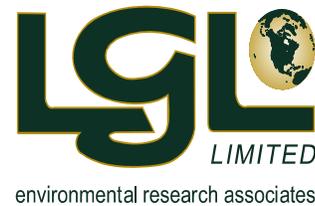


Enumeration of Salmonids in the Okanogan Basin Using Underwater Video



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ABSTRACT

The Confederated Tribes of the Colville Reservation (Colville Tribes) identified the need for collecting baseline census data on the timing and abundance of adult salmonids in the Okanogan River Basin in order to determine basin and tributary-specific spawner distributions, evaluate the status and trends of natural salmonid production in the basin, document local fish populations, and augment existing fishery data. This report documents the design, installation, operation and evaluation of mainstem and tributary video systems in the Okanogan River Basin. The species-specific data collected by these fish enumeration systems are presented along with an evaluation of the operation of a facility that provides a count of fish using an automated method. Information collected by the Colville Tribes Fish & Wildlife Department, specifically the Okanogan Basin Monitoring and Evaluation Program (OBMEP), is intended to provide a relative abundance indicator for anadromous fish runs migrating past Zosel Dam and is not intended as an absolute census count.

Okanogan Basin Monitoring and Evaluation Program collected fish passage data between October 2005 and December 2006. Video counting stations were deployed and data were collected at two locations in the basin: on the mainstem Okanogan River at Zosel Dam near Oroville, Washington, and on Bonaparte Creek, a tributary to the Okanogan River, in the town of Tonasket, Washington. Counts at Zosel Dam between 10 October 2005 and 28 February 2006 are considered partial, pilot year data as they were obtained from the operation of a single video array on the west bank fishway, and covered only a portion of the steelhead migration. A complete description of the apparatus and methodology can be found in *Fish Enumeration Using Underwater Video Imagery - Operational Protocol* (Nass 2007).

At Zosel Dam, totals of 57 and 481 adult Chinook salmon were observed with the video monitoring system in 2005 and 2006, respectively. Run timing for Chinook in 2006 indicated that peak passage occurred in early October and daily peak passage was noted on 5 October when 52 fish passed the dam. Hourly passage estimates of Chinook salmon counts for 2005 and 2006 at Zosel Dam revealed a slight diel pattern as Chinook passage events tended to remain low from 1900 hours to 0600 hours relative to other hours of the day. Chinook salmon showed a slight preference for passing the dam through the video chutes on the east bank (52%) relative to the west bank (48%).

A total of 48 adult sockeye salmon in 2005 and 19,245 in 2006 were counted passing through the video chutes at Zosel Dam. The 2006 run timing pattern was characterized by a large peak in passage from 3 August through 10 August when 17,698 fish (92% of total run observed for the year) were observed passing through the video chutes. The daily peak of 5,853 fish occurred on 4 August. Hourly passage estimates of sockeye salmon counts for 2005 and 2006 at the dam showed a strong diel pattern with increased passage during nighttime hours relative to daytime hours. Sockeye showed a strong preference for passing Zosel Dam on the east bank (72%) relative to the west bank (28%).

A total of 298 adult upstream-migrating steelhead were counted at Zosel Dam in 2005 and 2006, representing the 2006 cohort based on passage data from 5 October 2005 through 15 July 2006. Eighty-seven percent (87%) of the total steelhead observed passed the dam between 23 March and 25 April with a peak passage occurring on 6 April when 31 fish were observed. Steelhead passage at Zosel Dam exhibited no diel pattern. In contrast to both Chinook and sockeye salmon, steelhead were shown to have a preference for passing the dam on the west bank (71%) relative to the east bank (29%).

Both Chinook and sockeye passage at Zosel Dam were influenced by Okanogan River water temperature. When water temperatures peaked in late July (daily mean exceeded 24 °C and daily maximum exceeded 26.5 °C), Chinook and sockeye counts went to zero. A subsequent decrease in water temperature resulted in sharp increases in both Chinook and sockeye passage.

A total of six steelhead were observed with the video monitoring system at Bonaparte Creek in 2006, with three passage events occurring on 29 March and one each on 20, 21, and 23 April. This system was operational for only a portion of the migration.

INTRODUCTION

Salmon recovery within the Columbia River Basin has become a focal point in the Pacific Northwest region. Substantial amounts of time, effort and funding have been spent improving fish passage conditions, augmenting flows, enhancing and restoring critical habitats, reducing sport and commercial harvests, regulating power generation by providing spill at the hydroelectric dams, and promoting hatchery supplementation of depressed salmon stocks. The Colville Tribes are actively participating in a recovery program for salmonids in the Okanogan River Basin which include recent inventories of habitat condition and water quality, removal of fish migration barriers, and the collection and rearing of locally-adapted steelhead broodstock. Despite these efforts, many salmon populations continue to decline. Currently, there is limited quantitative information available to determine spawner abundance of anadromous fish in the Okanogan River Basin or associated tributary streams.

Okanogan River steelhead, (*Oncorhynchus mykiss*) were listed as *endangered* under the US Endangered Species Act (NOAA 1997) but were upgraded to *threatened* in 2006. The combined five-year escapement average for the Methow and Okanogan rivers from 1989 to 1993 was estimated at approximately 2,400 fish; 450 of which were from natural production. This population is estimated to be declining at 12% per year (NOAA 1997).

Summer/Fall Chinook salmon (*O. tshawytscha*) spawn in the Okanogan River Basin but currently are not listed as either threatened or endangered. As of 1998, these fish were classified as having a population of approximately 1,500 with the population increasing at 1%-5% per year (NOAA 1998). Washington Department of Fish and Wildlife's (WDFW) salmonid stock inventory program classified summer Chinook as having a "healthy" status with an average run of 4,346 for 12 years of data (<http://wdfw.wa.gov/fish/sasi>). The majority of this stock spawns in the Similkameen River below the migration barrier at Enloe Dam. Spring Chinook salmon in the Upper Columbia Evolutionary Significant Unit (ESU) are listed as *endangered*. However it is not certain if this run ever utilized the Okanogan River (NOAA 1999).

The Okanogan Nation Alliance (ONA) developed a status report on Okanogan River Chinook salmon for assessment by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) that provides recommendations for consideration of listing under the Species at Risk Act (SARA). Committee on the Status of Endangered Wildlife in Canada recommended that Okanogan Chinook salmon be listed initially as *endangered* based on an emergency assessment (April 2005) and then as *threatened* under the normal assessment process in May 2006 (Howie Wright, Okanogan Nation Alliance Fisheries Department, pers. comm.). A decision of whether to list Okanogan Chinook under SARA based on these recommendations is still forthcoming.

Sockeye salmon (*O. nerka*) in the Okanogan River ESU are not listed under the ESA; however the status of Okanogan sockeye salmon is rated as chronically "depressed" by the WDFW (<http://wdfw.wa.gov/fish/sasi>). This stock is of mutual concern to the United States and Canada as the Okanogan sockeye population is one of only two remaining

populations in the Columbia River Basin. The annual escapement of sockeye salmon spawners has varied between a low of 1,600 in 1994, to a high of 60,000 in 2000, and has a 16-year mean of 25,000 (<http://wdfw.wa.gov/fish/sasi>, as based on counts at Wells Dam). Fisheries and Oceans Canada recommends an escapement of 59,000 (<http://wdfw.wa.gov/fish/sasi>).

Further, Chapman et al. (1995) summarized available data on sockeye and illustrated a noticeable discrepancy in counts between returning adult sockeye crossing Wells Dam and the number estimated in spawning areas in Canada. Several hypotheses have been proposed for this discrepancy:

1. Substantial mortality of Okanogan sockeye salmon between Wells Dam and upriver spawning grounds;
2. Considerable error in spawning ground counts based upon visual observations; and
3. Undiscovered spawning areas existing above Wells Dam.

Improved counts of sockeye salmon in the Okanogan would help answer key questions regarding adult sockeye salmon spawner abundance.

The Biological Opinion (BiOp) released by the National Marine Fisheries Service (NMFS) in 2000 addressed the operation of the federal Columbia River power system. The BiOp defined criteria for acceptable fish population levels to ensure the survival of critical fish stocks (NMFS 2000). One indicator to ensure survival was the number of naturally spawning adult salmon returning to spawning areas. Therefore, accurate determination of adult salmon spawner abundance is of critical importance to fisheries managers (Faurot and Kucera 2002).

Visually monitoring fish passage at dam fish ladders provides excellent opportunities for enumerating adult fish migrating upstream to spawning areas. However, observer counts based on specimen identification at viewing windows should not be treated as absolute estimates because they are not repeatable and cannot be reviewed for accuracy (Hatch et al. 1994a). After several years of collecting visual observations at dams along the Columbia River, comprehensive monitoring efforts were reduced in order to cut costs. Due to reduced efforts, fish passage is generally monitored between 1 March and 15 December with fish being counted for the first 50 minutes of each hour during an 8, 10, or 16 hour period per day. Due to these limitations, it was necessary to improve methods for monitoring fish passage.

Fish enumeration programs throughout the Columbia River Basin have shifted to using time-lapse and motion detection video monitoring equipment due to its wide ranging applications (Irvine et al. 1991; Hatch et al. 1994b; Hiebert et al. 2000; Otis and Dickson 2001; Faurot and Kucera 2002; Anderson et al. 2004; Hetrick et al. 2004). Unlike mark/recapture studies, underwater video sampling requires no handling of fish and is a passive, non-invasive process that can potentially operate continuously throughout the year. Digital video images can be reviewed numerous times without degradation, are easily archived, are defensible, and can reduce possible study impacts to the species

being observed (Edwards 2005). Images captured with video technology provide a permanent record of fish passage events to obtain accurate specimen and population abundance estimates. Video also permits uninterrupted monitoring of fish passage events allowing for assessment of diurnal movement patterns. Coupled with fish guidance structures, underwater video can be deployed at virtually any location provided there is adequate flow and good visibility. Compared with on-site counting, video monitoring can reduce data gathering costs by approximately 80% while simultaneously increasing data collected by 33% (Hatch et al. 1994a). Unlike other sampling methods such as hydroacoustics and DIDSON systems which require verification of species composition, underwater video provides a way to efficiently collect data describing not only species and natal origin, but in some cases the sex of individual fish.

Zosel Dam has long been considered a desirable location for monitoring adult salmonids by local fisheries managers. Resource managers believed that a counting station placed on the Okanogan River would improve assessments of target salmonid populations entering Canada and better inform future fisheries decision-making. Efforts to count fish at Zosel Dam began with a hydroacoustic study in 1991, but this effort was abandoned due to the difficulty in interpreting the data with any level of certainty (Anglea and Johnson 1991). In 1991 and 1992, Super VHS video equipment was used to estimate sockeye salmon escapement at Zosel Dam (Hatch et al. 1992).

These two years of video estimation of sockeye salmon escapement concluded that:

1. Using underwater video for estimating fish passage was feasible at Zosel Dam;
2. Fish passage only occurred at temperatures below 73 °F (23 °C); and
3. Most fish passage occurred during nighttime hours.

The Colville Tribes recognized the importance of estimating escapement for all anadromous fish species migrating into Canada and solicited funding from the Northwest Power and Conservation Council (NPCC) for project #29008; a video-based, fish counting station at Zosel Dam. The Columbia River Basin Fish & Wildlife Authority (CBFWA) rated this project as a high priority in the 2003-2005 Fish and Wildlife program work plan. Although video enumeration would provide an assessment for the effectiveness of Bonneville Power Authority (BPA) funded projects and other salmon recovery efforts underway in the Okanogan sub basin, funding was not allocated (CBFWA 2002).

However, in 2005, as part of the Okanogan Basin Monitoring and Evaluation Program (OBMEP) to promote the recovery of Pacific salmon and steelhead populations, the Colville Tribes received funding and initiated a project titled "*Design and construction of video detection systems in the Okanogan River Basin to enumerate adult salmon and steelhead*" (hereafter called the OBMEP video project) to provide census counts at strategic locations throughout the Okanogan River Basin. The target species of the OBMEP video project include anadromous forms of *Salmonidae* that have known production in the basin, including summer steelhead, sockeye salmon, and Chinook salmon.

