

# Fish Counting at Large Hydroelectric Projects

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## Background and Objectives

In the Pacific Northwest, salmon and steelhead *Oncorhynchus mykiss* are an integral part of tribal and nontribal cultures, supporting important subsistence, commercial, and recreational fisheries. During the past century, salmon stocks have declined on the U.S. Pacific Coast to the point where several populations are now listed as threatened or endangered under the Endangered Species Act. The reasons for the decline are many, including extensive development of hydroelectric projects. Because salmon and steelhead are such an important part of the Pacific Northwest economy, culture, and heritage, widespread salmon recovery efforts are currently underway. Accurate juvenile and adult passage estimates at large hydroelectric projects can be vital to monitoring the success or failure of these efforts and are also frequently used for a variety of other management applications.

Hydroelectric projects can impede anadromous salmonid passage at adult and juvenile life stages. Where possible, passage facilities such as adult fishways and juvenile (smolt) bypass systems are often included in hydroelectric project design or retrofitted to older existing structures. Juvenile bypass systems are intended to divert downstream migrating smolts away from turbine intakes through screening, louver, gulper, or surface collection systems. At large hydroelectric projects, these juvenile bypass systems often include collection facilities where fish may be held and counted, anesthetized and examined, used in research studies, or loaded into vehicles such as tanker trucks or barges to be transported downstream around other hydroelectric projects. Adult passage facilities are typically of pool and weir design and are intended to attract and provide safe passage for adult upstream migrants. Such facilities are usually equipped with count stations that allow enumeration of migrants by either direct observation or interrogation of time-lapse video. In addition, adult fishways often include a trap so that fish can be sampled, marked, or loaded into tanker trucks for transport upstream around other existing nonpassable hydroelectric projects to otherwise inaccessible spawning habitat.

The Columbia River basin has been called the most hydroelectrically developed river system in the world. Large hydroelectric project development began with the completion of Rock Island Dam in 1932, followed by much larger federal projects such as the Bonneville and Grand Coulee dams completed in 1938 and 1941, respectively (see the Center for Columbia River History Web site, <[www.ccrh.org/river/history.htm#hydro](http://www.ccrh.org/river/history.htm#hydro)>). Eleven large hydroelectric projects currently exist in the U.S. portion of the mainstem Columbia River; numerous other projects occupy the tributaries.

Because of this extensive hydropower development, the Columbia River basin also supports what could arguably be described as the most advanced fish passage technology and associated counting programs in the world. It should be noted that although similarities exist between sites, the passage facilities and associated counting protocols are often site specific. The objective of this chapter is to provide an overview of the protocols used to conduct adult and juvenile fish

passage counts and to derive fish passage estimates in the Columbia River basin. While the data for this chapter is derived from hydroelectric projects located on the Snake and Columbia rivers of the U.S. portion of the Columbia River basin, the methods herein are intended to be applicable to all large hydroelectric projects, although some site-specific modification will likely be necessary.

### **Sampling Design**

The counting procedures for both juvenile and adult salmonids described in this paper are to occur at large hydroelectric projects that are fixed or otherwise preselected sites and are therefore not subject to discretionary site selection. Populations sampled will consist of all anadromous fish populations that originate from upstream locations.

## **Juvenile Salmonid Passage Monitoring**

### **Juvenile Passage Routes**

Downstream migrating salmonids can pass hydroelectric projects by several routes (see Figure 1). At projects equipped with screening systems, such as those at most U.S. Army Corps of Engineers (USACE) projects in the Columbia River basin, submersible screens are placed in turbine intakes that guide a portion of the juveniles entering the intakes away from the turbines and through a bypass system. The proportion of fish that enter the intakes but are guided away from the turbines and through the bypass system is termed fish guidance efficiency (FGE). Unguided fish pass the project through the turbines. FGEs have been shown to be highly variable. Potentially, such variability can occur within and between project powerhouses by such factors as fish species, race, age, and size, by unit operation configuration, and as a result of other external environmental factors (e.g., water temperature, amount of sunlight). Because it is not feasible to measure or monitor FGE throughout each passage season at large hydroelectric projects, FGE is normally not factored into juvenile passage estimates at large hydroelectric projects and is essentially assumed to be 100%.

Bypass systems route fish either to the project tailrace or to a collection facility located downstream. Fish that arrive at the collection facility may be held and then transported via truck or barge around other downstream projects to a release location.

Substantial fish passage may also occur through the project spillways. Spillway passage efficiency is the proportion of fish per unit of water flow that pass over the spillway versus through the powerhouse. Similar to FGE, it is not feasible to monitor spillway passage efficiency throughout each passage season at large hydroelectric projects, and therefore, a 1:1 ratio is normally assumed (i.e., when an equal amount of flow is passed over the spillway and through the powerhouse, then an equal number of fish are assumed to pass the dam through each of the two routes).

Other potential routes of passage include navigation locks or adult fishways downstream; however, given the relatively small amount of project flow that is diverted through these later two routes, passage at these locations is usually considered insignificant and is not included in passage estimates. (The Dalles Dam on the mainstem Columbia River is unique among USACE projects in that the ice and trash sluiceway is used to bypass juvenile fish to the project tailrace.)

## Juvenile Facilities Description

### Guidance and Bypass Systems

The juvenile fish bypass systems in place at seven of the eight lower Columbia and Snake River dams operated by the USACE guide fish away from turbines by means of submerged screens positioned in front of the turbines in the intake structures. The juvenile fish are directed up into gatewells where they pass through orifices into a collection channel that runs the length of the dam (see Figure 2). The fish are then either routed or “bypassed” back out to the river below the dam, or, at the four dams with fish transport facilities, fish can be routed to a holding area for loading onto specially equipped barges or trucks for transport downriver (USACE <[www.nwd.usace.army.mil/ps/colrvbsn.htm](http://www.nwd.usace.army.mil/ps/colrvbsn.htm)>).

