, and was not fish tight on five occasions for a total of four days due to broken rigid weir panels. The submergence of the weir on 7 September prevented us from counting most of the coho salmon run in 2002, as the run usually peaks in mid- to late September (Whitton 2003; Anderson 2005). In 2003, the weir was operational from 26 June until it was submerged on 2 October, and was not fish tight on two occasions due to high water for a total of 1.5 days. In 2004, the weir was operated from 22 June until it was submerged by high water on 20 September, and was submerged on three occasions for a total of seven days. Although the weir was submerged on 20 September 2004, we were able to count coho salmon passage with the video monitoring equipment until 29 September when high water made it unsafe to operate the electronic equipment.

The most difficult task when installing the V-shaped resistance board weir was anchoring the substrate cables on the stream bottom. This task required divers in dry suits to position and drive re-bar stakes and Duckbill anchors into the substrate. However, once the cables were initially set in late June 2002, they remained in place and fully operational through the 2004 field season. The complete weir installation in 2004 required 72 h. Prior to weir installation, two divers in dry suits worked for 8 h to ready the substrate cables, which required removing sediments that had accumulated over the previous winter and spring. The installation of the floating weir panels was accomplished with a crew of four persons in 6 h. Two crew members in dry suits secured the weir panels to the substrate cables with hooks, and two floated the panels into position and held them until divers secured them to the substrate cables. Four crew members worked an additional 8 h to construct the rigid weir panel bulkheads and sections on either end of the floating panels to make the weir fish tight.

The weak link in our design was the rigid weir panel bulkheads and sections on either side of the floating panels, as they were the first sections subject to failure during high water events. High water and high debris loads also damaged the rigid weir panels, necessitating repairs and reconstruction. The PVC pickets of the floating weir panels were also broken, mainly due to people walking on them. Repairing the floating weir panels between years consisted of replacing broken pickets and re-stringing panels with aircraft cable.

The weir was designed with the video monitoring chute as the primary fish passage area, located at the apex of the V. This sometimes made it difficult to capture fish in the live trap, as the trap entrance was not at apex of the V (Figure 2). Depending on fish densities, this necessitated closing the entrance to the video monitoring chute for several hours, or sometimes even all day, to capture enough fish in the live trap to meet our biological sample size goals.

We did not quantify initial weir construction hours as did Tobin (1994). However, construction of our weir without making individual pickets watertight saved us considerable time and effort. The weir flotation was not affected by the non-watertight pickets, as the lift and tension forces supplied by the resistance boards (see Tobin for discussion) were adequate to keep the structure above water during all but flood conditions.

Video Monitoring System

Camera- The underwater cameras operated properly in 2003 and 2004, and no major problems occurred. The Model 10 camera used in 2003 was adequate for identifying and counting resident and migratory fish. Although the wide angle lens was useful in obtaining a sufficient field of view, the barrel distortion had a warping effect on passing fish. The improved optics of the Model 250 camera reduced this distortion considerably. The image quality of the Model 10 camera was also affected by blooming. The iris of the camera adjusted to the neutral grey background of the video chute. Fish that passed through the chute in close proximity to the fluorescent lights would often reflect light back at the camera, essentially creating a hot spot due to the slow response time of the auto-iris. The Model 250 camera featured a more advanced and faster auto-iris that reduced blooming.

The Model 250 camera used in 2004 had better overall picture quality than the Model 10. The manual focus and zoom features of the Model 250 were also improvements, and helpful in achieving a sharp picture. We attempted to use the automatic focus setting on the Model 250 camera in 2004, but the camera would focus on different objects within the field of view and fish were sometimes out of focus during part of their passage through the video monitoring chute. We used the remote pendant to focus the camera manually on the back of the video monitoring chute, which allowed everything within the camera's depth of field to be in focus.

Camera box- The camera box was necessary to provide separation between the camera lens and fish to obtain full-frame images of large Chinook salmon. The in-line water filter used in 2004 was not able to remove all fine sediments and particulates, and we were unable to get perfectly clear water inside the camera box. After resting for 24 to 48 h, the particulate matter would settle out and the water inside the camera box would clear up considerably. It was necessary to clean the exterior of the camera box glass regularly, at least once per week, to remove algal growth. Access to the camera box interior was through a hatch on the top of the box and required the removal of 30 nuts, making it inconvenient to open the hatch and adjust the camera or lights.

Video monitoring chute- The video monitoring chute functioned well in 2003 in combination with the fluorescent lights, providing a controlled lighting environment for operation of the camera. However, we needed to modify the design in 2004 when we switched to halogen lights. Since the halogen lights did not flood the viewing area as the fluorescent lights did in 2003, external light was visible in the camera field of view. The external light entering the video monitoring chute affected the camera iris, causing incorrect exposure of the passing fish and background. Extensions to the video monitoring chute and floating plywood sunshades were installed to minimize the amount of external light entering the camera's field of view. We also needed to use cloth material to exclude external light entering through the gap between the camera box and video monitoring chute.

The addition of the D-shaped baffle to the video monitoring chute in 2004 improved picture quality in turbid water by reducing the amount of stream water in the depth of field from 51 to 25 cm. The fish were forced closer to the camera so less turbid water was between the camera and the fish, resulting in clearer images. Cleaning the back wall and baffle of the video monitoring chute was necessary at least once per week to remove algal growth.

Lights- The fluorescent lighting used in 2003 proved adequate for speciation and enumeration of resident and migratory salmonids. However, fish passing close to the camera box lacked consistent lighting. The fluorescent lights mounted above and below the camera box opening were able to illuminate the dorsal and ventral portions of these fish, but close proximity to the glass prevented direct lighting. The image of a fish passing close to the camera box glass was recorded as a dark silhouette (Figure 10). Although it was still possible to identify the species of these fish, the efficiency of this task was reduced.