The goal of the OBMEP video project was determining basin- and tributary-specific spawner distributions and evaluating the status and trends of natural salmonid species production in the basin. Target locations were chosen by weighing information regarding current and historic salmonid use, contemporary discharge levels and forecasts, in-stream hydraulic conditions, and access. This project was executed after an initial feasibility assessment exploring the use of video detection systems for enumerating fish passage at potential sites in the Okanogan Basin (Nass and Bocking 2005). Additional background information and history is provided in that document.

Objectives

The primary objectives of the OBMEP video project were to:

1. Design, install, operate and evaluate a video system at Zosel Dam to enumerate salmonid species; and
2. Design, install, operate and evaluate portable video systems at selected tributaries to enumerate summer steelhead, and other species as appropriate.

This report documents the results from operations conducted in 2005 and 2006, and evaluates the operation of a fish enumeration facility that provides a species-specific system-wide census count of anadromous fish using an automated method.

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METHODS

Study Area

The US portion of the Okanogan River is a 74 mile, low gradient waterbody draining a series of natural lakes located in Canada. The Okanogan River flows south through Oroville, Washington, and joins the Columbia River above Wells Dam near Brewster, Washington (Figure 1). Beginning in Canada, river discharges are regulated in order to maintain lake heights and supply irrigation water. The elevation of Lake Osoyoos, a transboundary waterbody, is controlled at the outlet by Zosel Dam, located approximately 4 miles south of the US/Canada border.

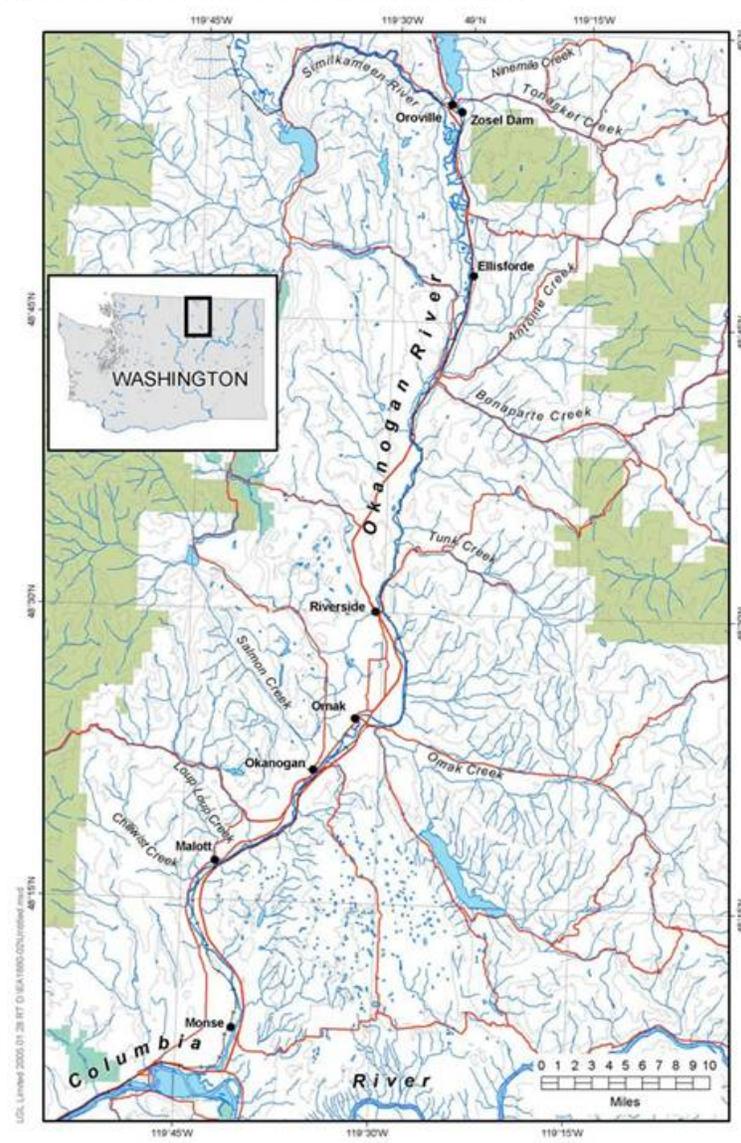


Figure 1. Map of the Okanogan River Basin showing the location of Zosel Dam and Bonaparte Creek. Video monitoring systems were deployed at these locations to enumerate adult salmonid passage.

Zosel Dam Site

Zosel Dam (Figure 2) is located at the extreme southern end of Lake Osoyoos and is of prime importance to agricultural interests in the Osoyoos, British Columbia (BC) and Oroville, Washington region. The lake further serves as a recreational resource and domestic water supply. Zosel Dam has four spillway gates and two pool and weir type adult fish ladders. Zosel Dam is a water control structure and does not have power generation facilities. Construction of the current facility was completed in 1987.

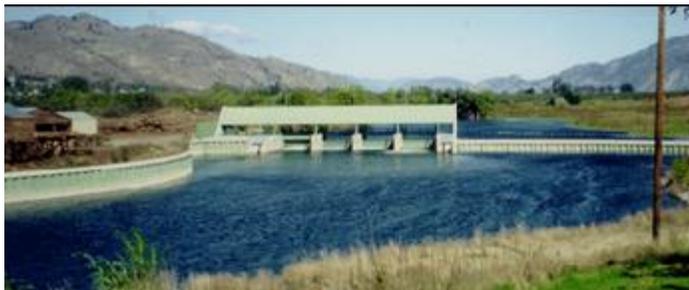


Figure 2. Photograph of Zosel Dam from the tailrace looking upstream.

Roughly one-third of the habitat currently accessible to anadromous fish in the Okanogan River Basin is found above Zosel Dam. Lake Osoyoos provides an area for suspended sediment to precipitate before reaching the dam. The flashiness and high turbidity that is characteristic of the lower Okanogan River during the spring freshet can be attributed to the snowmelt-driven Similkameen River which enters the Okanogan River a short distance below Zosel Dam.

Zosel Dam is owned by the Washington State Department of Ecology and operated by the Oroville-Tonasket Irrigation District (OTID) under orders established by the International Joint Commission (IJC). The IJC resolves disputes between the US and Canada under the *1909 Boundary Waters Treaty*.

The International Osoyoos Lake Board of Control, consisting of representatives from the BC Ministry of Environment, Environment Canada, the Washington Water Science Center, Land & Water BC Inc., and the US Army Corps of Engineers, was established by the IJC to supervise the operation of Zosel Dam in compliance with the IJC's Order of Approval. During normal years the lake elevation is held between a maximum elevation of 911.5 feet and a minimum elevation of 909.0 feet. However, during drought years water may be stored to lake elevations up to 913.0 feet. Zosel Dam effectively controls the elevation of Osoyoos Lake except during periods of very high snowmelt runoff when natural conditions force the lake above 913.0 feet.

Video Chutes

The exits of the fish ladders provide an excellent location for video enumeration stations on the mainstem Okanogan River. The Zosel Dam video chutes utilize pre-existing fish guidance structures as they sit at the top of permanent fish ladders. The video chutes are essentially an extension of the fish ladder. The fish ladder exits are approximately 24" wide and 78" high, and have a combined flow of approximately 45 cfs at normal operating reservoir elevation (Tom Scott, OTID Secretary/Manager pers. comm.). Chute design, fabrication, component and material selections were based upon several

factors including anticipated local conditions, ease of deployment, removal and maintenance. Individual units were then modified with respect to the local conditions for operational efficiency. Achieving quality imagery is partially dependent upon the clarity of the water. Under ideal conditions, camera to fish distances of 36" are feasible, but the distance decreases substantially under suboptimal water clarity conditions which requires guiding the fish to within 18" of the camera. Therefore, narrow chutes (e.g., 12") are essential for relatively high turbidity conditions.

A basic video chute consists of three components: fish passage chute, viewing window, and camera housing. Designing, building and installing the video chutes was a multi-step process accomplished with several factors in mind. First and foremost was the quality of image required to meet the study objectives. Since this was a pilot project, chutes were designed, fabricated and installed one at a time, incorporating design strengths and limitations revealed from previous attempts. The west bank array at Zosel Dam, installed on 5 October 2005, was comprised of two separate chutes (Figure 3). The east bank array, installed on 17 February 2006, was made up of four separate chutes (Figure 4). The Zosel Dam system uses eight underwater cameras placed in the two separate counting arrays. The cameras are separated from the fish chutes by removable, laminated glass viewing windows. Cameras 1-4 are located in the west bank unit with cameras 1 and 2 monitoring the top chute and cameras 3 and 4 monitoring the bottom chute (Figure 3). Cameras 5-8 are installed in the east bank unit. Individual cameras monitor single chutes, numbered bottom to top.



Figure 3. Photographs of Zosel Dam west bank video chute array prior to (left) and during deployment.



Figure 4. Photographs of Zosel Dam east bank video chute array prior to (left) and during deployment.

Spillway Passage Monitoring

An underwater video camera was mounted on 17 February 2006 on the downstream side of spillway Gate 1 and aimed downstream to capture upstream passage of adult salmonids through open spill gates. This video application was a feasibility test to determine if this technique could be effective at imaging spill passage.

Tributary Sites

Enumeration chambers in selected tributary streams were intended to collect data on returning steelhead. Okanogan Basin Monitoring and Evaluation Program (OBMEP) identified Bonaparte, Ninemile and Salmon creeks as key tributaries in the basin supporting steelhead spawning (Arterburn et al. 2005). Counting stations placed near the mouths of these creeks would provide data that otherwise could not be collected during redd counts due to lack of landowner permission to access upstream spawning and rearing areas. Site visits were conducted at these locations to determine feasibility of placing counting structures in the water and suitable sites were found at all targeted creeks.

The Bonaparte Creek watershed drains 102,120 acres and is approximately 20 miles at its longest length and 17 miles at its widest point (Figure 1). A suitable location for operating a video system was identified in the town of Tonasket near the confluence with the Okanogan River. The landowner, Blue Bird fruit packing, granted permission for installation of a system and also supplied an AC power source for our use. The Bonaparte Creek video chute was installed in March of 2006.

Ninemile Creek is an Okanogan River tributary entering Lake Osoyoos above Zosel Dam (Figure 1). A portion of the Ninemile Creek headwaters is in Canada and flows

from the northeast. The land, ranging from arid desert to coniferous forest, is held mostly in private ownership. The lack of access to the upper watershed has restricted the ability to collect data on the Ninemile Creek watershed and its fish populations. However, recent surveys in the lower, accessible reaches of Ninemile have confirmed that adult summer steelhead were present in this watershed, but information on abundance or production is still lacking (Arterburn and Fisher 2004). No fish barriers were identified in a recent survey of the lower two-plus miles of stream channel and sufficient flows were observed to provide passage for summer steelhead even during low water years. The landowner at the mouth of Ninemile Creek was contacted in early 2006 about placing a video chamber on their property, but the request was denied. Access to the creek was later obtained in June 2006 from a landowner adjacent to the Thorndike Loop Road crossing. Video operations were not conducted in 2006 as the steelhead run ended by the time permission had been obtained.

Salmon Creek is a perennial tributary of the Okanogan River with a total watershed area of approximately 167 square miles. Salmon Creek enters the Okanogan River at the town of Okanogan (Figure 1). The 119 square-miles of the upper Salmon Creek watershed are inaccessible to anadromous fish because of Conconully Dam and Reservoir, located approximately 15 miles upstream from the mouth of Salmon Creek. Although anecdotal evidence exists for the lower watershed supporting salmonids, the historic use of the upper Salmon Creek watershed by anadromous salmonids is unknown. Professional speculation is that salmonids were limited to less than three miles of available habitat above Conconully Dam. Controlled releases for irrigation deliveries are made from the Conconully Reservoir between April and October and are conveyed through 11 miles of natural and modified stream channel to the Okanogan Irrigation District (OID) diversion dam, located 4.3 stream miles above the confluence with the Okanogan River. The stream reach immediately downstream from the OID diversion dam has been dewatered since 1908 except during excessive snowmelt events that result in uncontrolled spill at the OID diversion dam.