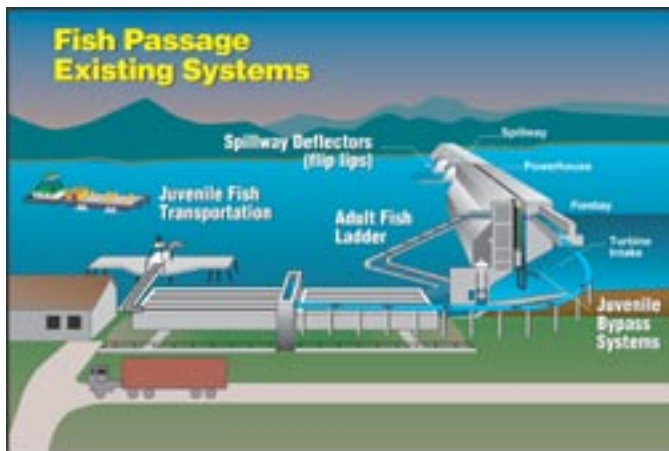


FIGURE 1. — Juvenile passage routes (Source: USACE <[www.nwd.usace.army.mil/ps/colrvbsn.htm](http://www.nwd.usace.army.mil/ps/colrvbsn.htm)>).

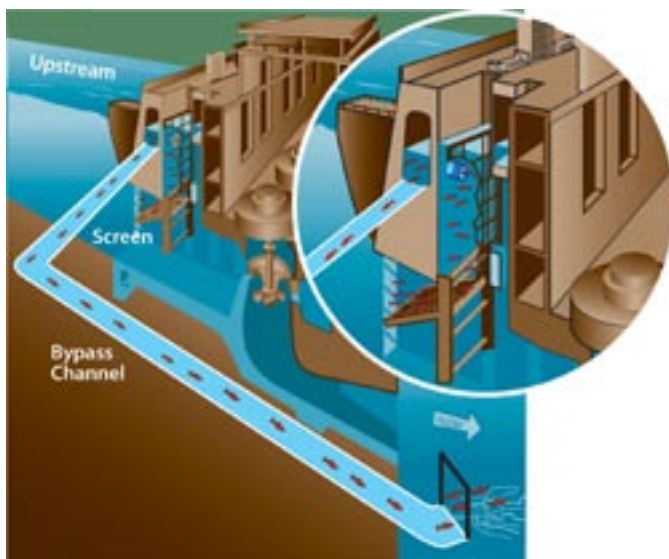


FIGURE 2. — Juvenile bypass system (Source: USACE <[www.nwd.usace.army.mil/ps/colrvbsn.htm](http://www.nwd.usace.army.mil/ps/colrvbsn.htm)>).

### Juvenile Fish Facilities

Fish-counting activities normally occur at existing juvenile collection facilities located within the bypass systems at these large dams (see Figure 3). Such

facilities typically route fish from the powerhouse via a screening system through a collection gallery and water elimination system. Fish are carried through the collection gallery channel past a primary dewatering unit where all but a small portion of the water is removed. Fish and remaining water pass through a bar separator (see Figure 4) where debris may be removed and large fish are separated from smaller fish. Timed sample gates are located on the flumes exiting the separator, and a portion of the juvenile fish collection is diverted through an electronic fish counting system into sampling tanks (see Figure 5) at a predetermined sampling rate. The electronic fish counting system normally consists of holding or “counter” tanks that discharge through electronic fish-counter tunnels and into the sample tanks. Juvenile collection facilities at large dams are normally staffed 24-h a day to allow immediate response to potential equipment failures or debris blockages or to prevent overloading of holding tanks or raceways. The electronic fish counting system allows hourly monitoring of the approximate number of fish sampled, and through simple extrapolation based upon the sampling rate, an estimate of the total number of fish collected. Some level of count error is usually associated with these types of electronic fish counting systems (e.g., due to the presence of debris, air bubbles, or multiple fish passing simultaneously through the counting field), and therefore, the electronic counts are corrected by actual hand counts of fish diverted into the sampling tanks at the end of each 24-h period.

#### **Sampling and Counting Overview**

In the Columbia River basin, the juvenile collection facilities are operated and maintained by the USACE at federal projects or by public utility districts. Most of the juvenile salmonid counting projects conducted at large hydroelectric projects are through the Smolt Monitoring Program (SMP). This Bonneville Power Administration–funded program samples fish at 14 sites—6 traps and 8 large dams within the Columbia River basin anadromous corridor. Until recently, counting operations at these sites were coordinated through the Fish Passage Center, located in Portland, Oregon; fieldwork is carried out by various agencies. Data are gathered on juvenile migrant salmon and incidental species under a well-developed set of protocols that will be emphasized in this chapter. Counting activities are scheduled to encompass the primary smolt outmigration period for all species, which is primarily from March through the end of October. A wide range of information is collected in association with the monitoring program, including species-specific passage timing, migrant mark recovery, external injury, disease, descaling, and mortality. Passive integrated transponder (PIT) tagging is also carried out at some SMP sites to aid in gathering longer-term data such as travel time, passage timing, and survival for specific mark groups (e.g., Berggren et al. 2000). Juvenile collection facilities are typically equipped with PIT tag interrogation systems, which allow passive interrogation of all fish collected.

Sample tanks may include pre-anesthetic chambers, in which fish are initially sedated or pre-anesthetized prior to handling (see Figure 6). Small allotments of fish are routed directly from the pre-anesthetic chambers into a laboratory building and held in a recirculating anesthetic bath where they are examined and counted (see Figure 7). Here, project staff examine each fish to determine species, age, rearing disposition (hatchery or wild); check for injuries and descaling; and, in some cases, measure lengths and weights as necessary for calculating barge, truck,

or raceway loading densities. The Fish Passage Center Data Entry Program Manual (Franzoni et al. 2004) provides detailed descriptions of data collected on individual fish and overall sample statistics such as mortality rate. Counts are usually tallied via a manual or electronic tabulation system located adjacent to the sampling trough (see Figure 8). After examination, anesthetized fish are routed to a recovery raceway (see Figure 9) where they are allowed to recover before being returned to the river or loaded onto transportation vehicles. To reduce the likelihood of predation losses, a 1-h minimum recovery time is recommended for juvenile fish that are to be returned to the river.



**FIGURE 3.** — McNary Dam juvenile fish collection facility.



**FIGURE 4.** — Juvenile fish facility bar separator at the McNary Juvenile Fish Facility.



FIGURE 5. — Juvenile fish facility sample tank at the McNary Juvenile Fish Facility.



FIGURE 6. — Sample tank pre-anesthetic chambers at the McNary Juvenile Fish Facility.





