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PIT-Tag Monitoring Systems for Hydroelectric Dams and Fish Hatcheries

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Abstract.—Juvenile salmonids implanted with passive integrated transponder (PIT) tags can be monitored remotely as they are released from fish hatcheries or as they pass through specially designed facilities at hydroelectric dams. We have also designed and tested a system that monitors PIT-tagged adult salmonids. The systems record the individual PIT-tag code, time, date, and location of detection. Interrogation systems at dams can monitor fish traveling up to 3.7 m/s and provide tag detection efficiency above 95% and reading accuracy (correct code identification) above 99.0%. The information collected at each dam is automatically transferred to a central data base for storage and processing. The system used to monitor hatchery releases can process over 20,000 fish/h (at a ratio of 1:4 tagged to untagged) with a 93%, or higher, PIT-tag detection efficiency and a reading accuracy above 99.0%.

Salmonids in the Columbia River basin implanted with passive integrated transponder (PIT) tags can be interrogated remotely by means of a computer-based PIT-tag monitoring system. Details on the tag, how it operates, and its biological and technical suitability have been presented by Prentice et al. (1984, 1985, 1986, 1987) and are reviewed elsewhere in this volume (Prentice et al. 1990a, 1990b). The PIT tag, available from Destron-Identification Devices, Inc. (D-IDI)[1], consists of an integrated circuit and a coil (antenna) encapsulated together in a glass tube. The integrated circuit is factory-programmed with a unique code (a 10-digit hexadecimal number displayed in an alphanumeric format—e.g., 7F7131000) which is automatically transmitted whenever the circuit is energized. The tag is energized and read when the fish passes through the loop antennas of the monitoring system. Individual code, time, date, and location of detection are recorded for each PIT tag interrogated by the monitoring system. The system can passively monitor juvenile PIT-tagged salmonids as they are released from fish hatcheries or as they pass downstream through specially designed facilities at hydroelectric dams. A system to passively monitor adult salmon also has been designed.

In this paper, we describe and evaluate the PIT-tag monitoring systems we designed for hydroelectric dams and fish hatcheries. All electronic components of the monitoring system are commercially produced by D-IDI.

Systems at Hydroelectric Dams

Most outmigrating salmonids in the Columbia River basin encounter hydroelectric dams that impede migration and increase mortality (Figure 1). Several of these dams include collection and diversion facilities for passing migrants around the turbines to increase fish survival. A typical juvenile collection–diversion facility consists of traveling screens that divert fish from the dam's turbine intakes into gatewells and then into a series of conduits leading to a wet separator (Figure 2). The separator reduces the volume of water and removes debris. Fish are then diverted to a raceway for later transport downstream via truck or barge, directly to a barge for transportation downstream, or back into the river below the dam.

Monitoring systems for PIT-tagged juvenile salmonids have been installed at three Columbia Basin dams that have collection–diversion facilities. The systems are positioned so that all the fish exiting the wet separator are passively interrogated for PIT tags. The prototype was installed at the wet separator at McNary Dam in 1985 (Prentice et al. 1986) and modified in 1986 (Figure 3) (Prentice et al. 1987). Subsequent systems were installed at Lower Granite Dam on the Snake River in 1986 (Figure 4) and at Little Goose Dam in 1987 (Figure 5).

[1]Reference to trade names does not imply endorsement by the National Marine Fisheries Service.