A 12-year water lease agreement was recently reached between the Colville Tribes and the OID to spill an additional 700 acre feet of water every spring from the Conconully Reservoir into Salmon Creek. The discharged water would be allowed to pass the OID diversion in order to reconnect upstream spawning and rearing habitat to the mainstem Okanogan and also help achieve the minimum flows needed for steelhead passage (Fisher 2006). The OID diversion dam and control structures provide an excellent location for installation of an underwater video system to monitor the effectiveness of this potential steelhead enhancement project. Video operations were not conducted at this site in 2006 as water provisions were obtained after the steelhead run had ended and funding for this water lease agreement had not yet been secured.

Video Chutes

The array on Bonaparte Creek used a rigid picket weir to guide fish through the video chute (Figure 5). Picket panels were comprised of aluminum frames that held 1" PVC pipe inserted into holes drilled on 1" centers. Sandbags and landscape cloth were used to armor the stream banks in the vicinity of the video chute. The weir was checked daily to remove debris and monitor the effectiveness of data collection. Other fish guidance methods investigated but not used at this site included floating pickets (which require design and construction of significant infrastructure) and electric fields (which are passable but carry potential liabilities).

Figure 5. Photograph of the Bonaparte Creek video enumeration station.



Permitting

Installation of an underwater video system required a Shoreline Exemption permit and an Hydraulic Project Approval (HPA) because components are installed directly within the high water mark of the tributary sites. A Joint Aquatic Resources Permit Application (JARPA) was submitted to Okanogan County and the Washington State Department of Fish & Wildlife for each site location and included site descriptions and project plans. For all video applications conducted by the Colville Tribes, the activities operate under NOAA Fisheries Permit #1412 - Direct Take authorization; Section B, Conditions 16 and 22.

Video Systems

The digital video recorder (DVR) is the central component of the video monitoring project (Figure 6). Honeywell DVR units were located at each monitoring site for capturing fish passage events. The DVR units contain tools for enabling cameras, adjusting image capture, setting image resolution and camera sensitivity, frame capture rate, length of motion clips, and time parsing of time-lapse clips. These settings were used to reduce the collection of unwanted false-trigger clips by reducing sensitivity and discriminating by size or direction of travel. The DVR and monitor were housed in a small shed located at the dam (Figure 6).



Figure 6. Photograph of the Zosel Dam digital video recorder and monitor.

In all systems, both time-lapse and motion detection video clips were collected in order to capture fish passage events. Time-lapse images were collected continuously at 2 to 3 frames per second (fps). The DVR also detects motion within a camera's wide-angle field-of-view and triggers the collection of 3- to 5-second video clips at between 10 and 25 fps. The video clips are stored on an interchangeable 250 GB hard-drive for later review on an identical DVR located at the office. At Zosel Dam, the DVR's Ethernet capability and an on-site wireless router provide the user with internet access to view real-time imagery. This allows remote access for checking the system's operational status and facilitates the efficient servicing of the system when needed. All underwater cameras used were manufactured by Integrated Aqua Systems of North Vancouver, BC (Figure 7) and fitted with wide-angle, 2.9 mm lenses. The cameras produce color images with 380 lines of resolution and are rated with a minimum illumination of 0.1 Lux.

Figure 7. Photograph of underwater video camera used for imaging salmonids in the video chutes deployed at Zosel Dam and Bonaparte Creek.

Underwater fluorescent lights mounted to the interior of the video chutes provide illumination during hours of darkness. Orientation of the lights differed on each of the Zosel arrays. The west bank chute used four light tubes mounted horizontally, one above and one below the respective viewing window in each chamber. The east bank chute used two light tubes mounted vertically on both sides of the viewing windows. Each light was connected to a ground fault interrupter (GFI) to reduce or eliminate electrical shock hazards.



Monitoring and Maintenance

In order to facilitate ease of Zosel Dam array removal and maintenance, davit cranes were attached to the dam's superstructure for each chute. Tributary units were much smaller and can be serviced while in place so installation and removal of tributary units occurs only once.

Maintaining the video arrays is an ongoing and important component of the video monitoring project. Maintenance visits to Zosel Dam generally occur every three to four days but are seasonally dependant. The units have operated without cleaning for as long as an entire week, while during other times of the year circumstances required daily cleaning. See Nass (2007) for operational protocols for use with the video systems.

Regular operations and servicing consists of:

1. Daily checks of the Zosel Dam cameras from the office via internet for monitoring system status and image clarity;
2. Daily site visits to the tributary locations in order to clear picket weir of debris and monitor DVR functions;
3. Frequent chute cleaning to reduce non-target motion triggers resulting from accumulated debris and macrophytes;
4. Frequent removal and cleaning of viewing windows;
5. Cleaning of camera lenses;
6. Monitoring of disk usage and status of underwater lights; and
7. Switching out hard drives when full.

Data Collection, Processing and Analysis

The goal of the video enumeration project is to describe species-specific passage of salmonids through the counting chambers across the entire passage season. Therefore, training technicians in salmonid identification is very important to the accuracy of the data and success of the project. A photo album of relevant fish species has been compiled using images collected by the underwater video system and serves as a resource for technicians learning the distinguishing characteristics of target species. The textbook *Inland Fishes of Washington* (Wydoski and Whitney 2003) is also used as a resource for fish identification.

The removable hard drives retrieved from monitoring sites were reviewed clip by clip in the office with a DVR and monitor in order to enumerate migrating fish (Figure 8). Location, date, hour and minute of passage, fish species, camera and reviewer were recorded into an Excel spreadsheet for data analysis. All motion clips of salmonids were archived by the reviewer. The archive clips were then reviewed by a tribal biologist for quality assurance and quality control of the data. Once the accuracy of reviewers' fish identification skills was verified, enumeration progresses without 100%

archival of imagery. Only clips of undetermined fish or clips of exceptional quality were saved for future reference.



Figure 8. Photograph of video data reviewing station.

During periods of increased fish passage, individual passage events were recorded onto a paper datasheet for later entry into the spreadsheet by hour rather than by hour and minute. Additionally, the one-hour time-lapse clips were reviewed for counting fish rather than the individual, 5-second motion clips. Construction is underway on an Access

database which will simplify data entry and substantially enhance our ability to analyze the data.

Fish passage events whereby adult salmonids were noted swimming downstream were handled in the following manner: a factor of one was subtracted from the sum total of upstream counts by camera, hour, and date for each downstream passage event.

Representative photographs are available for viewing by all interested parties on the following web page:

<http://nrd.colvilletribes.com/obmep/resized%20images/jpgs/vidgallery/index.htm>

RESULTS

Zosel Dam

Physical Variables

The pattern of mean daily discharge at Zosel Dam throughout the study period was characterized by primary peak flows (up to 2,860 cfs) occurring in May and June, and secondary peaks in February, April, and July (Figure 9). Mean daily water temperature at the USGS gauging station in Oroville, WA resembled a bell curve in 2006 with a peak of 27.4 °C on 23 July (maximum daily temperature also peaked on this date (30.1 °C) and a low of less than 1 °C in November and December (Figure 9). Water temperature also dipped below 1 °C in December, 2005.

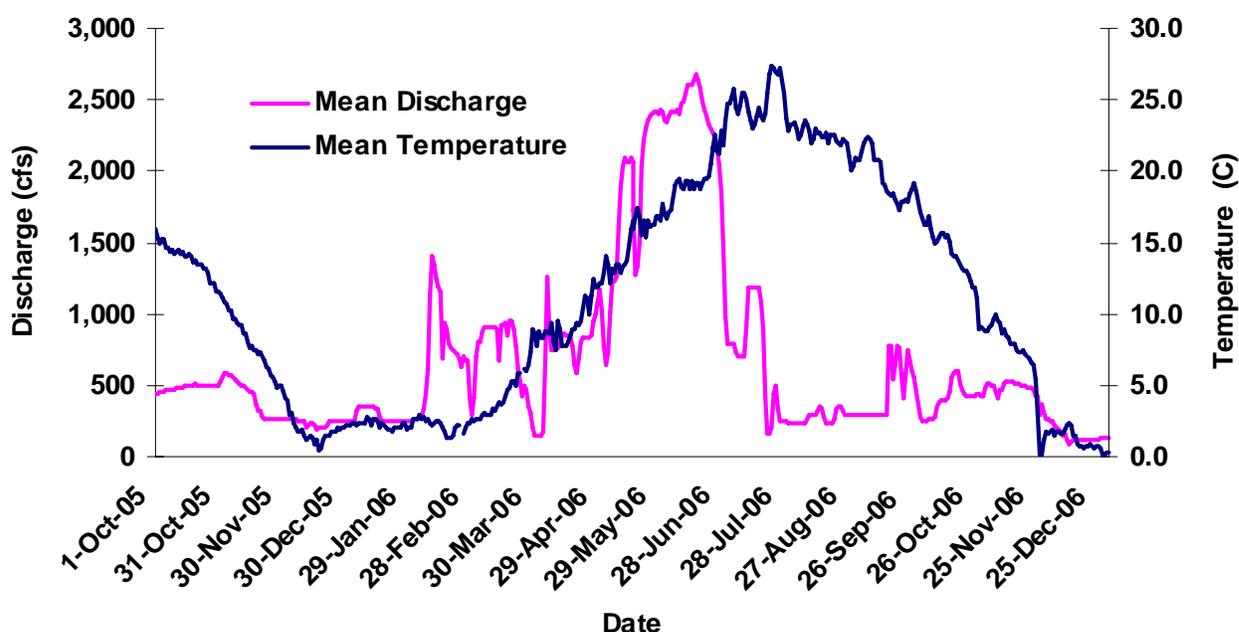


Figure 9. Daily mean temperature and discharge for the Okanogan River below Zosel Dam from 1 October 2005 through 31 December 2006. Data are from the USGS gauge at Oroville, WA (<http://waterdata.usgs.gov/wa/nwis>).

Spillway Operations

In response to the varying water discharge from Canada, Zosel Dam spillway gates were raised and lowered to achieve the target lake levels set forth in the IJC lake level agreement. Throughout the period 1 October 2005 to 31 December 2006, at least one spillway gate was opened greater than 12” on 210 days (Figure 10). The subsequent discharge conditions observed at the USGS gauging station in Oroville were a direct result of the spill pattern implemented by the OTID. The pattern of spillway operations at Zosel Dam throughout the sampling season controlled the pattern of mean daily discharge observed.

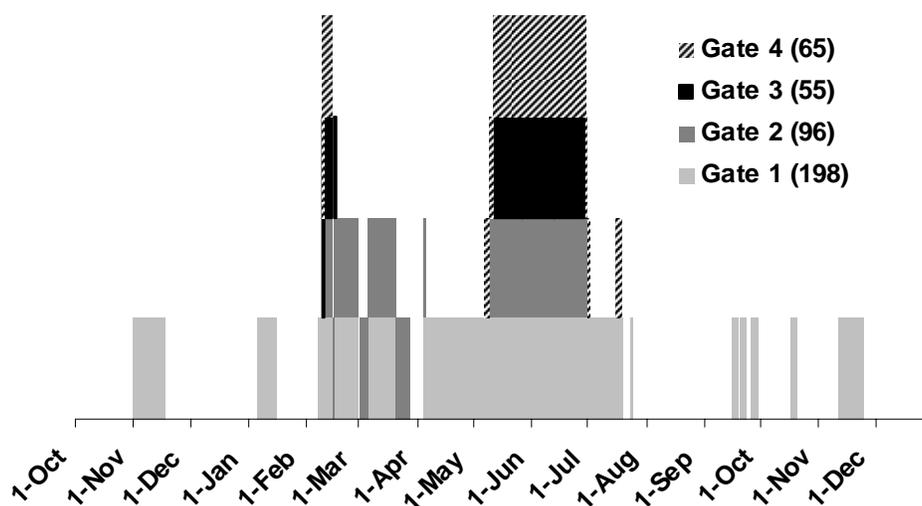


Figure 10. Dates in which individual spillway gates at Zosel Dam were opened more than 12” for the period 1 October 2005 through 31 December 2006. Numbers in parentheses indicate the number of days in which the gates were opened greater than 12”.