FIGURE 7.— Fish counting station at the McNary Juvenile Fish Facility.

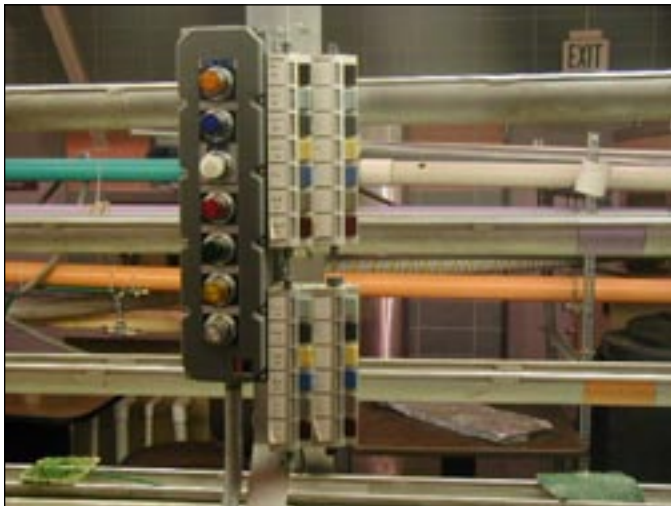


FIGURE 8.— Juvenile fish hand-tabulation system at the McNary Juvenile Fish Facility.



FIGURE 9.— Recovery raceway at the McNary Juvenile Fish Facility.

**Sampling Rates**

The sample rate is based upon the projected collection for the sample period, which is in turn based upon the number of fish collected the previous day and the operator’s best estimate of changes in passage. The goal is to sample between 500 and 800 juvenile salmonids per day. These numbers of fish reflect the need to maintain a coefficient of variation (cv = standard error of collection/estimate of collection) lower than 5%. Due to the nonuniform nature of emigration from the sample counting tanks, subsamples are recommended. The rates listed in Table 1 determine how often and what duration the sample gate will divert fish from the collection facility or bypass. As shown in Table 1, six subsamples per hour are preferred, with the exception of 100% sample rate or at very low sample rates. The Fish Passage Center recommends a minimum of two subsamples per hour with a minimum of 12 per sample to minimize edge effects during low rate sampling. Note that when more than 50,000 fish are expected, the Fish Passage Center further recommends a 1% sample rate—except when more than 75,000 fish are expected, in which case a lower sample rate may be necessary to avoid risk of capturing more fish than can be safely handled. Also, sampling to provide fish for research marking programs or for other purposes may require increases beyond the recommended sample rates. The presence of large numbers of nontarget species can also require that the sample rate be lowered to prevent exceeding holding density criteria. For example, at McNary Dam on the Columbia River, large numbers of juvenile American shad *Alosa sapidissima* in the sample during late summer operations often make it necessary either to reduce the sample rate or curtail sampling altogether, especially when transportation is ended early based on relatively small numbers of salmonids in the collection. Holding densities should not exceed 1.0 kg of fish per 16.5 L of water in volume, or 0.6 kg of fish per L/min in inflow (0.5 lbs of fish per gallon of water or 5 lbs of fish per gal/min in inflow) (USACE Northwestern Division 2005).

**TABLE 1.— Fish Passage Center (Portland, Oregon) recommended sampling rates for Snake River dams**

Estimated daily collection	Subsample rate %	Equivalent multiplier 1/sample rate	Sample s/h	Subsamples per hour	Subsample duration seconds	Estimated number of fish in sample
Emergency	0.50%	200	18	2	9	
>75,000	0.70%	143	25.2	2	12.6	>525
50,000–75,000	1.00%	100	36	3	12	500–750
35,000–50,000	1.50%	66.6	54	4	13.5	525–750
25,000–35,000	2.00%	50	72	6	12	500–750
16,500–25,000	3.00%	33.3	108	6	18	495–750
12,500–16,500	4.00%	25	144	6	24	500–660
10,000–12,500	5.00%	20	180	6	30	500–625
7,500–10,000	7.00%	14.3	252	6	42	525–700
5,000–7,500	10.00%	10	360	6	60	500–750
4,000–5,000	12.50%	8	450	6	75	500–625



Estimated daily collection	Subsample rate %	Equivalent multiplier 1/sample rate	Sample s/h	Subsamples per hour	Subsample duration seconds	Estimated number of fish in sample
3,000–4,000	15.00%	6.66	540	6	90	450–600
2,500–3,000	20.00%	5	720	6	120	500–600
1,500–2,500	25.00%	4	900	6	150	375–625
500–1,500	50.00%	2	1,800	6	300	250–750
<500	100.00%	1	3,600	1	3,600	<500

## Field/Office Methods

### Fish Anesthetization and Handling

Anesthetization and handling of fish are necessary components of a smolt monitoring program, and care should always be taken to minimize associated fish stress and mortality. Tricaine methanesulfonate (MS-222) is registered by the U.S. Food and Drug Administration for use as a fish anesthetic and is used at all SMP sites. A stock solution of MS-222 and river water is prepared prior to the daily handling of fish. Stock solution concentrations are typically 100 g/L. To minimize handling stress, small allotments of smolts are gently crowded into the sample tank pre-anesthetic chambers and initially introduced to anesthetic. The average concentration of MS-222 used at SMP sites varies between 40 and 85 mg/L and depends upon the number, species, and size of fish, water temperature, and water chemistry. Sites in the Snake River often have natural buffers in the water that make it necessary to use higher concentrations to be effective. Ideally, anesthetic induction time (time to which fish initially show visible signs of anesthetization, such as rolling over on their backs) should range from 2 to 3 min and should not be less than 1 min.

After most of the fish exhibit signs of anesthetization, they are then transferred from the pre-anesthetic chamber to a sorting trough where they can be examined and counted. At SMP sites, this “wet” transfer (i.e., fish remain in water at all times) is accomplished by opening an evacuation valve located at the bottom of the pre-anesthetic chamber, thereby delivering fish via gravity flow through a piping system to the sorting trough, which is located inside the laboratory building. Flushing water is turned on to ensure complete evacuation of the pre-anesthetic chamber and delivery of all fish to the sorting trough. The Fish Passage Center recommends that no more than 80 fish at one time be delivered to the sorting trough to minimize the amount of time that fish are held in anesthetic.