The halogen lights installed inside the camera box in 2004 provided consistent direct lighting of fish. However, the overall aesthetics of the image were affected by reflection of the halogen lights off the camera box glass. The reflection resulted in hot spots that could not be eliminated without compromising the direct lighting necessary for identifying fish to species (Figure 10). Also, the halogen lights were not sufficient to flood the entire video monitoring chute with light, and ambient light affected the image quality. Sunlight entering either the upstream or

Figure 10. Captured still images illustrating the silhouette effect caused by the fluorescent lights in 2003 (top; northern pike) and the hot spots created by the halogen lights in 2004 (bottom; Chinook, chum, and pink salmon).

downstream end of the video monitoring chute would overpower the halogen lights. The auto-iris feature of the camera would set itself for this bright light, resulting in an underexposure of the rest of the image. This was not an issue in 2003 as the fluorescent lights overpowered all external light sources. Regardless of aesthetics, hot spots, and blooming effects, the lighting used in both years was more than adequate to count and identify fish to species during normal operation.

The fluorescent lighting and video monitoring chute in 2003 were functional in turbid water. We were able to identify and count fish passing during underwater visibilities of 25 cm. However, the light attenuated rapidly in turbid water making species identification difficult. The halogen lights used in 2004 penetrated the turbid water better than the fluorescents. However, the halogen lights functioned as spotlights in turbid water and provided poor lighting to the bottom corners of the video monitoring chute. The baffle mounted inside the video monitoring chute in 2004 forced fish to swim within 25 cm of the camera box glass, which allowed us to identify and count fish during underwater visibilities of less than 18 cm.

Digital video recorder- Operation of the DSR-3000 initially required considerable training before technicians were competent in its use. An experienced operator would provide on-site training during the first week of each field season and as new crew members joined the project. The DSR-3000 operated without failure through the 2003 monitoring season, and through the 2004 season until mid August, when both internal hard disks failed. Upon return from the manufacturer in early September, the unit functioned through the remainder of the field season. The DSR-3000 was user-friendly to setup and operate, and the controls and search features were essential for rapid sequential review of recorded files. The motion detection zones and sensitivity were also easy to define. Motion detection sensitivity and detection zone parameters needed few adjustments throughout the study period, although such changes were required under extreme environmental conditions. The motion detection sensitivity would need to be increased during high water events because turbid conditions reduced underwater visibility. The detection zones also needed occasional modifications during periods of low stream flow, as the water surface would appear in the viewing zone and the rippling action typically triggered motion detection recordings (false triggers).

Effectiveness of motion detection was tested on 28 occasions in 2004, and we were able to compare live observations to motion detection counts on 22 of the 28 occasions. On four occasions, fish count comparisons were not possible because the technician conducting the counts left the monitor to open and close the gate to the video monitoring chute, and therefore did not count all fish during the live count. On two occasions, we experienced failures of the motion detection system. Counts of all species were similar with both methods (Table 1). In general, the crew had a tendency to misidentify Chinook salmon jacks, pink salmon, and sockeye salmon during the live observations. It was also difficult to distinguish between rainbow trout and Dolly Varden during live observations when they moved quickly through the field of view or in large groups. The average fish passage rate during the 18 trials when valid start and stop times were recorded was 169 fish/h (range 5 to 477) and the average number of motion-triggered video files recorded was 49/h (range 22 to 96). False triggers occurred for 40 of 1,490 (< 3%) motion detection events recorded during all trials in 2004; most false triggers were caused by drifting debris. Over all trials, 30.7 hours of video footage were recorded, which required 12.4 hours for technicians to review, a 60% time reduction compared to live observations.

Table 1. Comparison of live observations and video file review counts by species for $n = 22$ trials at the Big Creek weir, 2004.

	Count Method	
Species	Live Observation	Video File Review
Chinook salmon	2,020	2,045
Chum salmon	2,047	2,011
Pink salmon	316	322
Sockeye salmon	21	23
Coho salmon	47	44
Dolly Varden	356	354
Rainbow trout	35	38
Arctic grayling	3	3
Round whitefish	2	2
Other	9	5
Total	4,856	4,847

We experienced motion detection failures on two occasions while testing the system in 2004 (Table 2). On both occasions, failures were caused by large groups of chum salmon moving through the camera field of view in a continuous stream. The steady stream of fish prevented the motion detection algorithms from detecting a change in brightness in our detection zones, motion was not detected, and video files were not recorded. Fish passage rates were higher during these two occasions (608 and 1,392 fish/hr) than all other trials. During the two trials when motion detection failed, the system missed over 20% of fish passage (Table 2).

During normal operation in 2004, the majority of motion detection failures occurred when small resident fish and juvenile salmon failed to trigger motion events. The motion detection capabilities failed on a few occasions during late July and early August when large groups of chum salmon moved through the camera field of view in a continuous stream as described above. When this occurred, the crew recorded all fish passage on the digital video recorder and reverted to motion-triggered video file recording when the chum salmon passage rate slowed. Motion detection failures caused by high chum salmon passage rates occurred when the gate to the video monitoring chute was first opened in the morning, and were avoided by recording all fish passage on the digital video recorder in the morning when the gate was first opened.

Table 2. Comparison of live observations and video file review counts by species for two trials when motion detection failed at the Big Creek weir, 2004.

Species	August 11, 2004		August 19, 2004	
	Live Observation	Video File Review	Live Observation	Video File Review
Chinook salmon	16	15	14	13
Chum salmon	556	428	525	341
Pink salmon	26	23	9	7
Sockeye salmon	0	0	0	1
Coho salmon	27	28	8	5
Dolly Varden	0	0	1	1
Rainbow trout	3	3	0	0
Arctic grayling	0	0	0	0
Round whitefish	0	0	0	0
Other	0	0	0	0
Total	628	497	557	368

False triggers occurred throughout the course of the project, but did not have any serious affects on system operation. Most false triggers were caused by external light entering the field of view, and were corrected by blocking the light source as soon as the problem was discovered. Other causes of false triggers included drifting debris, vegetation becoming lodged inside the video monitoring chute, and small mammals swimming through the chute.

One drawback of the DSR-3000 is the lack of transferability of the recorded digital video files. Because the DSR-3000 was developed for the security industry, Sanyo's proprietary motion JPEG CODEC is not compatible with other consumer video products to prevent alteration of potential evidence. This prevented us from directly copying the digital video files to other digital video formats for use in presentations and other outreach activities. A digital camcorder was used to capture footage from the DSR-3000 hard disk using an analog cable, thus causing some degradation of the original digital source files. Once captured on the digital camcorder, the footage could then be retained in a digital format for editing and producing clips and still images.