Video Monitoring Operations

Video enumeration at Zosel Dam began on 5 October 2005 with the installation of the west bank monitoring chute. The east bank chute was installed and operational on 17 February 2006.

Missing Data

There were a number of instances during the sampling period in which passage data were not collected at Zosel Dam in 2005 and 2006 (Table 1). As a result, all passage data reported here should be considered as relative abundance estimates and not total census counts since the data do not reflect complete coverage of adult salmonid passage through Zosel Dam. In addition, the 2005 data were limited to just the last quarter of the year, and only the west bank array was operational.

Table 1. List of time periods in which data collection was interrupted at Zosel Dam in 2005 and 2006.

Time Period	Cameras Affected	Total Hours Affected	Problem
11 Nov 05 11:00 to 14 Nov 05 12:00	All	39 ^b	Power interruptions resulting in lights turning off (no images collected during hours of darkness)
21 Jan 06 21:53 to 24 Jan 06 14:37	All	65	Battery charger malfunction
1 Mar 06 18:18 to 4 Mar 06 21:35	All	75	Gap in passage data may be due to unknown problem ^a
6 Mar 06 12:01 to 12 Mar 06 16:00	All	100	Gap in passage data may be due to unknown problem ^a
16 Mar 06 01:57 to 17 Mar 06 07:00	All	16 ^c	Power interruptions resulting in lights turning off (no images collected during hours of darkness)
17 Mar 06 12:11 to 21 Mar 06 13:57	All	76	Gap in passage data may be due to unknown problem ^a
20 May 06 01:47 to 22 May 06 07:01	All	53	Gap in passage data may be due to unknown problem ^a
31 May 06 13:40 to 5 June 06 22:35	All	129	Gap in passage data may be due to unknown problem ^a
7 Jun 06 21:34 to 14 Jun 06 06:36	All	153	Gap in passage data may be due to unknown problem ^a
15 Jun 06 11:41 to 21 Jun 06 22:00	All	154	Gap in passage data may be due to unknown problem ^a
21 Jun 06 22:00 to 26 Jun 06 07:12	5 through 8	32 ^d	Power interruptions resulting in lights turning off (no images collected during hours of darkness)
27 Jun 06 12:54 to 30 Jun 06 01:15	All	60	Gap in passage data may be due to unknown problem ^a
1 Jul 06 11:56 to 5 Jul 06 01:40	All	86	Gap in passage data may be due to unknown problem ^a
6 Jul 06 20:40 to 10 Jul 06 01:39	All	77	Gap in passage data may be due to unknown problem ^a
11 Jul 06 06:15 to 14 July 06 09:54	All	76	Gap in passage data may be due to unknown problem ^a

^a Gap in passage data may be due to failure to restart the record function on DVR after servicing, failure to change out DVR drives when full, hard drive review errors due to multiple reviewers, or no fish were passing during this time.

^b Assuming 13 hours of darkness per day in November

^c Assuming 12 hours of darkness per day in March

^d Assuming 8 hours of darkness per day in June

Chinook Salmon

Totals of 57 and 481 adult upstream-migrating Chinook salmon were counted at Zosel Dam in 2005 and 2006, respectively (Table 2). In 2005, five fish were observed to be marked with adipose fin clips. In 2006, five fish were observed to be marked with adipose fin clips, and four fish were of unknown origin.

Table 2. Total number of adult salmonids observed based on video counts at Zosel Dam in 2005 and 2006. Numbers of observed marked and unmarked fish are listed by species and year.

	2005		2006		
	Chinook	Sockeye	Chinook	Sockeye	Steelhead
Unmarked	52	48	472	19,229	152
Marked	5	0	5	9	146
Unknown	0	0	4	7	0
Total	57	48	481	19,245	298

Chinook salmon showed a slight preference for passing Zosel Dam through the video chutes on the east bank (52%) relative to the west bank (48%) (Table 3). Within the chutes, all passage events were recorded by the deeper deployed cameras (cameras numbered 3 through 6).

Table 3. Total number and proportion of adult salmonids observed by bank location based on video counts at Zosel Dam in 2005 and 2006.

	Chinook		Sockeye		Steelhead	
	Count	Percent	Count	Percent	Count	Percent
East Bank	279	51.9%	13,939	72.4%	87	29.2%
West Bank	259	48.1%	5,306	27.6%	211	70.8%

The run timing plot of Chinook salmon in the truncated 2005 sampling season indicates that the first fish was detected on 5 October and the last fish on 26 November (Figure 11). The 2005 run timing data shows little patterning other than perhaps a slight mode of passage evident from 5 to 15 October characterized by daily peaks between four to six fish. The remainder of the 2005 passage season was typified by daily passage of few fish.

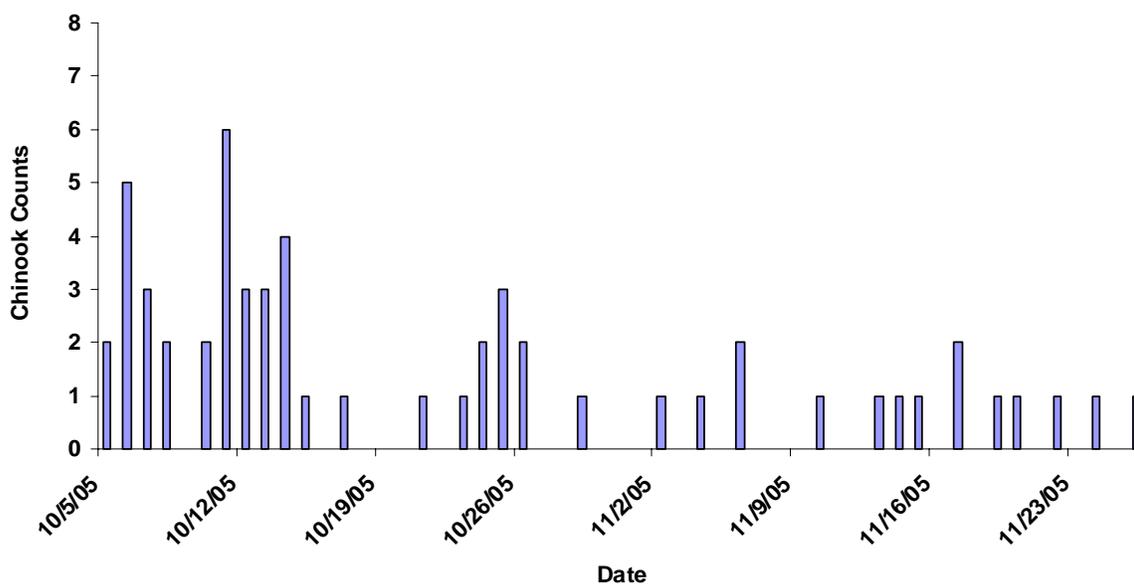


Figure 11. Adult Chinook salmon run timing based on video counts at Zosel Dam in 2005.

In 2006, Chinook salmon were first observed on 16 July and the last fish was detected on 24 November (Figure 12). Within this span of time, two primary modes of passage (first week in August and the first three weeks in October) and two secondary pulses of passage (third week in July and middle of September) were evident. The October passage mode was more sustained than the one occurring in August and peaked on the 5th with 52 fish. The timing of the October passage mode resembles to some extent what was observed in 2005 (compare Figure 11 and Figure 12).

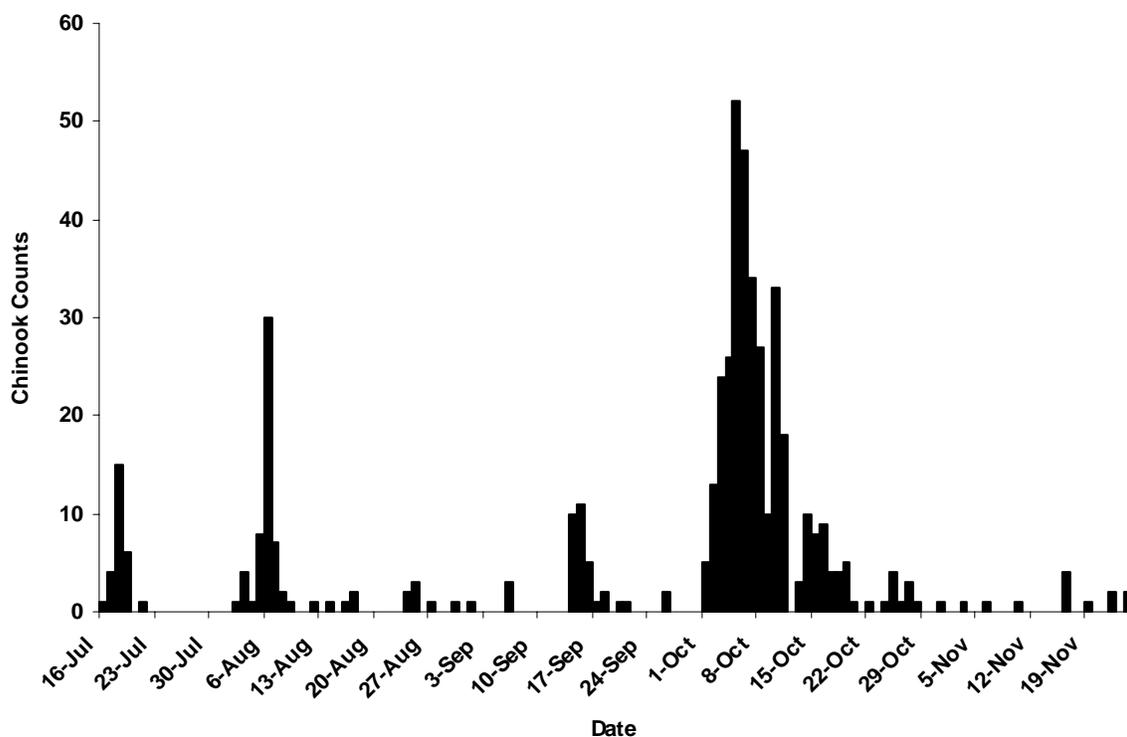


Figure 12. Adult Chinook salmon run timing based on video counts at Zosel Dam in 2006.

Examination of hourly passage counts of Chinook salmon for 2005 and 2006 at Zosel Dam reveals a slight diel pattern. Chinook passage remained low from 1900 hours through 0600 hours relative to other hours of the day (Table 4, Figure 13). Through most of the hours of day however, hourly passage patterns were not evident. Peak Chinook passage occurred during 0800 hours.

Table 4. Hourly data of adult salmonid passage based on video counts at Zosel Dam in 2005 and 2006. Total counts and percent frequency values reflect a combination of 2005 and 2006 hourly data.