The sorting trough contains a recirculating MS-222 bath. The anesthetic concentration in the recirculation system should be held at 35 to 45 mg/L to allow fish to be examined and counted while they slowly recover from initial anesthetization. Because the recirculating anesthetic system is a closed system, it should include water-cooling capability. Water within the system should be maintained at a temperature appropriate for the species present and should be monitored frequently throughout the course of fish handling activities, especially during the summer months. System operators should also be aware that large numbers of fish can metabolize and reduce the anesthetic concentration within the recirculation system. Additional anesthetic may need to be added periodically when large numbers of fish are processed for programs such as research marking.

After fish are handled and counted, they are transferred via a gravity flow piping system to a recovery raceway or tank. In all cases involving the handling or counting of fish, wet transfer is recommended. The Fish Passage Center further recommends that the time between initial exposure to anesthetic in the pre-anesthetic chambers and delivery to the recovery raceway not exceed 15 min. All mortalities should be removed from the recovery raceway and counted daily so that daily mortality rates can be calculated to allow assessment of the effect of sampling and handling activities on the well-being of the sampled fish. Sampling activities should be adjusted to minimize mortality rates.

General strategies to minimize fish stress and mortality include the following

1. Minimize the time fish are held in a crowded condition to the extent possible.
2. Minimize the time fish are held in anesthetic to the extent possible.
3. Start with relatively low concentrations of anesthetic and then increase as necessary. Fish should be anesthetized no more than needed (i.e., just so they may be easily handled and the necessary information obtained). Note that there is a fine line that separates underanesthetized from overanesthetized, and both conditions are detrimental to fish. Overanesthetization will simply overdose and kill fish directly; however, underanesthetized fish can jump from examiners hands or require excessive squeezing during examination, which can elevate mortality rates as well. Anesthetists should communicate regularly with fish handlers during fish processing operations and procedures, or anesthetic concentrations should be adjusted as necessary to minimize detrimental effects.
4. Remove smaller or more sensitive species (or species listed under the Endangered Species Act) from anesthetic first, followed by larger, less sensitive species.
5. Leave fish in water to the extent possible during examination.
6. Wet transfer whenever possible.
7. Check water temperatures in closed systems regularly and adjust as necessary.
8. Flush closed piping fish delivery systems at least three times at the conclusion of daily activities to prevent fish from becoming stranded in the pipe once the flow is turned off for the day. Operators should be cognizant that underanesthetized fish or fish that have recovered early from anesthetization can hold in delivery pipes (such as from the pre-anesthetic chambers to the sorting trough or from the sorting trough to the recovery raceway). Increasing the flow to flush fish out of such systems is generally ineffective as juvenile salmonids tend to swim harder and more actively towards the flow source when the velocity is increased. The preferred and recommended method to remove fish from such systems is to shut the flow off, allow the pipe to drain momentarily, and then restore the flow long enough to allow fish the opportunity to turn downstream and exit the pipe. This procedure should be repeated at least three times or until operators are certain that all fish have been cleared from the pipe.

## Data Handling, Analysis, and Reporting

### Collection Estimates

Sample counts of juvenile fish by species and rearing disposition (when rearing type can be determined based on clips and marks) are tallied daily throughout the sampling season at large hydroelectric projects equipped with collection and sampling systems. Typically 6 samples per hour, over a 24-h period (often 7 a.m. to 7 a.m., not a calendar day), are diverted to the sample tank at smolt monitoring program sites. Collection estimates are then extrapolated from the daily juvenile fish samples at each site by dividing the sample count by the sample rate. This is typically reported by species and rearing type.

### Passage Index

The passage index is a real-time statistic that can be used to measure in-season passage timing for management purposes. The passage index is the collection count expanded to account for the proportion of water passing through the powerhouse compared to other routes, such as spill. So for a given daily collection ( $C$ ), average daily powerhouse discharge ( $PH$ ), and average daily total discharge ( $Q$ ), the daily passage index ( $PI$ ) is calculated as shown in equation 1. Note that all values are daily averages based on the sample day, which typically runs from 7 a.m. to 7 a.m. at smolt monitoring program sites in the Columbia River basin.

$$PI = C*(Q/PH) \quad (\text{eq 1})$$

As can be seen by equation 1 the passage index adjusts the collection upward to account for discharge through nonpowerhouse routes, especially spill; however, the passage index does not account for fish passing through turbines and assumes a 1:1 fish to water ratio for expansions. The passage index is not sensitive to changes in FGE or spill efficiency, the proportion of fish passing in spill per volume of water spilled. Based on analyses by the Fish Passage Center (FPC), the passage index has proven quite robust to changing operations at projects for any given year, and therefore, because of its minimal assumptions and ease of calculation, has been adopted for use in determining season passage timing for migrating juvenile salmonids. The passage index is typically smaller in magnitude than the overall out-migrating population because no attempt is made to estimate actual spill efficiency or turbine passage; therefore, the magnitude, or population size, of the run is often not fully accounted for by the passage index. Other methods must be incorporated to determine the total size of the run migrating past a given dam.

### Population Index and Population Estimates

The simplest method to determine the overall size of the out-migration is to estimate seasonal collection efficiency for each species and then divide the total collection for that species by the collection efficiency as shown in equation 2.

$$N = \frac{C}{ce} \quad (\text{eq 2})$$

where

$N$  = estimated seasonal population size

$C$  = estimated total seasonal collection

$ce$  = estimated seasonal collection efficiency

If greater precision and statistical comparisons are required, the FPC recommends using methods similar to those described in Sandford and Smith (2000). Peven et al. (2005) provide important insights into specific methodologies for conducting juvenile salmonid survival studies.

### **Data Handling Validation (Quality Assurance and Quality Control)**

There are three levels of quality assurance and quality control applied to the collection and dissemination of smolt monitoring program data in the Columbia River basin. Smolt data is accumulated 24 h per day and are summarized and transmitted to a central repository once per day. Each of these transmittals is considered a “batch” of data. Data are first collected on hand logs during the sampling day and then transcribed into an electronic form to complete the batch. The first level of quality control is applied to this transcription process. Each data element passes through an initial validation process as it is transcribed from paper to electronic form. These validation checks are built into the remote data entry systems and occur at the moment of data entry. User inputs are automatically examined to verify that they consist of realistic values and are internally consistent.