Microwave Link

The microwave equipment operated without major problems throughout the field season in 2004, although we did experience minor technical difficulties. The video feed received at KSFO and the Visitor Center would sometimes lockup overnight if the overhead camera was selected, and the camera view would need to be reset using the Visitor Center controls. Also, the picture quality received at KSFO and the Visitor Center was somewhat degraded compared to the video signal at the Big Creek weir site. The images were not as sharp, the date-time stamp would smear across the screen, and interference was sometimes apparent. Adjustment of the video gain of the microwave transmitter at the weir site was unable to compensate for these image degradation issues. Despite the degradation in quality, the image received at KSFO and the Visitor Center was high quality and acceptable for fish identification and counting. KSFO used the video signal from the microwave feed to calibrate the replacement digital video recorder when the DSR-3000 failed, and the unit functioned properly using the microwave signal.

The outreach and education component of the microwave link at the Visitor Center was also a success. In addition to the video and camera controls, we displayed posters highlighting work that KSFO is doing, and usually had someone present at the Visitor Center a few times during the week to answer questions. Visitors enjoyed the hands-on control of the PTZ camera and especially enjoyed the live underwater camera view when fish were passing through the video monitoring chute.

Remote Power Generation

Proper installation of our remote power system required technical competence, and is not a task to be taken lightly. The solar arrays we used in 2003 and 2004 were not adequate to operate the video monitoring equipment, except in July and early August. The video monitoring equipment used in 2004 required over 4 kW of energy per day to operate (Table 3); however, the solar arrays could not produce this amount except in times of abundant sunlight (Table 4). The 800-Ah battery bank was able to power the equipment for about 2 days without being charged (assuming 80% effective battery bank capacity). The gasoline-powered generator was necessary to charge the battery bank during times when solar energy did not meet our needs from mid August through September. The lack of available power also prevented us from operating the equipment at night. During the 2003 operating season, no major power equipment malfunctions occurred. In 2004, however, one solar charge controller failed and needed to be replaced. The gasoline-powered generator did not function properly near the end of the 2004 monitoring season and required service.

2005 Modifications

In 2005, KSFO monitored two streams simultaneously near Cold Bay, Alaska, using a multi-channel digital video recorder at one of the streams in conjunction with a microwave link between the sites (Dion 2006). The project utilized bi-directional fixed picket weirs to direct upstream and downstream migrant fish through a video monitoring chute. Camera boxes, Applied Microvideo Model 10 cameras, and underwater halogen lights were used as previously described. The Sanyo DSR-3510 multi-channel digital video recorder setup was similar to the DSR-3000, with motion detection zones, pre-alarm, and motion-triggered file recording. The two weirs were unmanned, and crews monitored passage by reviewing recorded video files from both streams daily. Underwater video was also used in 2005 at Mortensens Creek near Cold Bay to monitor sockeye and coho salmon escapement. Dion (2005) describes the video setup used at Mortensens Creek in 2004.

Based on performance issues discussed above, KSFO made several changes to the camera box and video monitoring chutes deployed during the 2005 field season. Changes for 2005 included better filtration of the water inside the camera box, painting the interior of the camera box white, and moving the baffle in the video chute closer to the camera box glass. The combination of

Table 3. Daily power requirements for video monitoring equipment at the Big Creek weir, 2004. Wh = watts*hours; Ah = Amperes*hours. All loads are for 12-V DC.

Equipment	Watts	Hours/day	Wh/day	Ah/day
Digital Video Recorder	45	24	1,080	90
Monitor	165	6	990	83
Underwater camera	24	12	288	24
Pan-tilt-zoom camera	24	6	144	12
Microwave transmitter	12	24	288	24
Halogen lights	70	12	840	70
Lasers	1.2	12	14	1
DC to AC power inverter	20	24	480	40
Total:			4,124	344

Table 4. Daily solar power production and daily power requirements at the Big Creek weir, 2004. Estimates assume 25% solar system loss and proper panel orientation.

Effective sun-hours	Watts/day produced	Watts/day required
4	2,160	4,124
6	3,240	4,124
8	4,320	4,124

these three changes significantly improved our image quality in turbid stream water (Figure 11). Better filtration of water inside the camera box was provided by a 10 µm filter. Painting the inside of the camera box white provided better reflection of the halogen lights, which we were able to aim sideways to bounce light off of the walls of the camera box. This provided better and more even light dispersion than we achieved in 2004 when lights were aimed towards the camera box glass to provide direct lighting of fish. Reflecting light off the side of the camera box also eliminated the hot spots observed in 2004 when we had to point the lights forward. In 2005, we moved the baffle in the video monitoring chute 10 cm closer to the glass than in 2004, from 25 to 15 cm. This forced fish even closer to the glass and eliminated 10 cm of turbid water for the camera to shoot through. All three improvements were implemented simultaneously, so we are unsure which had the greatest impact on our improved image quality in turbid water.

We also made physical improvements to the camera box in 2005. The light mounting brackets were improved by creating articulating arms using ball-and-socket joints (Figure 12). This allowed us to aim and secure the lights in any position, something we could not do with the limited mounting hardware used in 2004. Secondly, the cable access standpipe was moved to the rear of the box and extended in length from 18 cm to 1.5 m (Figure 12). The new standpipe was not watertight, as the height of the pipe was well above any potential high water event. This gave us the ability to change out components inside the camera box without having to reform a watertight seal in the standpipe. Finally, the access hatch to the camera box was replaced with a commercial marine hatch that opened with the turn of a knob instead of requiring the removal of 30 nuts. This improvement allowed easy access to the camera box interior to adjust lights or the camera as necessary. However, the hatch was not watertight from the inside. We were therefore unable to fill the camera box completely with filtered water because it leaked out of the hatch from the inside. Because the standpipe was not watertight, evaporation occurred over the course of the field season and water inside the camera box occasionally needed to be replaced. Although this did not affect operations in 2005, it is an issue that will be corrected for future projects.

Discussion

Constructing the weir in a V-shaped formation guided fish to the video monitoring chute at the apex. The effectiveness was confirmed by our difficulties in capturing fish in the live trap, which was off-center to the weir apex. Also, fish were not observed challenging the weir as they have been in other KSFO projects using weirs perpendicular to stream flow (KSFO, unpublished data). As the weir design at Big Creek was modified from 2000 to 2002, we also made efforts to avoid injuries to fish that came into contact with the weir. This was accomplished by taking extra time during weir construction to eliminate sharp edges and protruding hardware, giving the weir as smooth of a surface as possible. Fish that did contact the weir were unlikely to incur any physical injury.