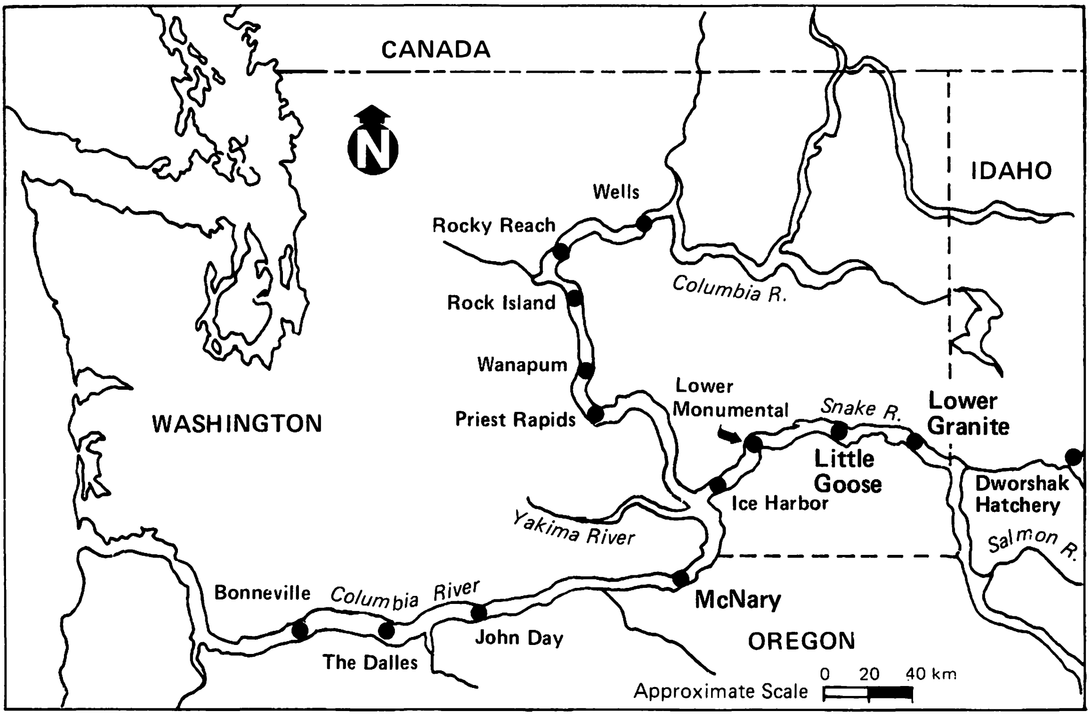


FIGURE 1.—Hydroelectric dams on the Columbia and Snake rivers. Those dams with PIT-tag monitoring systems appear in bold print.

In 1987, a prototype system for monitoring PIT tags in adult salmonids was installed at Lower Granite Dam at the entrance to an existing fish trap (Figure 6) (Prentice et al. 1987). All adult fish passing over this dam are trapped for biological sampling. Fish entering the trap pass over one of two false weirs, down a pipe 31 cm in diameter, through a coded wire tag (CWT) detector, and finally through a PIT-tag monitoring system.

We evaluated the efficiency and accuracy of all these systems by passing a set of known tags through their monitors at various times during the field season. Over 3 years, they detected more than 95% of the tags and correctly read more than 99% of the codes (Prentice et al. 1986, 1987). Two minor equipment problems that reduced efficiency and accuracy were corrected in 1988.

The PIT-tag monitoring systems consist of several components (Table 1) interconnected by shielded cable as shown schematically in Figure 7. A dual loop antenna assembly (DLAA) comprises a waterproof aluminum radio frequency (RF) shield housing, two transmitting and receiving loop antennas wrapped around a nonmetallic pipe or flume, and two loop tuners (LT). The number and size of DLAAs at each of the dams vary (Table 1). The DLAAs were constructed by NMFS personnel according to the specifications of the manufacturer and were modified for each application and location.

For each loop antenna of the DLAA, the number of wire wraps varies with the cross-sectional area of the pipe or flume and functions as a 400-kHz exciter coil and tag sensor. The loop antennas are wrapped in opposite directions and energized with opposite polarities to reduce radiated RF signals generated by the system. One LT is attached to each loop antenna to tune it to the correct 400-kHz energizing signal and aid in reducing RF emissions. Each LT is connected to the dual exciter (DE), which energizes the loop antennas and receives and amplifies the returning signal from a tag. The DE consists of two independent circuit boards (one for each loop antenna), connectors for signal input and output, and a tuning system and meter to tune the DLAA to 400 kHz for maximum efficiency. The maximum operational distance between the loop tuner and the DE is 6.1 m. Power for the DE is supplied by a dual power supply (DPS) that converts 110-V AC power to a variable DC voltage. Each DPS independently powers one of two DE circuit boards.