The second level of data quality control occurs at the other end of the data entry process, at the data repository. The smolt monitoring program conducts work at seven dams in the Columbia River basin. Monitoring at these sites occurs 7 d per week over periods varying from 21 weeks (Rock Island Dam) to 30 weeks (Lower Granite, Little Goose, Lower Monumental, John Day, and Bonneville dams) to 36 weeks (McNary Dam). Each smolt monitoring site sends one batch per day to a central repository, and once per week a second quality-assurance protocol is applied to data from each site to compare the hand logs (daily data sheets) to the electronic data summaries. The goal of this quality assurance and quality control (QA/QC) protocol is to cross-check enough daily batches with enough daily data sheets to assure that the potential discrepancy rate across the total batches for a given site is acceptably low. This QA/QC procedure requires cross-checking two of the seven daily batches per week at each of the monitoring sites. The FPC randomly selects the two batches to be examined each week. FPC personnel located in Portland, Oregon, is responsible for conducting the data cross-check and reporting the results back to the site personnel. The cross-check of a daily batch consists of manually verifying that the data entries in the SMP database match those from the hand logs. The data entries are arranged in several data tables: (1) catch summary, detailing the sample-related parameters and flow/spill entries; (2) catch detail, summarizing the fish counts per species, number of fish descaled, mortalities, and sample rates; (3) incidental catch detail, which enumerates the number of nontarget fish collected; (4) a mark detail table summarizing counts of fish with elastomer tags, photonic tags, spaghetti tags, and freeze brands; and (5) a transportation detail table showing the number of fish transported and bypassed at the collector dams.

If no discrepancies are found within the two batches examined for a given site, then the QA/QC procedure for that site is finished for that week and the process will begin again the following week. Under the condition that no discrepancies are found in any of the batches examined over the full season, the FPC will be 95% confident that the discrepancy rate across all batches for the season will not exceed approximately 5%. This estimation utilizes methods given in Cochran (1977). If for each site we let  $N$  = total number of batches,  $X$  = number of batches

with discrepancies,  $n$  = number of batches checked, and  $x$  = number of checked batches with discrepancies, then we may use the hypergeometric distribution to determine the probability of finding  $x$  discrepant batches in the  $n$  batches examined when  $X$  discrepant batches actually exist in the total  $N$  batches. The number  $X$  that satisfies the probability statement  $\Pr(x = 0|X, N, n) = 0.05$  is the upper 95% confidence limit for the number of discrepant batches in the total  $N$  batches when no discrepant batches ( $x = 0$ ) are found in the  $n$  sampled batches. In this case, there is a high probability that the seasonal discrepancy rate is less than  $X/N$ .

If a discrepant batch is found at a site during a given week, then the FPC randomly picks two additional batches from that week to be cross-checked. If neither of these new batches shows discrepancies, then the QA/QC procedure is finished for that week; however, if additional discrepancies are found, then selection of batches and cross-checking will continue until the site is back in compliance.

The third level of data quality assurance also occurs once a week. Each week, all the data that has been entered year-to-date at a site is sent back to the site as a large “validation” spreadsheet. These spreadsheets are then used by remote site personnel to compare to their own internal records of the data collected year-to-date, and any additional discrepancies between the data at the central repository and the data at the remote site are addressed at this time.

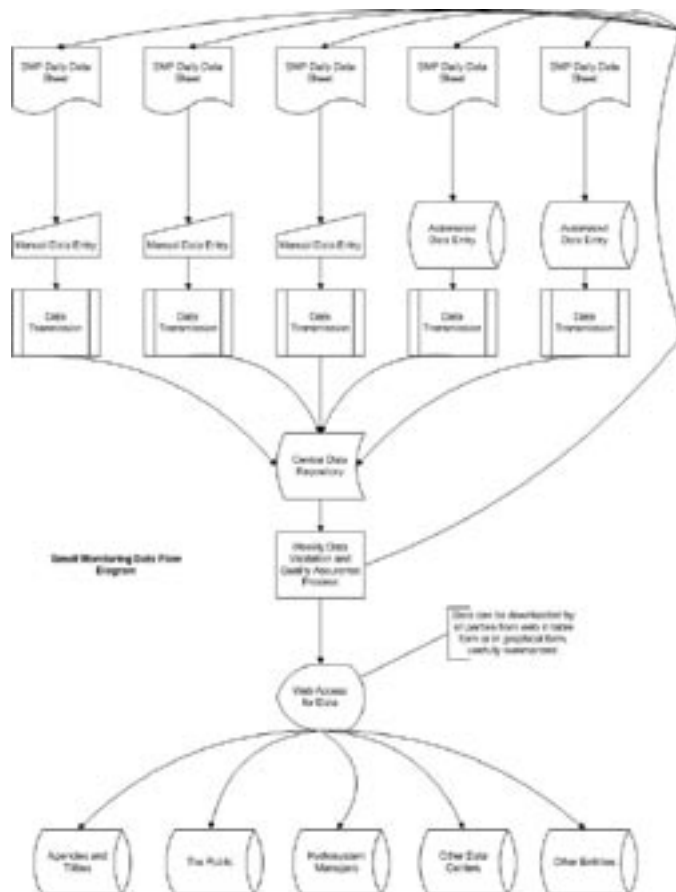


FIGURE 10. — Smolt Monitoring Program data flow diagram (Source: Fish Passage Center, Portland, Oregon).

### **Regional Integration**

In the Columbia River basin, smolts originate from three states and cross multijurisdictional lines on their way to the Pacific Ocean. Because of this, smolt monitoring data collected at large mainstem hydroelectric projects must be regionally integrated to satisfy the needs of multiple managers.

Presently, the most useful data format for enabling regional data integration is the comma separated value (.CSV) format. The Federal Geospatial Data Committee has created a metadata format that is useful for regional integration, and the U.S. Geological Survey has further refined this metadata format for biological purposes and created a superset metadata format that is part of the National Biological Information Infrastructure. Another type of data that is useful for regional data integration is geographic reference data that can be used in geographic information systems.