The improved optics and functionality of the Model 250 were important for our objective to measure fish lengths with lasers in 2004 (Anderson 2005), but the difference in cost between the Model 10 and Model 250 was considerable (Appendix A). Barrel distortion on the Model 250 was negligible, and we were able to successfully calibrate the laser system and measure fish lengths (Anderson 2005). The barrel distortion of the Model 10 camera did not affect our ability to identify and count fish in 2003. The Model 10 camera is more than adequate for monitoring projects that do not require a flat image, and is the camera KSFO has used for other underwater video projects (Anderson et al. 2004; Hetrick et al. 2004; Dion 2005, 2006).

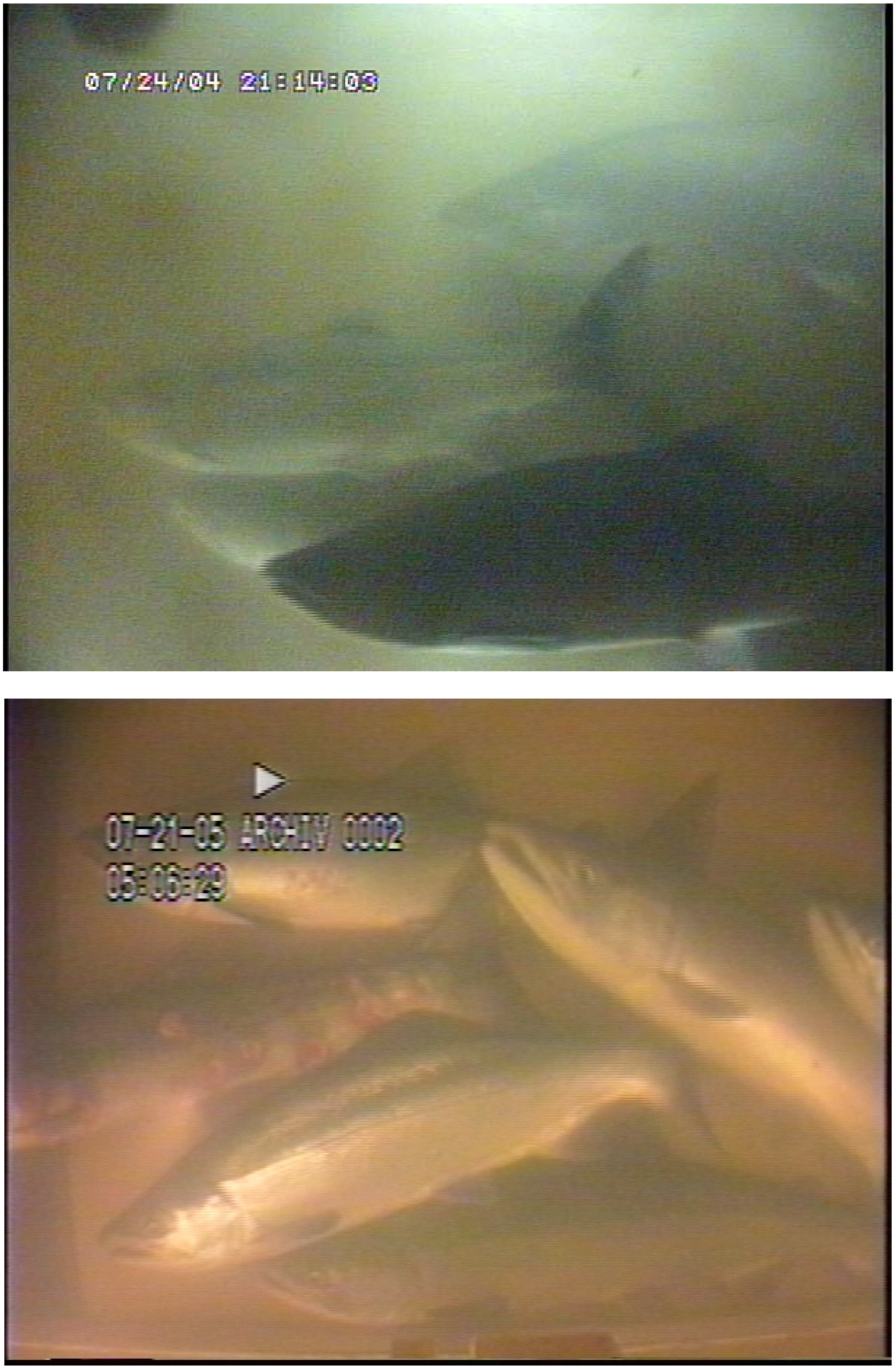
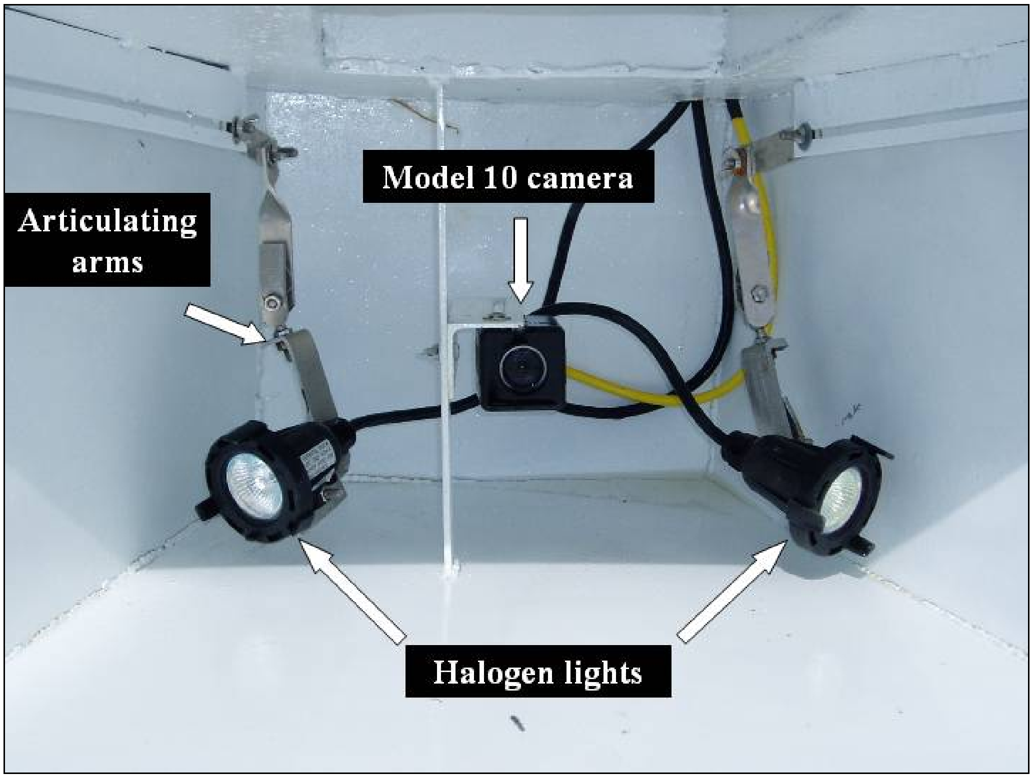