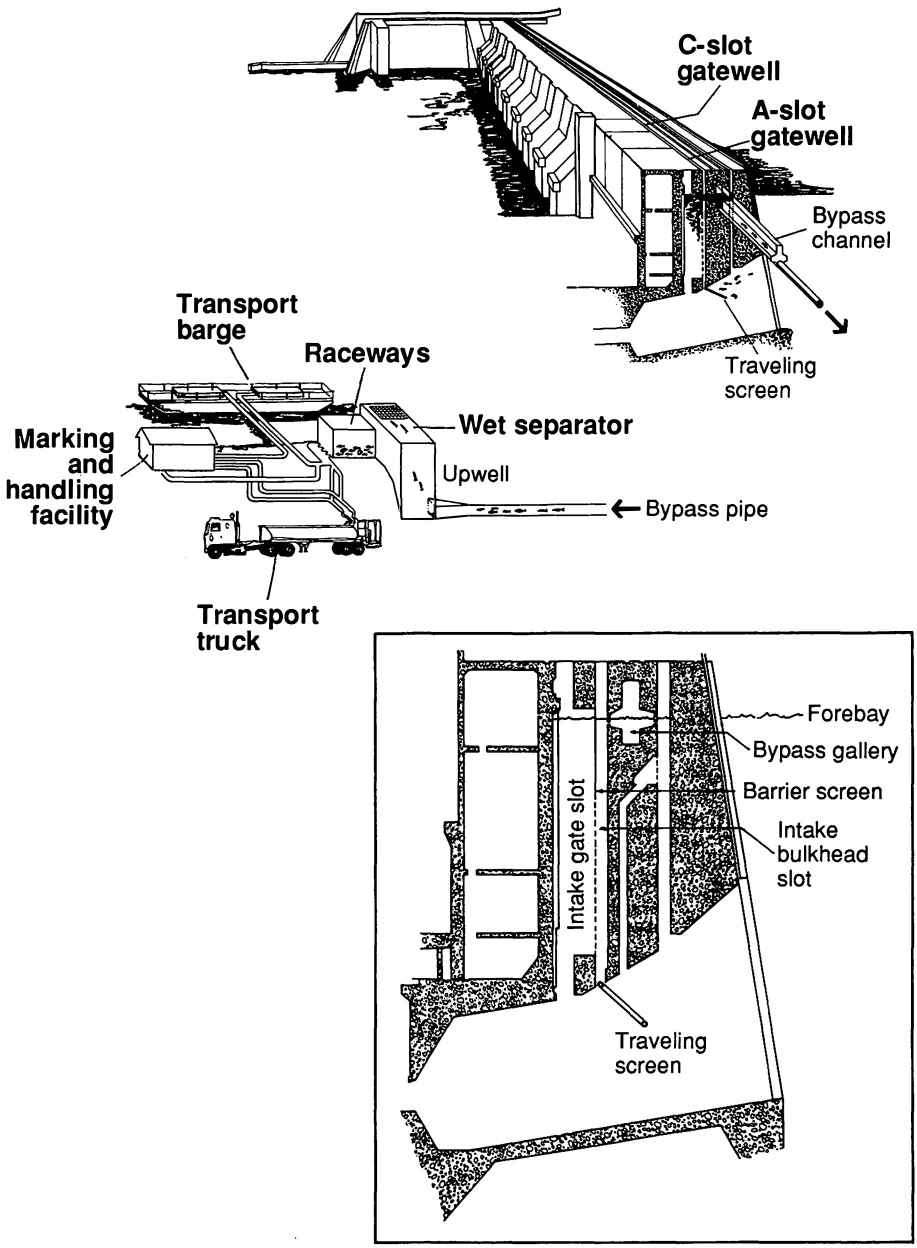


FIGURE 2.—Side view of a hydroelectric dam showing a fish collection–diversion system.

Power levels are controlled by switches within the DPS, and a dual filter between the DE and the DPS reduces RF signal interference.