When monitoring smolt passage across a large hydrosystem such as those in the Columbia River basin, one key concern for hydrosystem managers who review smolt data at this scale is whether the fish collected are actually active downstream migrants or true “smolts.” Juvenile salmonids in the mainstem that have a fork length of 60 mm or less have been shown to be too small to be active downstream migrants, and these fish are therefore categorized as fry. While finer categorical distinctions (e.g. parr, fry, sac fry) may be useful to the life stage researcher studying juvenile salmonids in the tributaries, when juvenile passage data are summarized at the larger regional scale, the most useful distinction is simply between fry and smolts.

## **Personnel Requirements and Training**

### **Responsibilities and Qualifications**

The number of personnel required to conduct smolt monitoring activities at a dam site is ultimately dependent upon the number of fish to be handled on a daily basis. At a bare minimum, a three-person crew per sampling day is recommended: (1) a supervisory biologist, (2) an anesthetist, and (3) a fish handler/counter. Additional fish handlers/counters will be necessary to accommodate increased sampling needs such as to provide additional fish for research marking programs.

The supervisory biologist schedules, trains, and supervises staff, oversees and participates in handling and counting activities, communicates with the anesthetist and the fish handlers/counters to ensure proper coordination between anesthetization and counting activities, and monitors water temperatures and checks the recovery raceway periodically during sample processing for mortalities. The supervisory biologist is also responsible for coordinating with other activities, such as research marking programs, that may impact the operations of the smolt monitoring program. This person typically performs much of the electronic data entry, is ultimately responsible for ensuring that QA/QC protocols are followed at the site, and writes the annual report.

The anesthetist is responsible for preparing the stock anesthetic solution, watering up the recirculating anesthetic system at the start of the day and adding anesthetic, removing debris from the sample tank, crowding the sample fish into the pre-anesthetic chambers in the proper allotments and anesthetizing them at the proper dosage, flushing each allotment of sample fish to the sorting trough,



dewatering the recirculation system at the end of each day, and periodically disinfecting the system. This person should also maintain a written log of daily anesthetic concentrations used for both the recirculation and pre-anesthetic systems.

The fish handlers/counters are responsible for identifying and counting the fish, hand-recording data for the supervisory biologist as necessary, and assisting the supervisory biologist with electronic data entry at the end of each sampling day.

## Equipment

- Aquarium nets and dip nets
- Fish anesthetic (MS-222)
- Anesthetic dispenser
- Gram scale (for weighing fish and anesthetic)
- Buckets (20) (5 gal)
- Chlorine (for disinfecting the recirculation system)
- Rubber gloves and filtration mask (for mixing anesthetic or working with chlorine)
- Clipboards, mechanical pencils, and data forms
- Desktop computer(s), preferably with DSL or better data transfer capability
- Hard hats and steel-toed shoes (if required by dam operators to work at the dam site)
- Thermometer

## Adult Passage Counts

### Adult Passage Routes

Upstream passage of adult salmonids at large hydroelectric projects is largely restricted to the adult fishways. At projects so equipped, navigation locks may provide an additional route of passage, although this is normally considered negligible and not taken into consideration in adult passage estimates.

### Fallback

Adult upstream migrants can also pass downstream, and these fallbacks can confound upstream passage estimates. Fallbacks are defined as prespawn upstream migrants that first pass upstream past a hydroelectric project and then fall back downstream. This is in contrast to kelts or members of *iteroparous* species such as steelhead that survive after spawning and pass back downstream as true downstream migrants. Fallbacks are upstream migrants that theoretically should be taken into consideration in upstream passage estimates; kelts are true downstream migrants and should not. Fallback may result in significant count error in terms of tracking the number of fish that remain above the dam after passing through the fishways. For example, 7%–10% of the adult steelhead that passed upstream through the adult fishways at McNary Dam were shown to fall back eventually through the juvenile bypass system prior to spawning (Wagner 1990; Wagner and Hillson 1991). Fallback routes include all those potentially

available to juvenile downstream migrants as described earlier. Because it is usually not feasible to measure or monitor adult fallback comprehensively at large hydroelectric projects throughout each passage season, fallback, although mentioned here, is normally not taken into consideration in adult passage estimates.

### **Adult Facilities Description**

Adult fishways at large hydroelectric projects typically are of a pool and weir design (see Figure 11) with attraction flows provided at the downstream entrances to help guide the adults to the fishways. This design creates a series of gradual steps that allow adult salmonids to pass from the project tailrace upstream to the forebay (see Figure 12).

Counting facilities are normally built into the fishway. The most common type of facilities feature picket leads, which effectively restrict fish passage to a narrow count slot. The spacing between the picket leads is 2.5 cm. The width of the count slot ranges from 46 to 56 cm; it is generally accepted that its width be no less than 46 cm. A large viewing window adjacent to the count slot allows personnel or cameras to view passing fish from an enclosed count room. The windows may be partitioned such that juvenile salmonids, jacks (precocious males), and adults can be readily distinguished and counted separately (see Figure 14). Placing a white backboard opposite the viewing window and controlling the source and direction of light within the count slot improves viewing conditions. Preferably, all sources of light originate within the count room and show through the viewing window and onto the white backboard. Lighting can affect fish passage and is best kept to a minimum.

A less common type of counting facility includes the same picket lead structure as previously mentioned, but the count slot includes a ramp that forces the passing fish very near to the surface. Personnel located above the count slot view the fish from above for identification. Again, controlling the source of light and painting all surfaces of the count slot white improves viewing conditions.

Last, there is a recently developed counting facility design for fishways that does not include overflow weirs. This design consists of a caisson installed into the ladder on the upstream side of a weir. The caisson includes a submerged viewing window that is perpendicular to the orifice in the weir. Fish are viewed as they pass through the weir.

In each type of facility, all fish ascending the fishway are counted either by direct observation by personnel stationed in the counting room or by interrogation of time-lapse video.

Trapping facilities may also be part of the fishway design; they allow operators to handle and examine fish directly for a variety of reasons, such as to collect tissue samples, tag fish, or remove fish for hatchery broodstock or transportation operations. PIT tag interrogation systems are becoming increasingly common in adult passage facilities. Such systems allow passive interrogation of all adult upstream migrants for PIT tags as the fish pass through the counting stations. PIT tag interrogation information can be automatically stored on local computer drives or transferred through the Internet to a central repository. Radio receivers may also be installed at adult fishways and allow counting of fish tagged for radio telemetry studies; however, these systems are usually installed to address a particular research need during a specific migration period and are usually not a permanent part of the adult counting system.