Figure 11. Captured still images showing typical quality of video footage recorded at Mortensens Creek in 2004 (top) and 2005 (bottom). Underwater visibility in both images is about 30 cm.



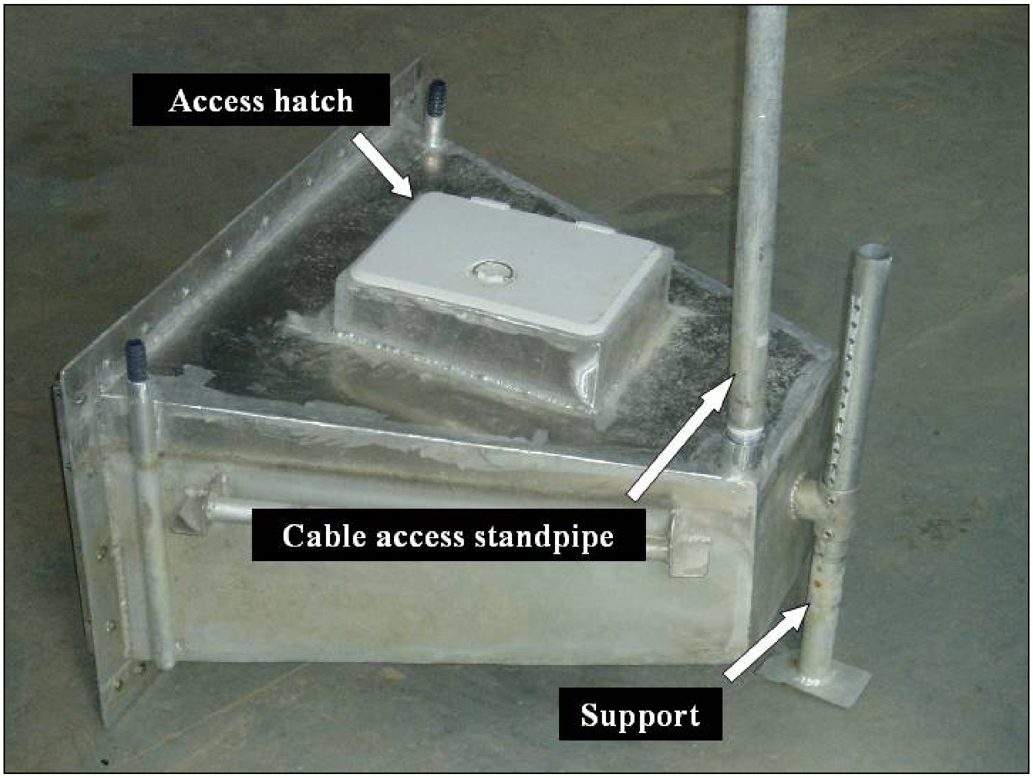


Figure 12. View of camera box interior (top) and exterior (bottom) used in 2005.

We have yet to realize the complete benefits of using a microwave link to monitor fish passage from a remote location. We were not properly set up to monitor fish passage at the Big Creek weir from our office in 2004, as the controls for switching between camera views were located at the Visitor Center (Figure 8). Therefore, we could not directly control when the underwater camera was selected to monitor fish passage. The inclusion of the Visitor Center in the system was necessary to add partners to share the cost of the microwave equipment, and the outreach component at the Visitor Center was a great success. In 2005, we did not have a direct line-of-sight signal from either weir to an office in Cold Bay and did not have enough equipment to monitor both streams remotely from an office environment (Dion 2006). Utilizing the full benefits of a microwave link would allow us to monitor fish passage at a remote site from an office environment. This would eliminate about half of the power requirements at our remote sites (Table 3), making it more economical and logistically feasible to operate video monitoring projects in remote locations. Housing the sensitive electronic equipment in an office environment would also remove the hazards of extremes in temperature and humidity that can be problematic to electrical equipment operated in remote field camps throughout Alaska.

The main unresolved issue affecting the performance of our underwater video monitoring projects is difficulty in monitoring fish passage at night. In 2003, little effort was made to monitor fish passage at night due to the lack of available power at the Big Creek site. However, we did attempt to monitor nighttime passage on several occasions with power from the gasoline-powered generator, and fish exhibited erratic behavior. Fish would swim into the video monitoring chute and dart around rapidly passing upstream and downstream. This made it difficult to get accurate counts. In 2004, similar behavior was observed at night using halogen lights. It appeared that fish would swim into the lighted video monitoring chute unaffected, but were reluctant to leave the lighted video monitoring chute to the dark environment upstream of the chute. We attempted to light the stream above the video monitoring chute to entice fish to migrate, but this was not successful. The fish would still dart around rapidly inside the video monitoring chute making accurate counts difficult. On 19 August 2004, a live count/motion detection verification trial was conducted between 2400 and 0100 hours. During this trial, 19 fish entered the video monitoring chute, causing 26 motion-triggered video files to be recorded. However, only five fish passed upstream of the weir (KSFO, unpublished data).