Hour	Chinook Count				Sockeye Count				Steelhead Count (06 cohort)	
	2005	2006	Total	Freq.	2005	2006	Total	Freq.	Total	Freq.
6	2	12	14	2.6%	3	1,047	1,050	5.5%	6	2.0%
7	1	39	40	7.4%	2	646	648	3.4%	9	3.0%
8	2	52	54	10.0%	2	482	484	2.5%	8	2.7%
9	1	38	39	7.2%	0	471	471	2.4%	14	4.7%
10	2	23	25	4.6%	2	448	450	2.3%	9	3.0%
11	3	37	40	7.4%	3	574	577	3.0%	8	2.7%
12	3	21	24	4.5%	1	542	543	2.8%	4	1.3%
13	4	23	27	5.0%	1	513	514	2.7%	15	5.0%
14	4	19	23	4.3%	1	303	304	1.6%	9	3.0%
15	3	32	35	6.5%	0	258	258	1.3%	15	5.0%
16	3	30	33	6.1%	1	318	319	1.7%	18	6.0%
17	3	29	32	5.9%	1	376	377	2.0%	15	5.0%
18	1	21	22	4.1%	2	340	342	1.8%	19	6.4%
19	0	10	10	1.9%	3	281	284	1.5%	10	3.4%
20	3	8	11	2.0%	3	377	380	2.0%	12	4.0%
21	0	13	13	2.4%	0	350	350	1.8%	9	3.0%
22	2	6	8	1.5%	2	975	977	5.1%	14	4.7%
23	2	3	5	0.9%	0	1,998	1,998	10.4%	12	4.0%
0	10	2	12	2.2%	11	1,756	1,767	9.2%	22	7.4%
1	3	13	16	3.0%	2	1,565	1,567	8.1%	16	5.4%
2	3	16	19	3.5%	3	1,383	1,386	7.2%	11	3.7%
3	1	9	10	1.9%	1	1,305	1,306	6.8%	15	5.0%
4	1	10	11	2.0%	2	1,000	1,002	5.2%	16	5.4%
5	0	15	15	2.8%	2	1,889	1,891	9.8%	12	4.0%
Total	57	481	538		48	19,197	19,245		298	

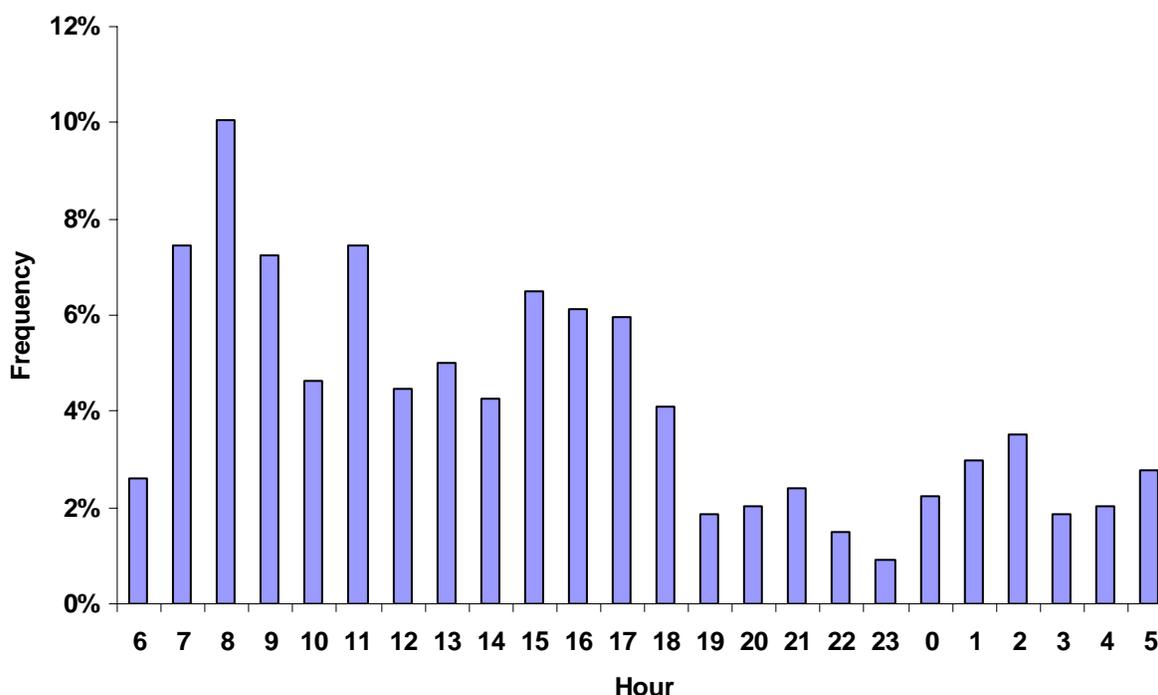


Figure 13. Percent frequency distribution of hourly adult Chinook salmon passage based on video counts at Zosel Dam in 2005 and 2006 combined. For differences in hourly passage between years, see Table 4.

Sockeye Salmon

A total of 48 adult sockeye salmon in 2005 and 19,245 in 2006 passed through the video chutes at Zosel Dam (Table 2). All sockeye observed in 2005 were unmarked whereas in 2006, nine fish were observed to be marked and seven fish were not known to be marked or unmarked. Sockeye showed a strong preference for passing Zosel Dam on the east bank as over 72% of all passage events occurred in video chutes on the east bank (Table 3). Within the video chutes, the overwhelming majority of all passage events were detected by the deeper deployed cameras.

Run timing of sockeye salmon in 2005 indicated an initial detection on 5 October and the last detection on 11 November (Figure 14). Throughout this time period, counts of sockeye were generally less than four per day, with daily peaks of six fish occurring on 6 and 11 October.

In 2006, sockeye were first observed at Zosel Dam on 16 July and the last detection was on 22 November (Figure 15). The 2006 run timing pattern was characterized by a large mode of passage from 3 through 10 August when 17,689 fish (92% of total run observed for the year) were observed passing through the video chutes. The daily peak of 5,853 fish occurred on 4 August. Secondary pulses of sockeye passed the dam during the latter half of August, early September, and late September/early October. After mid October, sockeye passage was limited to fewer than 10 fish per day.

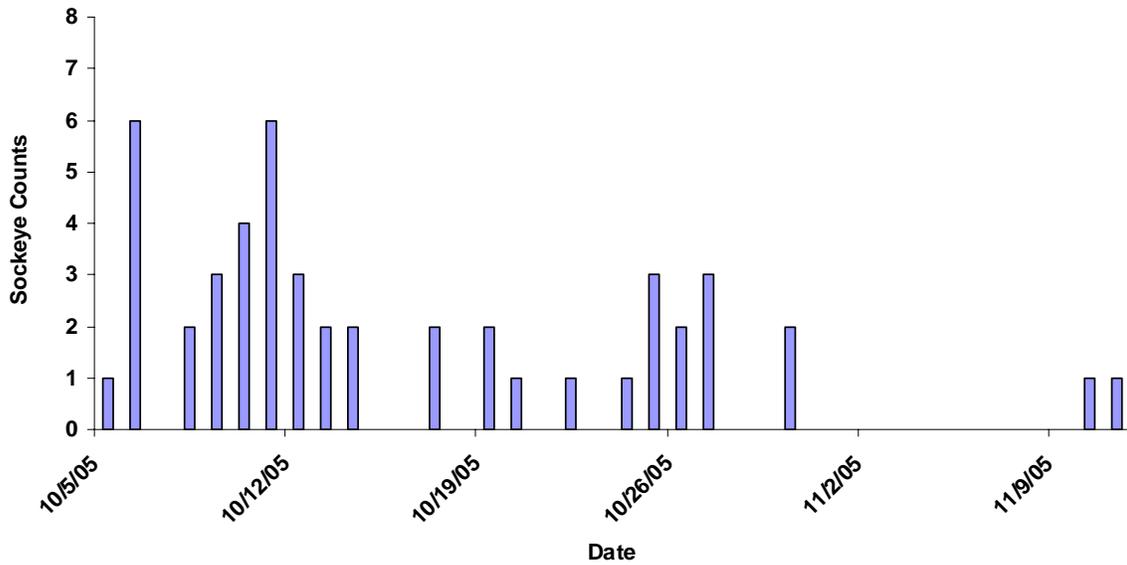


Figure 14. Adult sockeye salmon run timing based on video counts at Zosel Dam in 2005.

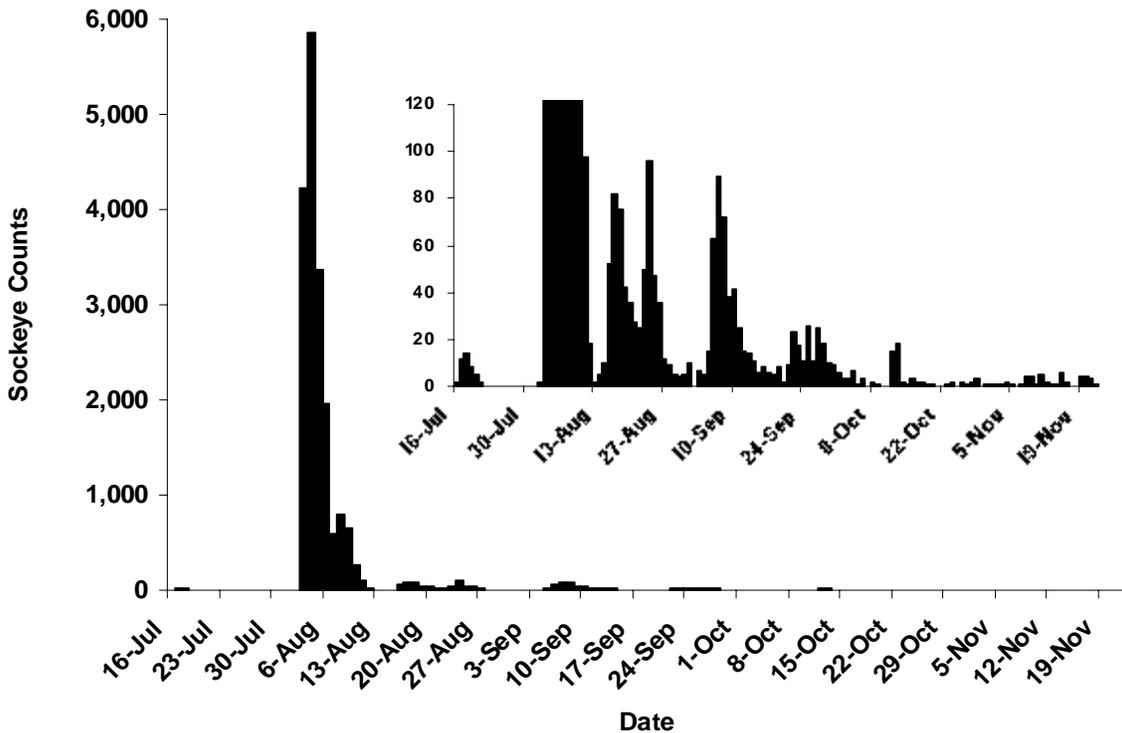


Figure 15. Adult sockeye salmon run timing based on video counts at Zosel Dam in 2006. The superimposed plot shows the same count data but scaled to allow for examination of passage in which sockeye passed in numbers less than 100 per day.

Hourly passage counts of sockeye salmon for 2005 and 2006 at Zosel Dam show a strong diel pattern with increased passage during nighttime hours relative to daytime hours (Table 4, Figure 16). Nearly 57% of all sockeye passage events occurred between 2300 and 0500 hours compared to the remaining 17 hours of the day. Fish passage was observed to be lowest between the 1500 and 1900 hours.