FIGURE 11. — Typical adult fishway (Source: USACE <[www.nwd.usace.army.mil/ps/colrvbsn.htm](http://www.nwd.usace.army.mil/ps/colrvbsn.htm)>).

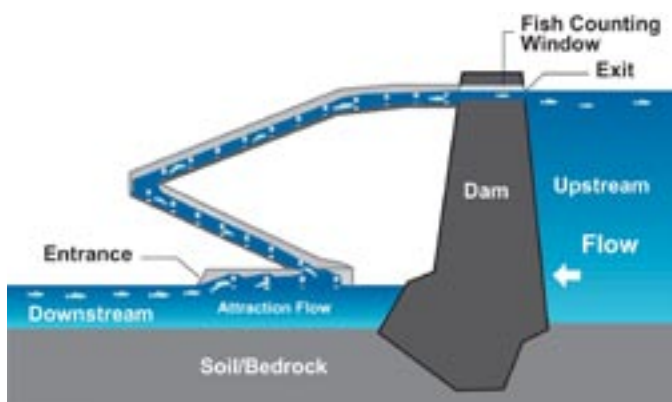


FIGURE 12. — Typical Columbia River fishway design (Source: USACE Fish Passage Plan 2005).



FIGURE 13. — Adult fish count viewing area (Source: Washington Department of Fish and Wildlife).

**Sampling Rates**

Virtually all upstream migrants—with the exception of those fish that are caught in the fishery, fall back, or die—must pass through the fishways and counting facilities at large hydroelectric projects and, thus, can be counted. Large river systems often support multiple species of upstream migrants, such as summer and winter steelhead; coho salmon *O. kisutch*; spring, summer, fall chinook salmon *O. tshawytscha*; sockeye salmon *O. nerka*, pink salmon *O. gorbuscha*, and chum salmon *O. keta*. These species—especially those that overwinter in river systems such as summer-run steelhead—can potentially pass hydroelectric projects 24-h per day each day throughout the year. Under such conditions, comprehensive accounting of all adult passage would require year-round, 24-h-per-day counting; however, a variety of constraints usually negate year-round counting, and the counting season is usually set to encompass the majority of each run. Fish that pass outside of the counting season are considered to be negligible in number.

Determination of an actual sampling rate to attain a specified sampling goal requires at least a site-specific understanding of both diurnal migration characteristics and seasonal migration periods for each species or race of concern. Counting periods should be adjusted to satisfy site-specific goals. In the Columbia River basin, the primary goal is to allow fish passage and minimize migration delay. Counting is therefore conducted during time frames that account for the majority of each run, without inhibiting fish passage.

The Washington Department of Fish and Wildlife is contracted to conduct adult passage counts at most of the USACE projects in the Columbia basin. The goal of the counting program is to account for at least 95% of the daily passage of Pacific salmon and steelhead (and at least 85% of the American shad) at each USACE project. It is based upon a 16-h-per-day, 7-d-per-week counting schedule, which is maintained throughout the primary migration periods for each species. An example of this schedule is provided in Table 2. The example schedule takes into consideration that adult passage occurs primarily during daylight hours, and with some-site specific adjustment, the migration season is generally April through December. It should also be noted, as further detailed in the Methods section, that direct ocular counts are conducted for 50 min each hour, and therefore, the true daily sampling rate is only 83.3% of the hourly counting periods identified below. Video interrogation counts occur continuously throughout each counting period.

**TABLE 2.— Example counting schedule used at USACE Columbia River basin projects (Source: Washington Department of Fish and Wildlife )**

Portland District	Walla Walla District
Bonneville Lock and Dam: Count both ladders.	McNary Lock and Dam: Count both ladders.
Jan 1–Mar 31: Video count 0400–2000 PST.	Mar 1–Mar 31: Video count 0400–2000 PST.
Apr 1–Oct 31: Visual count 0400–2000 PST.	Apr 1–Oct 31: Visual count 0400–2000 PST.
Nov 1–Dec 31: Video count 0400–2000 PST.	Nov 1–Dec 31: Video count 0400–2000 PST.
The Dalles Lock and Dam: Count both ladders.	Ice Harbor Lock and Dam: Count both ladders.
Feb 20–Mar 31: Video count 0400–2000 PST.	Mar 1–Mar 31: Video count 0600–1600 PST.
Apr 1–Oct 31: Visual count 0400–2000 PST.	Apr 1–Oct 31: Visual count 0400–2000 PST (Count south shore ladder by direct observation and north shore ladder by closed-circuit TV).

Portland District	Walla Walla District
Nov 1–Dec 7: Video count 0400–2000 PST.	Lower Monumental Lock and Dam: Count both ladders.
John Day Lock and Dam: Count both ladders.	Apr 1–Oct 31: Visual count 0400–2000 PST.
Feb 20–Mar 31: Video count 0400–2000 PST.	Little Goose Lock and Dam: Count one ladder (south).
Apr 1–Oct 31: Visual count 0400–2000 PST.	Apr 1–Oct 31: Visual count 0400–2000 PST.
Nov 1–Dec 7: Video count 0400–2000 PST.	Lower Granite Lock and Dam: Count one ladder (south).
	Mar 1–Mar 31: Video count 0600–1600 PST.
	Apr 1–Oct 31: Visual count 0400–2000 PST.
	Jun 15–Aug 31: Video count 24 hours per day (Interrogate videotape fish counts from 2000 to 0400 PST and only for the hourly 10-min breaks during visual counting 0400–2000 PST).
	Nov 1–Dec 15: Video count 0600–1600 PST.

## Field/Office Methods

### Counts by Direct Observation

Counts by direct observation are obtained instantaneously by fish counting staff during each daily count period. This counting technique simply requires that individual counting staff be present at each counting station to conduct direct counts of fish as they pass upstream through the viewing area. Counts are registered on hand tabulators appropriately labeled to represent each fish group of interest. An example of the fish groups counted at USACE projects in the Columbia River basin is provided in Table 3. Counts are registered for each fish that successfully passes upstream past the viewing area. Fish that pass back downstream through the viewing area are subtracted from the hourly count total.