In 2005, KSFO monitored two streams simultaneously using a multi-channel digital video recorder at one of the streams in conjunction with a microwave link between the sites (Dion 2006). Initially we intended to monitor passage at both streams 24 hours per day. However, shortly into the field season it became apparent that this was not practical. Erratic fish behavior in the video monitoring chutes during darkness would cause an almost constant triggering of the motion detection, resulting in near constant recording. At times it required technicians over 12 h to review the previous day's fish passage for both streams (KSFO, unpublished data). This defeated the purpose of using motion detection. It was extremely difficult to get accurate counts as fish would dart upstream and downstream through the video monitoring chute. Once it was determined that monitoring passage around the clock was not practical, KSFO installed motorized gates on the downstream end of the video monitoring chute to prevent fish from passing at night. Once the gates were installed, it usually required only 2 to 4 h for technicians to review the previous day's passage for both streams. However, once the gates were installed, fish were blocked from passing the weir at night.

Blockage of fish passage at night may lead to delays in migration timing for some Pacific salmon species, although varying diel migration patterns have been reported. Irving et al. (1995) and Finn (1990) observed varying migration patterns among Pacific salmon species using sonar on the Togiak River, southwest Alaska; Finn (1990) found that coho salmon moved primarily between 2300 and 0700 hours. This is in contrast to Sandercock (1991), whose literature review found that most coho salmon stocks migrate upstream during daylight hours. Daum and Osborne (1998) and Troyer (1993) found chum salmon passage past sonar counting sites on Yukon River tributaries was greater during darkness. Heibert et al. (2000) observed 70% of Chinook salmon passage at a dam on the Yakima River, Washington, occurred at night when infrared light was used to monitor passage with video equipment. Faurot and Kucera (2002) found 37 – 82% of Chinook salmon migrated past their video monitoring station on an Idaho stream between 2200 and 0400 hours. Hatch et al. (1994) found 14% of Chinook salmon and 7% of sockeye salmon migration occurred at night during a three-year study using video at a dam on the Wenatchee River, Washington, which is comparable to passage rates observed at Columbia River dams at night (Calvin 1975). Chinook salmon have been observed to migrate past the Chignik River weir, southwest Alaska, at all hours of the day, although sockeye salmon passage occurs primarily during the day (K. Bouwens, ADFG, personal communication). Otis and Dickson (2002) also observed minimal nighttime migration of sockeye salmon for a stream on the Kenai Peninsula, Alaska.

We believe the presence of white light in our video monitoring chutes causes most of the erratic fish behavior observed at night. Other monitoring projects use artificial light to count migrating Pacific salmon at night. Counting towers are used extensively to monitor salmon escapement, and lights are used to count and identify fish at night (Cousens et al. 1982). Sockeye salmon have exhibited avoidance to white light at night in Bristol Bay rivers as well as to red and amber light in the Kvichak River (Cousens et al. 1982). White light also caused salmon to hold downstream or swim quickly and erratically through the illuminated area at a counting tower on the Kulukak River, southwest Alaska; infrared light, however, did not seem to affect fish behavior (Price and Larson 1999). Neave (1943), however, monitored fish passage at Skutz falls on the Cowichan River, British Columbia, and found that artificial light did not influence migration patterns at night.

Video monitoring projects have also used artificial light to monitor nighttime passage. At the Chignik River weir, white lights are used in conjunction with underwater video equipment to monitor nighttime passage of sockeye and Chinook salmon (Pappas et al. 2005). Although some erratic fish behavior has been observed at night in the lighted video passage chutes, the presence of lights does not appear to affect migration past the weir (K. Bouwens, ADFG, personal communication). Hatch et al. (1994) used ten 150-W incandescent flood lamps aimed at a viewing window to monitor passage at a dam on the Wenatchee River, Washington, and did not report any problems with fish passage rates or erratic behavior attributable to the lights, either during daytime or at night. Faurot and Kucera (2002) used red light to monitor Chinook salmon passage with underwater video equipment on Lake Creek, Idaho, and also did not report any erratic behavior or disruptions in nocturnal migration.

Heibert et al. (2000) tested the effect of infrared and visible light on migration of Chinook salmon, coho salmon, and steelhead *O. mykiss* at a dam on the Yakima River, Washington, and found that most fish did not experience any delays in migration regardless of light source. However, the use of infrared light substantially increased the proportion of salmonids passing the fish ladder at night. When infrared lights were used, most Chinook salmon passage (70%) occurred at night with a peak passage between 2400 and 0200 hours. When the light source was visible light, most Chinook salmon passage (51%) occurred during the day, with a peak passage between 1000 and 1200 hours (Heibert et al. 2000).

Infrared light might be a viable alternative to white light to monitor nighttime passage without affecting fish behavior. In laboratory tests and field investigations, Beach (1978) found that infrared light could be used to monitor fish at night without affecting behavior. Hinch and Collins (1991), Grant et al. (2004), and Heibert et al. (2000) have successfully used infrared light and underwater video equipment to monitor fish in darkness without affecting behavior. However, researchers have identified limitations of using infrared light in water. Heibert et al. (2000) found that image quality was better and species identification was easier with visible light compared to infrared. Haro and Kynard (1997) attained poor image quality at night at distances greater than 1 m using a low powered (6 W) infrared array. Fleming (2004) used underwater video with infrared lights to monitor nocturnal rainbow trout passage at a weir on the Gulkana River, central Alaska, and recommended closing the weir at night because the infrared light was only able to penetrate 30 cm into the water, which was inadequate for successful monitoring. Beach (1978) observed a 50% reduction in intensity of infrared light in water at depths greater than 18 cm.

Although confounding examples exist, nocturnal migration of Pacific salmon can account for a substantial portion of total escapement for some species. Therefore, if unimpeded migration is important in a video escapement monitoring project, infrared light may be necessary at night to avoid potential avoidance behaviors caused by artificial visible light. Design of the video system will need to compensate for the penetration and image quality shortcomings of infrared light in water.