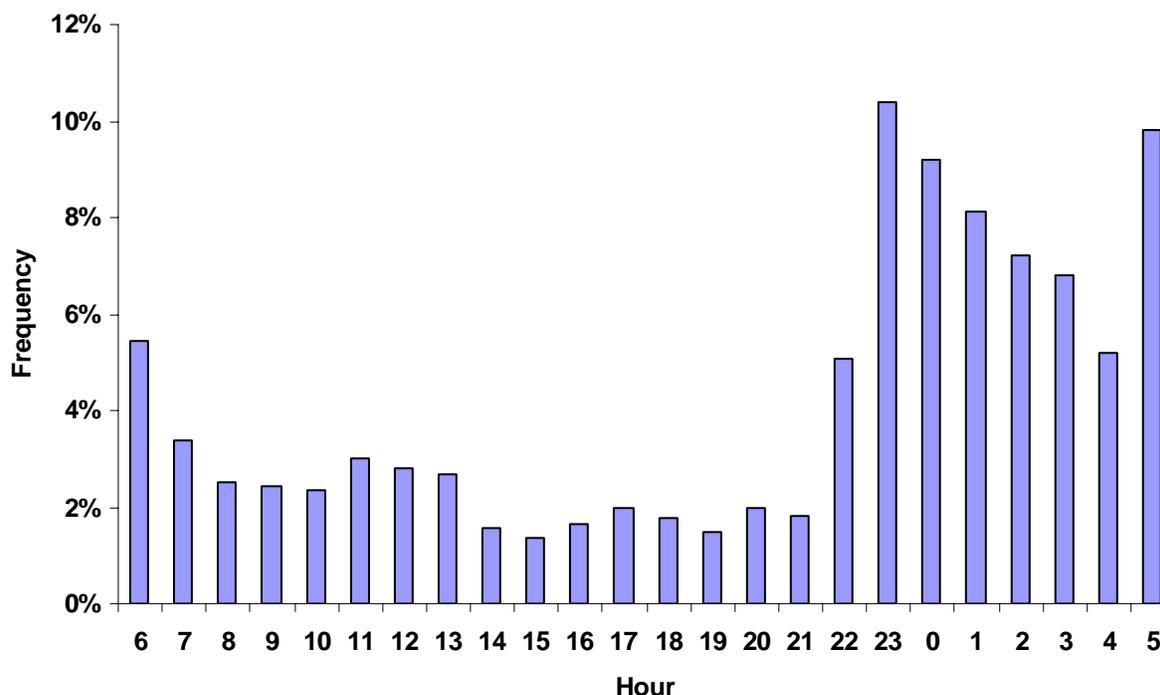


Figure 16. Percent frequency distribution of hourly adult sockeye salmon passage based on video counts at Zosel Dam in 2005 and 2006 combined. For differences in hourly passage between years, see Table 4.

Steelhead

A total of 298 adult upstream-migrating steelhead were counted at Zosel Dam in 2005 and 2006, representing the 2006 cohort based on passage data from 5 October 2005 through 15 July 2006 (Table 2). One hundred and forty seven (147) steelhead were observed with fin clips. In contrast to both Chinook and sockeye salmon, steelhead were shown to have a strong preference for passing the dam on the west bank as almost 71% of all steelhead passage events occurred in video chutes on the west bank (Table 3). As with sockeye, the overwhelming majority of all passage events were detected with the deeper deployed cameras.

The 2006 Steelhead cohort were first detected at Zosel Dam on 25 October 2005 and last detected 10 May 2006. Passage throughout the early portion of this time period was sporadic, with no more than two fish detected on any given day (Figure 17). The majority of fish passed the dam from 23 March through 6 May (87% of the total observed for the year). The peak in steelhead passage occurred on 6 April when 31 fish were observed passing through the video chutes.

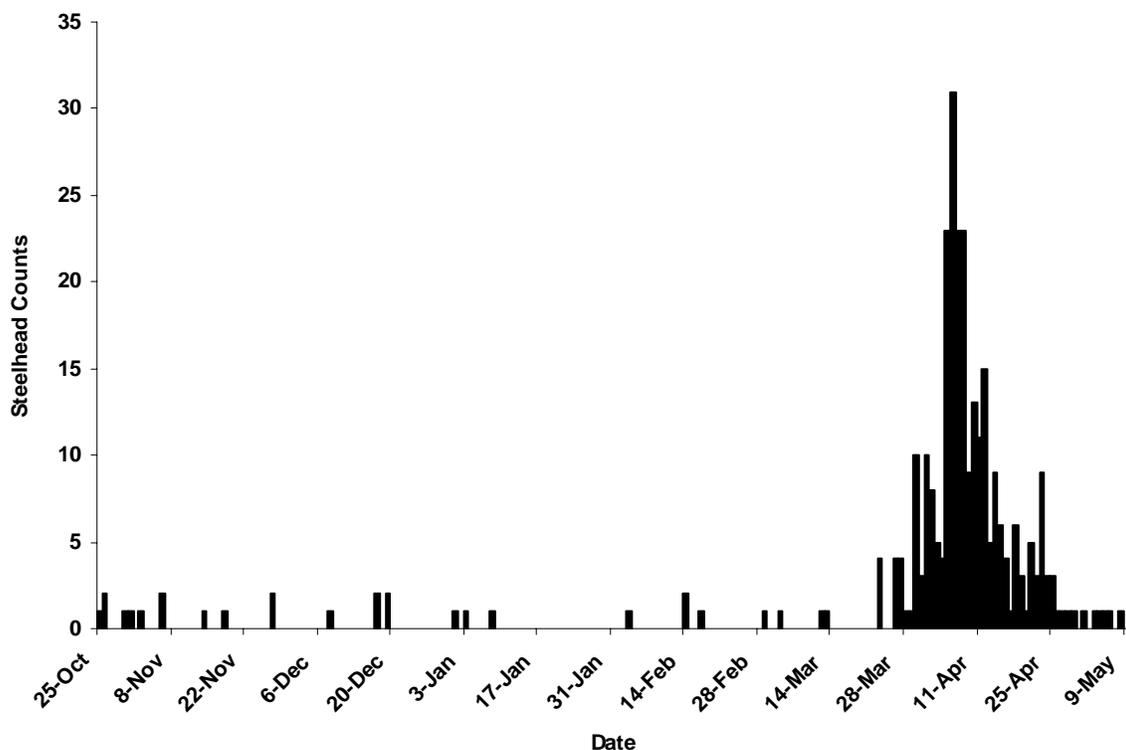


Figure 17. Adult spring migrant steelhead (2006 cohort) run timing based on video counts at Zosel Dam in 2005 and 2006.

Steelhead passage at Zosel Dam exhibited no diel patterning (Table 4, Figure 18). Hourly passage peaked during the midnight hour and the lowest passage occurred during the noon hour.

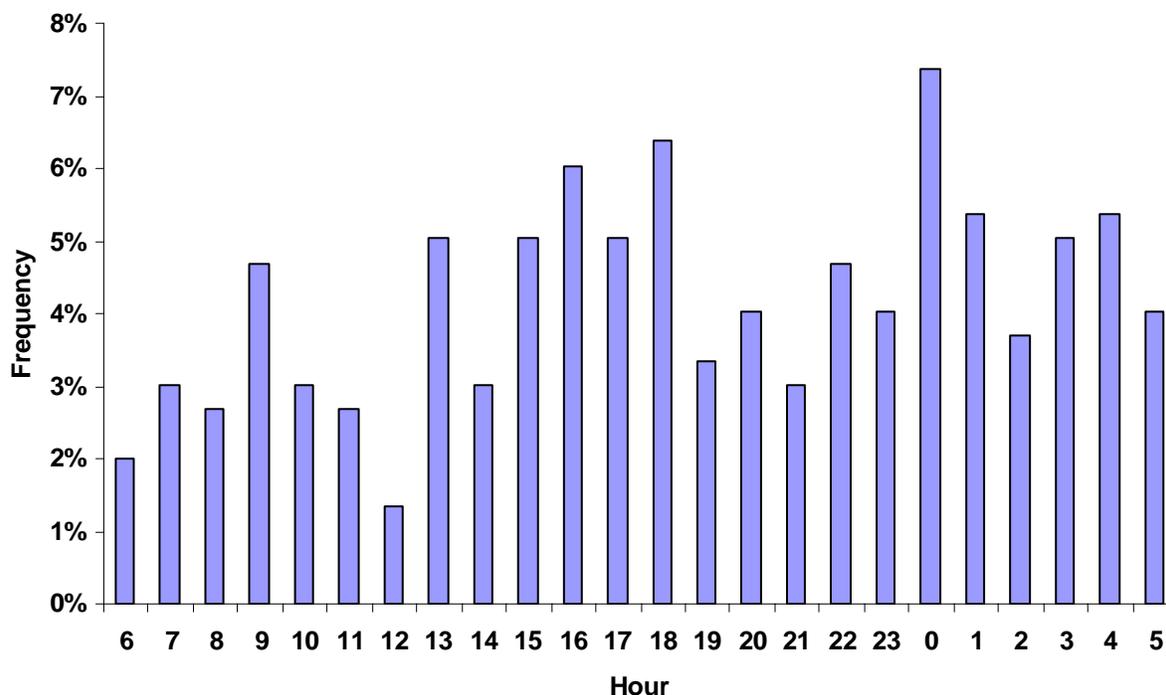


Figure 18. Percent frequency distribution of hourly adult steelhead passage based on video counts at Zosel Dam in 2005 and 2006 combined. Only 2006 cohort data (passed the dam between 5 October 2005 and 15 July 2006) are shown. For differences in hourly passage between years, see Table 4.

Temperature and Flow Effects on Fish Passage

There were apparent effects of water temperature on Chinook, sockeye and steelhead passage at Zosel Dam in 2006 (compare Figure 9, Figure 15 and Figure 17 to Figure 9). During the last 10 days in July when mean daily temperatures exceeded 24 °C and maximum daily temperatures exceeded 26.5 °C, salmon passage ceased at Zosel Dam. When water temperatures began to decrease in early August, Chinook and sockeye passage was observed to sharply increase (at approximately 23° C).

With respect to flow, at least for Chinook (Figure 11 and Figure 12) and sockeye salmon (Figure 14 and Figure 15), patterns of discharge across the sampling season (Figure 9) had no discernible effects on passage patterns. However, a relationship between discharge and steelhead passage in 2006 was evident during the primary mode of passage that occurred in the spring (Figure 19). The increase in steelhead passage leading up to the daily peak of 31 fish on 6 April coincides with an increase and spike in discharge of 1,260 cfs on that same day. The decrease in discharge following the spike also coincides with a decrease in steelhead passage.

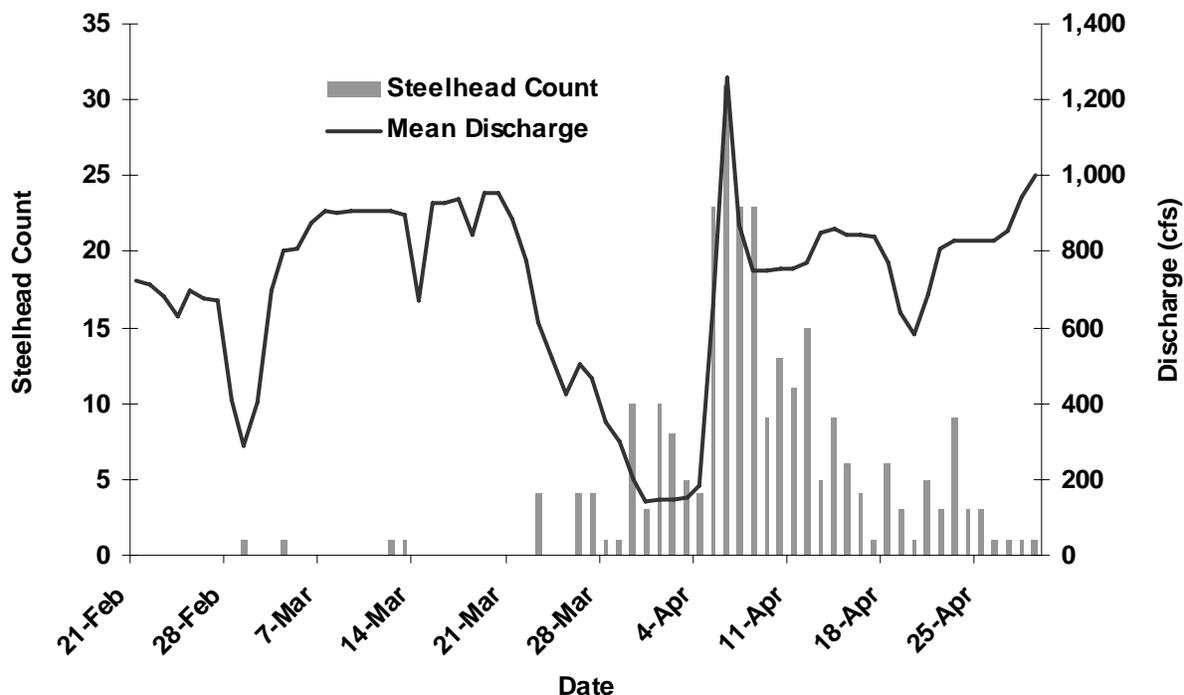


Figure 19. Adult steelhead run timing based on video counts and mean daily discharge at Zosel Dam for selected dates in 2006. Discharge data are from the USGS gauge at Oroville, WA.