**TABLE 3. — Fish species counted at USACE projects in the Columbia River basin (Source: Washington Department of Fish and Wildlife)**

1. Chinook salmon:
  - Adult—56 cm or longer in length.
  - Jack—30.5 to 55.9 cm in length.
2. Coho salmon:
  - Adult—46 cm or longer in length.
  - Jack—30.5 to 46 cm in length.
3. Sockeye salmon.
4. Pink salmon.
5. Chum salmon.
6. Steelhead.
7. Bull trout *Salvelinus confluentus*.
8. American shad *Alosa sapidissima*.
9. Pacific lamprey *Lampetra tridentata* (also known as *Entosphenus tridentatus*).

Counts by direct observation are normally conducted for 50 min each hour. This is done to allow fish counting staff the opportunity to transfer hourly counts from the tabulators to a daily summary form as well as to allow employee break periods. A 1.2 expansion factor is used to estimate fish passage during the 10-min period when counts are not taken. Daily forms are simply totaled, expanded by 1.2, and then delivered to the supervisory biologist.

**Counts by Video Interrogation**

The utilization of time-lapse video equipment to record the passage of fish has become increasingly popular in recent years as this counting technique does not require that personnel be present at the counting stations. Video cameras are installed at each counting station and continuously record fish passage through the viewing window. Required maintenance of this equipment is minimal. The typical video monitoring system consists of an analog video camera, digital video recorder (DVR), and monitor. The DVR is set to record 5 to 10 frames per second at the highest resolution possible for the duration of the count period. At a later time, a technician interrogates the video data for fish passage. Certain DVRs allow the technician to interrogate video data simultaneously while the DVR is recording current fish passage data. Other DVRs allow for the removal of a portable hard drive so the technician may interrogate the video data off site. In either case, manual review of videotapes is the most labor-intensive aspect of counting by video interrogation. Utilizing time-lapse video to perform video interrogation has several advantages over counting via direct observation:

1. Video interrogation is more accurate because it does not require count expansion to account for the 10-min-per-h break periods.
2. If desired, filming can occur 24 h per day with very little additional staff time required.
3. Video interrogation allows a greater level of quality control because the video data can be replayed and reanalyzed.
4. Video interrogation counts, including tape review, generally require less staff time than direct observation counts.

New digitally based video monitoring systems are now being developed and field-tested. Such systems consist of an area scan camera that is linked directly to a computer installed with a frame grabber card. The analog video signal is streamed to the PC from the camera. The generated images (~three frames per second) are filtered for the presence of fish using a motion-detection-based algorithm. Once the motion detector is triggered, the fish image(s) are captured and image file(s) are created and stored to the computer hard drive. Each fish image file is stored with an associated time-stamp image file. A photo-editing software program is used to sort through a series of fish images generated from fish passage events and the aforementioned data is recorded (Hubble 2000).

Digital imagery is a relatively new technology that is being applied to conduct adult fish passage counts at Rocky Reach Dam on the Columbia River and at the Prosser and Rosa counting facilities on the Yakima River (J. Hubble, Yakama Nation, personal communication). Digitally based systems provide sharp images, image enhancement capabilities, and PC-based image storage. Ethernet data transfer and downloading capability minimize the need for manual servicing at the data collection site. In addition, when the technology is further developed and refined,



automated image editing capability will also become available. Because self-editing technology is still in development, manual editing of digital adult passage counts is currently required.

## **Data Handling, Analysis and Reporting**

### **Data Handling**

Manual count sheets are delivered to the supervisory biologist and all counts are expanded by 1.2 (to account for the 10 minutes per hour that counting is not conducted) and totaled for the day to provide a daily passage estimate for each species/group. In the case of video monitoring, videotapes are normally removed from the counting stations and reviewed at a central office, and fish passage is tallied for the day. In the Columbia River basin, daily adult fish passage counts are provided to such entities as the FPC, and this information is posted on the FPC Web site and made publicly accessible.

### **QA/QC**

Quality control measures for direct observation count data are difficult to implement because these data are based upon live counts of fish passing through the viewing area. The supervisory biologist should regularly perform simultaneous fish counts with each technician to help identify problems. Technicians should be well trained in species identification and familiar with the equipment used in daily operations. Potential sources of error include species misidentification, missed observations due to the simultaneous passage of a large number of fish past the viewing area, and inadequate viewing conditions due to poor lighting or heavy accumulation of algae on the viewing window and count slot surfaces.

Counts via video interrogation are far easier to control for quality because these counts can be checked and rechecked as necessary to ensure accuracy. Although video counts do provide permanent records of fish passage, these records must still be manually reviewed and tabulated. As with direct observation counts, these manual tabulations should be checked for numeric accuracy at the conclusion of each count period by the supervisory biologist or by a second technician to minimize the likelihood of simple tabulation error.

## **Personnel Requirements and Training**

### **Responsibilities and Qualifications**

The number of personnel required each day to conduct adult counting activities at a given large hydroelectric project depends upon the number of adult fishways present and the duration of the daily count period. A supervisory biologist schedules, trains, and supervises staff, oversees the counting activities, performs QA/QC protocols, and writes the annual report. A total of four fish counters per day will be required to conduct 16-hour counts at two adult fishways. The fish counters are responsible for species identification and enumeration, preparation of daily count tally sheets, and review of video data at sites where video interrogations occur. They are also responsible for performing routine maintenance at the counting stations or informing responsible parties when such maintenance is needed (e.g., keeping the viewing window clean and algae free).

### Equipment

- Hand tabulators
- Pencils, notepads
- Calculator
- Digital video recorder (e.g., Sanyo DSR 300)
- High-resolution 33-cm (13-in) monitor
- High-resolution 0.83-cm (1/3-in) 520 line video camera with V/F Lens

### Acknowledgments

Dave Hurson (USACE) and Steve Richards (Washington Department of Fish and Wildlife) provided valuable information regarding adult passage facilities and counting programs at USACE projects in the Walla Walla District. Brad Eby (USACE) and Rosanna Tudor (Washington Department of Fish and Wildlife) provided helpful information regarding the juvenile bypass and sampling system configuration and smolt monitoring program procedures at McNary Dam. Jerry McCann (Fish Passage Center) provided a thorough description of the smolt monitoring program, much of which was adopted directly into this chapter.

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