Accuracy of fish counts using above water and underwater video has been demonstrated by several researchers, although underwater monitoring appears better suited for multi-species runs. Hetrick et al. (2004) used above water and underwater video to monitor multi-species Pacific salmon escapement on a tributary to the Togiak River, southwest Alaska. Species identification was easier with the underwater images compared to above water images, especially in low light conditions, and species identification at night was not possible using above water images (Hetrick et al. 2004). Otis and Dickson (2002), and Estensen and Cartusciello (2005) used above water video monitoring to count fish passage, and compared their results to counts at nearby or integral weirs. Both projects also used underwater cameras to aid in species identification and apportionment. Otis and Dickson (2002) found that escapement estimates using above water video were 85% (Delight Creek) and 93% (Port Dick Creek) accurate compared to weir counts, although estimates of species composition were less successful. At Delight Creek, the proportion of Dolly Varden was underestimated, whereas the proportion of pink salmon was overestimated using video; estimates of pink salmon abundance at Port Dick Creek were accurate, but abundances of chum salmon and Dolly Varden were underestimated. Estimates of species composition were likely flawed due to incomplete stream coverage of the underwater cameras (Otis and Dickson 2002). On the Nome River, northwest Alaska, the estimate of total fish passage using video was 99% of the corresponding weir count (Estensen and Cartusciello 2005). The abundance estimate for pink salmon with video was also accurate compared to the weir, although coho and chum salmon abundances were underestimated. This discrepancy was due to several factors, including an initial camera setup that did not provide an optimal view for speciation, and the relative low numbers of chum and coho salmon (2% of escapement) compared to pink salmon (94%) observed at the weir (Estensen and Cartusciello 2005).

Hatch et al. (1994) used underwater time-lapse video to produce a continuous record of fish passage during salmon migration periods from 1989 to 1991 at Tumwater Dam on the Wenatchee River, Washington. Except for some fish that were captured and passed through a separate live trap, this record represents a census of fish passage through the fish ladder at the dam. Counts were made and species were identified by reviewing the time-lapse tapes. Accuracy of escapement and species composition estimates among five different observers were not significantly different. Sockeye salmon escapement estimates were also similar to independent dam counts, although it is likely that the video estimates of Hatch et al. (1994) were more accurate than the other dam counts to which their estimates were compared. Review of recorded video files is more accurate than live observations, as technicians in the field are often required to make on-the-spot decisions regarding the number and species of fish as they quickly pass monitoring sites in large groups. Also, direct visual counts often require long periods of alertness, which can be difficult to maintain (Beach 1978). The ability to replay video files repeatedly in slow motion and pause on individual frames allows reviewers to accurately identify species, identify individuals within groups, and determine direction of travel (Hatch et al. 1994; Hetrick et al. 2004; Anderson 2005).

When the motion detection was functioning properly at the Big Creek weir, we recorded Pacific salmon passage through the video monitoring chute at census levels. However, motion detection failures when large groups of chum salmon were passing compromised the integrity of the data to some degree. This issue is largely due to the automatically updated reference image function on the Sanyo digital video recorder, which stores an image that is then compared with the live video feed to determine if motion occurs. If the reference image is initially established or automatically updates during a period of high fish passage, that then becomes the standard to compare with the live video signal. Under these circumstances, motion detection recording may actually be triggered if fish passage stops abruptly because of the dramatic change from the reference image containing numerous fish to a view of an empty passage chute. Other recorders are available that are capable of storing a static reference image, have the ability for the reference image update interval to be adjusted, or use an average of several frames extracted at user-defined intervals to establish the reference image.

Other motion detection systems designed specifically for video monitoring of fish passage have been used successfully. Hatch et al. (1998) developed a motion detection algorithm to detect the presence of fish on time-lapse video by comparing pixel luminance values between consecutive videotape frames. Counts of their source and edited video tapes were nearly identical, even during times of high fish passage (> 400 fish/day; Hatch et al. 1998). However, application of their technology has been problematic in some instances (Faurot and Kucera 2002), and other motion detection algorithms have also proven difficult to implement (Hetrick et al. 2004; Estensen and Cartusciello 2005). Passage rates at the Big Creek weir when the motion detection failed were greater than 600 fish/h, well above the "high" fish passage density category (> 400 fish/day) described by Hatch et al. (1998).

One reason that we used motion detection at the Big Creek weir was to eliminate blank or fishless video so that technician time was devoted to counting and identifying fish images instead of reviewing blank frames. Use of time-lapse video recording alone has reduced review time of fish passage by over 90% compared to live counts, regardless of the presence of fishless frames (Hatch et al. 1994; Otis and Dickson 2002), whereas use of motion detection at Big Creek that eliminated fishless video frames reduced review time by only 60% compared to live observations during motion detection verification trials. However, this is not a valid direct comparison as Hatch et al. (1994), and Otis and Dickson (2002) reported review times for an entire season of operation that included many hours of low fish passage density, whereas our motion detection trials at the Big Creek weir specifically targeted times when high fish passage was likely to occur. Lower fish passage rates with video monitoring require less time to review compared to higher passage rates, regardless of the method used (time-lapse or motion detection).

A second reason for using motion detection is to eliminate the potential error associated with technicians missing fish when reviewing time-lapse video recordings. At times this can involve long periods of blank footage, and can be a tedious and monotonous task (Hatch et al. 1994; Otis and Dickson 2002). When reviewing time-lapse video, reviewers replay a tape in the fastest mode while monitoring the screen for fish activity; once activity is detected, the reviewer then slows the playback to count and identify fish (Otis and Dickson 2002). If the reviewer's attention is distracted during the process, fish passing the monitoring site could be missed. Hatch et al. (1994), however, found these errors may be negligible, as no significant differences were found in counts among different observers who examined the same videotape record.

Time-lapse video uses low recording intervals (frame rates), usually less than 3 frames/s, to compress time on storage media (tape or hard disk). For comparison, television signals are broadcast at 30 frames/s. Recording at 3 frames/s instead of 30 frames/s represents a ten-fold reduction in the amount of storage and review time necessary for a comparable unit of time (Table 5). However, individual fish can be difficult to identify at time-lapse rates (< 3 frames/s). Otis and Dickson (2002) found that individual fish were difficult to track during playback at longer time-lapse intervals (≤ 1.66 frames/s), and that higher frame rates (5 frame/s) were better. Hetrick et al. (2004) found that frame rates of 4 to 5 frames/s were necessary to identify fish to species using above water and underwater cameras. Hatch et al. (1994) tested the accuracy of counts at two different time-lapse recording intervals, 2.5 and 1.66 frames/s. Although fish counts for paired hourly and date counts were different for some species, the differences were not significant for their test of 168 hours of recorded passage. However, these differences could be important in some management contexts. The maximum difference for sockeye salmon paired-hourly counts was 60 fish, representing 23% of passage for that hour; the maximum paired-hour difference for Chinook salmon was 5 fish, 14% of that hour's passage (Hatch et al. 1994). For paired-date tests, Hatch et al. (1994) found maximum differences of 42 fish (6% difference) and 17 fish (10% difference) for sockeye and Chinook salmon.