Downstream Passage

A total of 104 downstream passage events were observed with the video monitoring system at Zosel Dam in 2006 (none were recorded in 2005). Of these events, 100 were sockeye salmon, three were Chinook salmon and one was a steelhead. All sockeye downstream passage events occurred between 2000 and 0500 hrs. Similarly, the three Chinook passed at night (0100 hr) as did the steelhead (2300 hr). All sockeye downstream passage events occurred from 18 August through 1 October, after the majority of fish had passed the dam. One downstream-swimming Chinook was observed on 6 September while the other two were observed on 4 October.

Non-Target Fish

Twenty (20) non-target fish species were observed with the video monitoring system at Zosel Dam in 2005 and 2006 (Table 5).

Table 5. List of all fish species observed with the video monitoring system at Zosel Dam in 2005 and 2006.

Common Name	Species	Family
Chinook	<i>Oncorhynchus tshawytscha</i>	Salmonidae
Steelhead	<i>Oncorhynchus mykiss</i>	Salmonidae
Rainbow	<i>Oncorhynchus mykiss</i>	Salmonidae
Sockeye	<i>Oncorhynchus nerka</i>	Salmonidae
Brook Trout	<i>Salvelinus fontinalis</i>	Salmonidae
Mountain Whitefish	<i>Prosopium williamsoni</i>	Salmonidae
Yellow Perch	<i>Perca flavescens</i>	Percidae
Brown Bullhead	<i>Ameiurus nebulosus</i>	Ictaluridae
Yellow Bullhead	<i>Ameiurus natalis</i>	Ictaluridae
Burbot	<i>Lota lota</i>	Gadidae
Carp	<i>Cyprinus carpio</i>	Cyprinidae
Chiselmouth	<i>Acrocheilus alutaceus</i>	Cyprinidae
Northern Pikeminnow	<i>Ptychocheilus oregonensis</i>	Cyprinidae
Peamouth	<i>Mylocheilus caurinus</i>	Cyprinidae
Redside shiner	<i>Richardsonius balteatus</i>	Cyprinidae
Black Crappie	<i>Pomoxis nigromaculatus</i>	Centrarchidae
Bluegill	<i>Lepomis macrochirus</i>	Centrarchidae
Largemouth Bass	<i>Micropterus salmoides</i>	Centrarchidae
Pumpkinseed	<i>Lepomis gibbosus</i>	Centrarchidae
Smallmouth Bass	<i>Micropterus dolomieu</i>	Centrarchidae
White Crappie	<i>Pomoxis annularis</i>	Centrarchidae
Bridgelip Sucker	<i>Catostomus columbianus</i>	Catostomidae
Largescale Sucker	<i>Catostomus macrocheilus</i>	Catostomidae

Bonaparte Creek

Stream Flow

Through the period in which the video monitoring system was operational (17 March through 20 July), the discharge in Bonaparte Creek was characterized by peak flows of 38 cfs in late May and otherwise moderate flows ranging between 6 to about 16 cfs (Figure 20). Lows in the mean daily flows through this period occurred in mid March and during the third week in July.

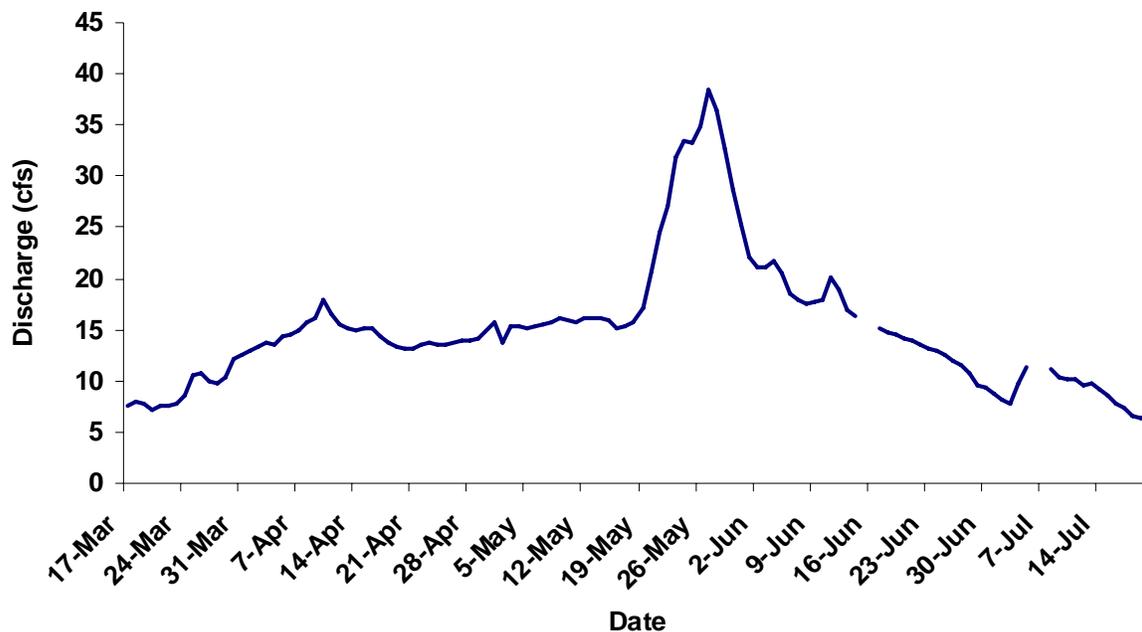


Figure 20. Mean daily discharge in Bonaparte Creek from 17 March through 20 July. Discharge data from Washington Department of Ecology gauge station at Tonasket, WA (<https://fortress.wa.gov/ecy/wrx/wrx/flows/station.asp?Sta=49F070>).

Missing Data

Data collection at the Bonaparte Creek site was interrupted for extended periods throughout the sampling season. Electrical problems, an incorrectly programmed DVR, and inadequate maintenance contributed to the interruptions in data collection. No data were collected during the time period 3 May through 18 July. Additionally, inadequate lighting prevented the recording of nighttime passage events and at times, excessive turbidity resulted in poor image quality during daylight hours.

Fish Passage

A total of six steelhead were observed with the video monitoring system at Bonaparte Creek in 2006, with three passage events occurring on 29 March and one each on 20, 21, and 23 April (Table 6). Of these six fish, two were noted to have adipose fin clip markings.

Table 6. List of steelhead observations based on video monitoring at Bonaparte Creek in 2006.

Date	Hour	Marking
29-Mar	1100	Unmarked
29-Mar	1300	Fin Clip
29-Mar	1300	Unmarked
20-Apr	1300	Unmarked
21-Apr	0500	Unmarked
22-Apr	2200	Fin Clip

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DISCUSSION

Run Timing and Relative Abundance

It is instructive to compare the 2006 Zosel Dam passage data with the adult counts at Wells Dam (Fish Passage Center 2007) to better understand spawner distribution and run timing dynamics in the Upper Columbia and Okanogan river basins. Chinook salmon run timing through Zosel Dam was episodic with two primary passage modes (peaks in early August and early October) apparent through the sampling season (Figure 12). The adult summer Chinook run timing at Wells Dam was also episodic but very protracted, with peaks in early July and mid August (Figure 21). Plotting both data sets on the same time scale (Figure 21) indicates that summer Chinook began arriving at Zosel Dam 18 days after they were first observed at Wells Dam and continued to be detected at Zosel up to 88 days after which the last summer Chinook was seen at Wells. Of the 27,196 summer Chinook counted at Wells, 481 fish, or 1.7% were detected at Zosel Dam. In 2006, Zosel Dam Chinook counts were unaffected by the gaps in passage data since the gaps occurred prior to all observed passage events (Table 1).

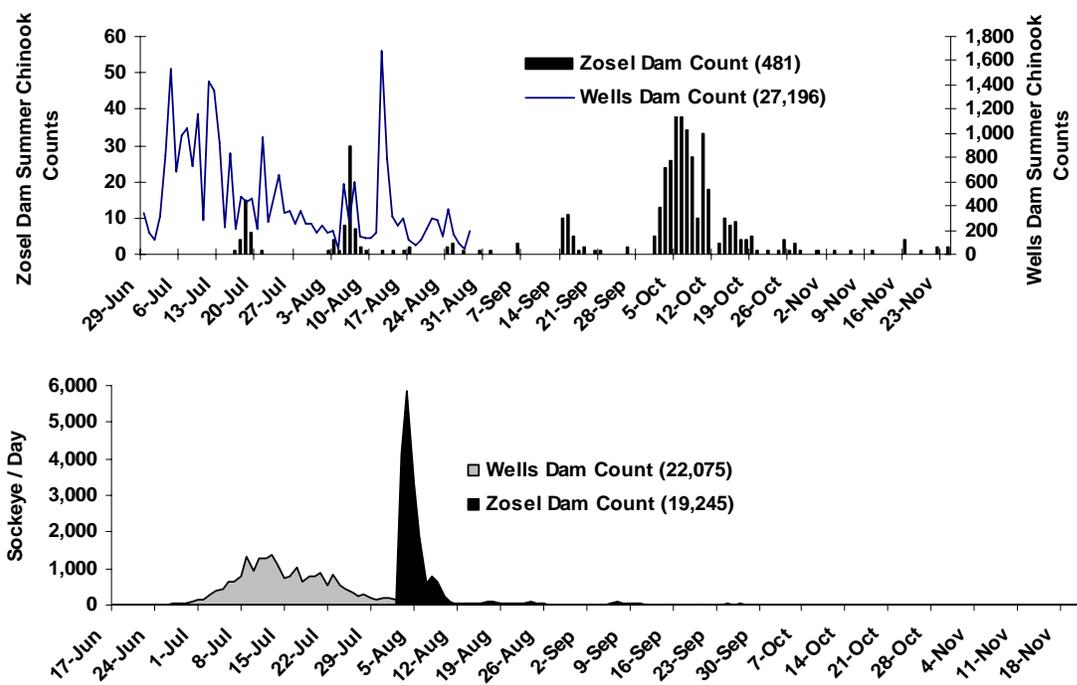


Figure 21. Run timing of summer Chinook and sockeye salmon at Zosel Dam on the Okanogan River and Wells Dam on the Columbia River in 2006. The origins of the x-axis scales are based on initial detection at either Zosel or Wells Dam (whichever came first). Note that the Chinook counts for Zosel and Wells Dams have different Y-axes. Wells Dam data from Fish Passage Center Website: <http://www.fpc.org/>. Note that Wells Dam counts are reported on the FPC website from 1 May through 15 November.

Sockeye salmon run timing at Zosel Dam was characterized with an initial primary passage mode in early August followed by several smaller pulses of passage in late August and early and mid September (Figure 15). Sockeye run timing at Wells Dam indicated initial peaks in mid July followed by a general decline in passage through July and into August (Figure 21). Examination of daily sockeye counts from both dams reveals that peak passage rates at Zosel Dam exceeded those observed at Wells Dam (Figure 21), indicating that sockeye exhibit staging behavior prior to passing through Zosel en route to their spawning grounds. This staging behavior is likely the result of the presence of a temporal thermal barrier at the confluence of the Columbia and Okanogan rivers (Duree 1991; Hatch et al. 1992; Alexander et al. 1998). Of the 22,075 sockeye counted at Wells Dam, 19,245 fish, or 87.2% were observed at Zosel. In 2006, sockeye counts were unaffected by data gaps since the data interruptions occurred prior to any observed sockeye passage events (Table 1).