Higher recording rates can result in more accurate fish counts (Hatch et al. 2004; Otis and Dickson 2002; Hetrick et al. 2004). However, higher recording rates also result in larger data files which require more physical space (tape or hard disk) for a given amount of time (Table 5). A motion detection system provides the benefits of time compression and minimizing data storage requirements similar to time-lapse video, while using higher frame rates necessary to count and identify individual fish to species.

We believe that a video monitoring system with motion detection is better suited for identifying multiple fish species than a system with time-lapse. However, motion detection using

Table 5. Effects of recording interval on storage capacity for video files based on a 160 GB hard disk, recording at normal (22 kB) picture quality. Table is adapted from Sanyo (2004).

Recording rate (frames/s)	Recording time (hours)
30	30
15	60
10	90
5	180
3	301
1.5	602
1	904

photographic triggering may not be practical in all monitoring environments. Photographic triggering requires constant background lighting that contrasts with the image of the fish and works better in a controlled environment (Daum 2005). Hetrick et al. (2004) found that a number of factors affected the performance of a motion detection algorithm in the natural environment using above water cameras. These factors included wind, lighting, rain, camera angle, camera field of view, and aspect of the fish in relation to the camera. Although control or compensation for many of these factors is possible, motion detection using photographic triggering did not perform well in a natural environment (Hetrick et al. 2004). The factors affecting motion detection efficacy with underwater cameras at our weirs are light, turbidity, and fish passage density, although two of these (light and turbidity) can be controlled or compensated for. As technology continues to improve, motion detection algorithms should become available that will allow successful monitoring of fish passage with overhead cameras in a natural (i.e., uncontrolled) environment, thereby eliminating the need for a fish weir in clear water streams and further enhancing fish passage.

In addition to improved accuracy of our counts and species identification, the use of video monitoring at our weirs has produced other benefits. The video equipment remains functional during high water events when it is not safe or practical to access the passage chute to do a live count. For example, the peak coho salmon count at the Big Creek weir in 2004 (2,641 on 20 September; Anderson 2005) was captured by the video equipment when water levels and velocities prevented the crew from accessing the live trap. Although the weir might not be completely fish tight during these high water events, the data captured by the video equipment would otherwise not be available. Even though the weir was submerged on 20 September 2004, we were able to count coho salmon with the video monitoring equipment until 29 September when high water made it unsafe to operate the electronic equipment.

The improvements we implemented in 2005 have further improved our ability to monitor fish passage in turbid water. The underwater video equipment at our weirs has also allowed us to obtain more comprehensive counts of resident fish species than in previous years (Table 6). Prior to using video, live counts were made by observers passing fish through a counting chute

Table 6. Numbers of fish observed at the Big Creek weir, 2000 to 2004. Data for 2000 to 2002 are from Whitton (2003); data for 2003 are from Anderson et al. (2004); data for 2004 are from Anderson (2005).

Species	2004	2003	2002	2001	2000
Chinook salmon	11,906	10,063	4,791	649[a]	1,298
Chum salmon	24,957	33,943	28,812	11,981[a]	3,241
Coho salmon	10,451[a]	9,600	806[a]	4,523	969[a]
Sockeye salmon	189	119	45	38	57
Pink salmon	3,295	873	31	15	80
Dolly Varden	1,529	4,901	347	21[b]	24
Rainbow trout	673	549	24	11[b]	2
Arctic grayling	55	83	3	1[b]	2
Round whitefish	179	210	16	--	4
Northern pike	14	52	1	--	2
Longnose sucker	--	--	--	--	1

[a] Incomplete count due to weir failures.
[b] Numbers observed in live trap.

and accurate counts of Pacific salmon were the highest priority. Smaller resident fish such as rainbow trout, Dolly Varden, and round whitefish were difficult to identify to species from above, especially when they would pass quickly in large multi-species groups. With the use of a video system, instantaneous species identification and counts are no longer necessary. We now have the ability to replay video files repeatedly in slow motion and pause on individual frames, which allows reviewers to accurately count and identify fish to species.

Finally, the use of underwater video technology has removed much of the variability associated with observation conditions. Wind-generated surface turbulence, glare, and turbidity can all affect the accuracy of live observations. The presence of swarms of biting insects can also affect an observer's ability to concentrate on counting and identifying fish. The video chute provides a controlled lighting environment, eliminates the water surface as a source of error, and the system functions well in turbid water.

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Appendix A. Model number, manufacturer, and approximate cost of equipment used at the Big Creek video monitoring site in 2003 and 2004. All prices are in US dollars for year of purchase.

Item Description	Model Number	Manufacture	Qty	Unit Price	Total
Underwater video camera	Model 10	Applied Microvideo	1	$560	$560
Underwater video camera	Model 250	Applied Microvideo	1	$3,400	$3,400
Digital video recorder	DSR-3000	Sanyo	1	$1,400	$1,400
13” color monitor	VMC-8613	Sanyo	1	$320	$320
Underwater fluorescent lights	Pro48	The Fishinglights Company	4	$175	$700
Underwater halogen lights	Low voltage	Little Giant	2	$65	$130
Water pump	T1500	Calpump	1	$180	$180
In-line water filter	BioForce250	Cyprio	1	$45	$45
1000-W power inverter	1000/GFCI	STP Prosine	1	$850	$850
90-W solar panel	SR-90	Siemens	8	$550	$4,400
Solar disconnect breaker	GF221N	Siemens	1	$90	$90
30-A solar charge controller	C30A+	Trace (Xantrex)	2	$120	$240
175-A DC disconnect breaker	175-A	Trace (Xantrex)	1	$320	$320
100-AH sealed AGM batteries	various	various	8	$150	$1,200
75-A battery charger	DLS75	Iota	1	$550	$550
Generator	EU3000i	Honda	1	$2,600	$2,600