The relative abundance estimate for sockeye passing Zosel Dam compares favorably with the preliminary estimate of 20,819 spawning sockeye derived from Area-Under-the-Curve estimation (Hyatt et al. 2006) and based on spawning ground surveys in the Upper Okanogan River in 2006 (Kari Long, Okanogan Nation Alliance Fisheries Department, pers. comm.). The similarity of the Zosel sockeye relative abundance estimate to both the Wells Dam count and the spawning ground survey preliminary estimate underscores the utility of the Zosel Dam video monitoring system to provide accurate adult count data.

Steelhead run timing at Zosel Dam in 2006 was characterized by a primary mode of passage in early April and a small number of fish passing prior to and after that time period (Figure 17). The relative abundance of steelhead passing Zosel Dam was likely underestimated due to the gaps in monitoring data that occurred from March through May (a total of 320 hours, or the equivalent of 13.3 days: Table 1), the time period in which steelhead passage was highest (Figure 17). Unmonitored passage of steelhead through the spillway (see section below) would also have contributed to underestimates of steelhead passage. The magnitude of the underestimation of steelhead relative abundance in 2006 is unknown.

Difficulty existed in discerning the resident rainbow trout life history form of *O. mykiss* from the anadromous steelhead form. Every effort was made when reviewing video data to make a determination based on relative size and body shape of suspect individuals, but it is unlikely that neither the precision nor the accuracy of proper identification were consistent throughout the year.

Diel Passage

Patterns of hourly passage varied across all migrant salmonid species. Sockeye indicated a very strong diel patterning, with increased passage between 2300 and 0500 hours, and lows in passage during the early afternoon hours (Figure 16). Chinook exhibited less patterning than did sockeye, but a decrease in passage during the 1900 hour to the 0600 hour was evident, and a peak occurred at 0800 hours (Figure 13). Steelhead showed little diel patterning, with peak passage at midnight and the lowest passage occurring during the noon hour (Figure 18).

Based on hydroacoustic sampling at Zosel Dam in 1991, sockeye passage was dissimilar to what was observed in 2005 and 2006 as sockeye were reported to pass most frequently during the 1900 and 0600 hours, with lows during the mid-morning hours (Anglea and Johnson 1991). However, Hatch et al. (1992) reported an even more pronounced nighttime trend in sockeye passage at Zosel Dam in 1992 than was observed in 2005/2006 as nighttime (2000 to 0600 hours) passage accounted for 93% of total passage. Also contrary to the results reported here, Hatch et al. (1994b) observed that nighttime passage of sockeye at Tumwater Dam on the Wenatchee River accounted for only 6.7% of total passage throughout the day. In the Tumwater Dam passage study, Hatch et al. (1994b) reported that nighttime passage for steelhead and Chinook accounted for 16.2 and 13.6% of total passage, respectively, estimates that are lower than what are reported for Zosel Dam in 2005 and 2006. In a video sampling study at Prosser Dam on the Yakima River, Hiebert et al. (2000) found that peak Chinook passage occurred during the 1000 to 1200 hour time period, also a result unlike what was observed at Zosel Dam in 2005 and 2006.

Temperature and Discharge Effects

Prior investigators have reported that salmonid passage at Zosel Dam was regulated in part by water temperature, and that sockeye passage only occurred when water temperatures did not exceed 23 °C (Hatch et al. 1992). Alexander et al. (1998) clearly illustrated using radio-telemetry that Chinook and sockeye destined for spawning in the Okanogan River demonstrated migration timing patterns that were inextricably linked with the temperature of the river. Migration into the Okanogan ceased at 21 °C when water temperature was ascending and restarted at 21 °C when the temperature was descending. Major and Mighell (1967) also noted that high water temperatures had a negative effect on migration and that a sharp drop in temperature resulted in increased passage. The 2006 results support the temperature/fish passage relationship as well: when daily mean water temperatures exceeded 24 °C and maximum daily temperatures exceeded 26.5 °C in late July (Figure 9), Chinook and sockeye counts went to zero (Figure 12 and Figure 15). A subsequent decrease in water temperature resulted in sharp increases in both Chinook and sockeye passage.

Discharge had less effect on adult salmonid passage than did water temperature in 2005 and 2006. Discharge patterns (Figure 9) had no apparent influence on Chinook or sockeye passage at Zosel Dam, but flow did affect steelhead passage. During the primary mode of steelhead passage, daily counts were observed to closely track patterns of mean daily discharge (Figure 19). As discharge increased to a high of over 1,200 cfs in early April steelhead counts reached their peak during the same time period.

Lateral and Vertical Passage Distributions

Distribution of fish utilizing the east and west bank video chutes varied according to salmonid species (Table 3). Chinook, and to a larger degree sockeye salmon passage was skewed toward the east bank (52 and 72%, respectively) which indicates a preference for passing on the east side of the dam. In contrast, steelhead passage was skewed toward the west bank as 71% steelhead passed predominantly on the west side of the dam. Spillway operation may have influenced passage preference. Spill Gate 1,

located near the west bank fish ladder, was most frequently open when steelhead were passing the dam. The open spill bay may have attracted steelhead migrants towards the west bank as attraction flows in that area were increased. Anglea and Johnson (1991) reported that sockeye salmon showed an 80% preference for the west bank ladder, and attributed the preference to an influence of attraction flows set up by the exclusive use of Gate 1 during their study. Hatch et al. (1992) found no sockeye preference for either ladder with approximately the same volume of water passing through gates 1 and 4 (nearest gate to the east bank ladder). The preference observed by both Chinook and sockeye for the east bank chute in 2006 is inconsistent with the notion of spill gate opening influencing fish passage since Gate 4 was not open during the periods in which these species were passing Zosel Dam in 2006 (Figure 10).

The video monitoring results were also informative with regards to vertical distribution of passage since the video chutes were vertically compartmentalized. Passage data strongly indicated that when flow conditions resulted in all levels of the chutes being watered up, Chinook, sockeye and steelhead all passed the monitoring stations through the deepest portions of the chutes.

The Spillway – An Unmonitored Passage Route

Video monitoring arrays at Zosel Dam sampled only the primary passage routes; the pool and weir type fish ladders. However, upstream passage by salmon through open spill gates has been documented at Zosel Dam (Major and Mighell 1967; Anglea and Johnson 1991; Hatch et al. 1992). Therefore, an attempt was made to monitor passage through this route using high intensity lights and color cameras on the tailrace side of Gate 1. A single spill bay stop log was fitted with cameras and lights and lowered onto the spill apron. Unfortunately, this location proved to have conditions beyond the capabilities of the equipment. In particular, the low contrast background, the variable effects of sunlight, and entrained air at the gate edge made image recognition virtually impossible. In addition, it is likely that water velocity and entanglement with debris would have become a serious problem during parts of the monitoring season. As a result, the extent to which upstream or downstream passage occurred through the spill gates in 2005 and 2006 is unknown. However, since spill gates were typically not open more than 12" through the period in which Chinook and sockeye were passing Zosel Dam (compare Figure 10 with Figure 12 and Figure 15), it is likely that few, if any fish of these species passed through the spillway on their way upstream. This thereby makes these counts reliable. For steelhead it is likely that some number of fish may have passed up through the spillway undetected. At least one spill gate was open more than 12" for 91% of the steelhead migration period (March through May), the time frame in which the majority of steelhead passed the dam (compare Figure 10 with Figure 17). As a result, steelhead passage estimates from Zosel Dam in 2006 likely underestimate the number of steelhead that actually passed.

Bonaparte Creek

Despite numerous technical difficulties and challenges in 2006, the Bonaparte Creek video monitoring site was still able to successfully image a total of six steelhead (Table 6). Given the interruption of data collection, the actual number of steelhead migrating up Bonaparte Creek may have been considerably higher than what was observed. A broodstock collection weir and trap box setup by the Colville Tribes immediately upstream of the video monitoring site captured 12 adult steelhead during the period 8 April through 2 May.

The Bonaparte Creek site had significant channel confinement and lent itself well for deployment of the video monitoring system. However, due to accumulations of coarse woody debris and increased water velocities during high water events, conditions led to bank erosion and collapse of the weir. After removal of the video system and picket weir, it was necessary to perform habitat restoration in order to stabilize the eroded embankments.

RECOMMENDATIONS

Based on the efforts and results from this study, we offer the following recommendations to further enhance the effectiveness and reliability of continued assessment of timing and abundance of adult salmonids in the Okanogan River Basin. Following these recommendations would allow for refined efforts to determine basin and tributary-specific spawner distributions, and evaluation of the status and trends of natural salmonid production in the Basin.

Minimize Data Collection Interruptions

The biggest limitation of the 2005/2006 study was the high frequency of interruptions to data collection. In part, these interruptions prevented the estimation of accurate adult counts and run timing patterns for steelhead passage in 2006. In order to minimize these interruptions, future efforts should include:

- More frequent visits to the Zosel Dam and tributary sites to ensure data are being collected appropriately and the maintenance and system operation data bases are continually updated.
- For sites with remote access via the Internet, ensure that total functionality of the video monitoring system is accessible, including the amount of hard drive space available for storage and the status of the record function.

Monitor Additional Tributary Sites

Monitoring key tributaries in the Okanogan River Basin will broaden the knowledge base regarding status and distribution of tributary-specific steelhead stocks. In order to develop a better understanding of the abundance and production of those steelhead stocks, future monitoring efforts should include:

- Continued sampling of steelhead passage in Bonaparte Creek using a video monitoring system. Efforts in 2006 demonstrated the feasibility of this approach, and with more frequent site visits for maintenance and operability

- to ensure minimally interrupted data collection, future efforts should result in more robust data sets.
- Sample Ninemile and Salmon creeks for steelhead passage using video monitoring systems. As with the Bonaparte Creek site, frequent site visits for maintenance and operability to ensure minimally interrupted data collection, efforts should result in more robust data sets.

Optimal Spillway Operation Protocol

Previous investigators determined that with spillway gate openings less than or equal to 12", anadromous fish passage up through the spillway gates at Zosel Dam was minimal. Gate openings larger than 12" facilitate passage through the spillway (Hatch et al. 1992). If spillway passage cannot be monitored, then stock abundance estimates for anadromous fish based on video sampling are not census counts but instead are less accurate relative abundance estimates. This was likely the case in 2006 for steelhead since the gates were open more than 12" for 91% of the days in the time period March through May, the time frame in which the majority of steelhead passage occurred. It is important then to minimize spillway passage in order to increase the value and utility of the video counts. To do so, a spillway operation protocol should be put in place and implemented by the dam operators during the primary steelhead passage season. As increased discharge warrants the use of spill, the protocol should consist of only opening individual gates a maximum of 12" until all gates are open by that height. This approach would spill the same volume of water as opening a single gate 48" but would minimize unmonitored spillway fish passage compared to the latter approach. It is recognized that during the spring freshet period, the recommended protocol is not usually practical due to the high discharge requirements.

Assess Spillway Passage and Fallback

More complete abundance estimates of salmonid stocks passing Zosel Dam could be obtained if spillway passage and adult fallback were to be monitored and assessed. This could be accomplished by deploying a DIDSON in the forebay and aimed across the spillbay openings. With the low-frequency sampling mode, the DIDSON could sample a 70 foot radius, which would cover two adjacent spill bay openings. Directional information is readily apparent with DIDSON imaging, so estimating spill passage and fallback would not be difficult. Where there are clear size differences among the salmonid species, species identification can be obtained with DIDSON. Salmonids would likely be discernible from other resident species, and during the majority of the steelhead run, species identification would not be a major issue since the Chinook and sockeye will not be migrating during that time period. When the Chinook and sockeye are running together, the DIDSON counts could be apportioned by date based on the video monitoring counts from the ladders. A short-term feasibility study to determine the efficacy of monitoring spillway passage and fallback with a DIDSON at Zosel Dam in 2007 would be a reasonable step towards gaining a more complete understanding of the abundance of salmonid stocks in the Okanogan River Basin.

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