A PIT tag is energized as it passes through the electromagnetic field of the loop antenna, which causes it to emit a coded low-frequency (40–50 kHz) signal. PIT-tag signals are amplified at the DE and are then sent to a standard (STD) bus controller for processing. The maximum distance between the DE and the controller is 61 m. One controller can process signals for as many as three DEs. During tag interrogation, the controller demodulates and decodes the amplified tag return signal from the DE. In addition to decoding the 10-digit tag code number, the controller produces a 2-digit check sum of the tag code (the code's

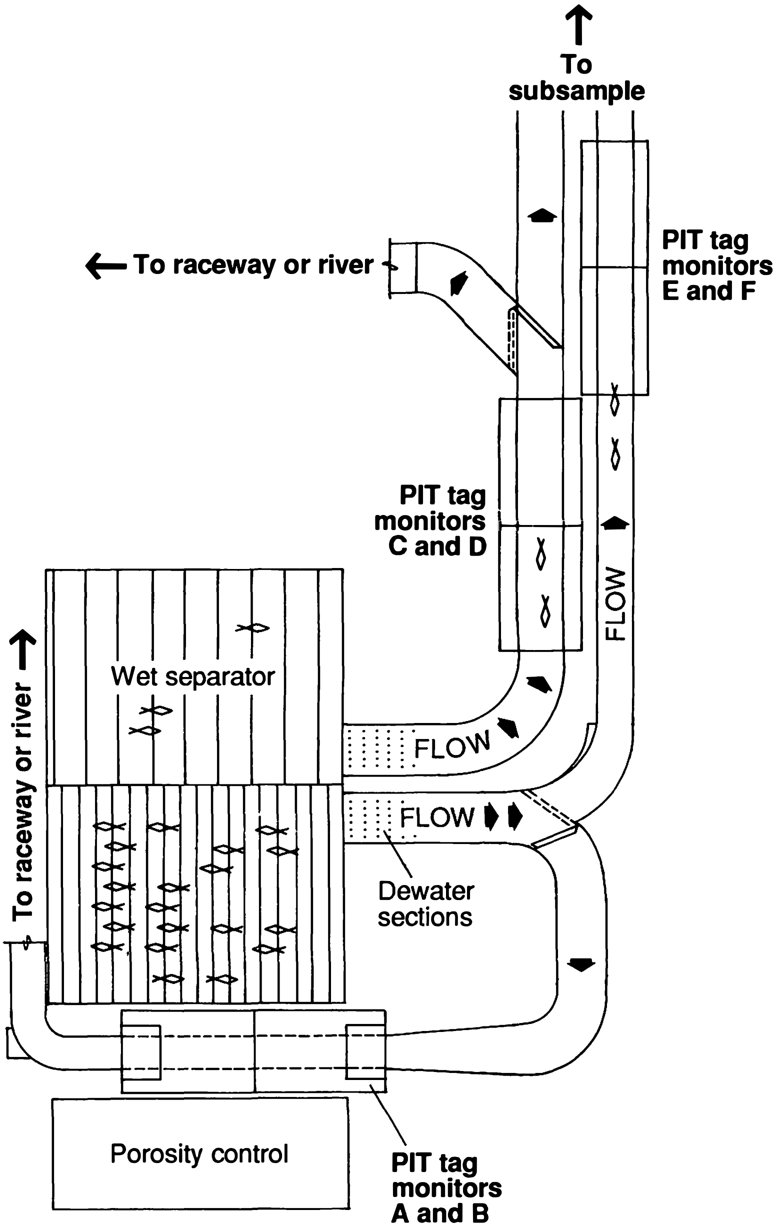


FIGURE 3.—Wet separator and PIT-tag monitoring system for juvenile salmonids at McNary Dam.

hexidecimal sum), a 2-digit origin code (loop antenna identification number), a 2-digit system code (controller number), and the date and time of day (hour, minute, and second). The time of day and date are generated hourly by the controller, even in the absence of PIT tags. All information is transferred independently from the controller via separate standard RS232 ports to a printer, and via a multiport to a computer compatible with a MicroSoft Disk Operational System (MS-DOS). Each DLAA, and its supporting electronics, can operate as an independent system to provide backup in the event of an electronic problem. The multiport controls the simultaneous transmission of information from one or more controllers to the computer. Furthermore, buffers within the con-

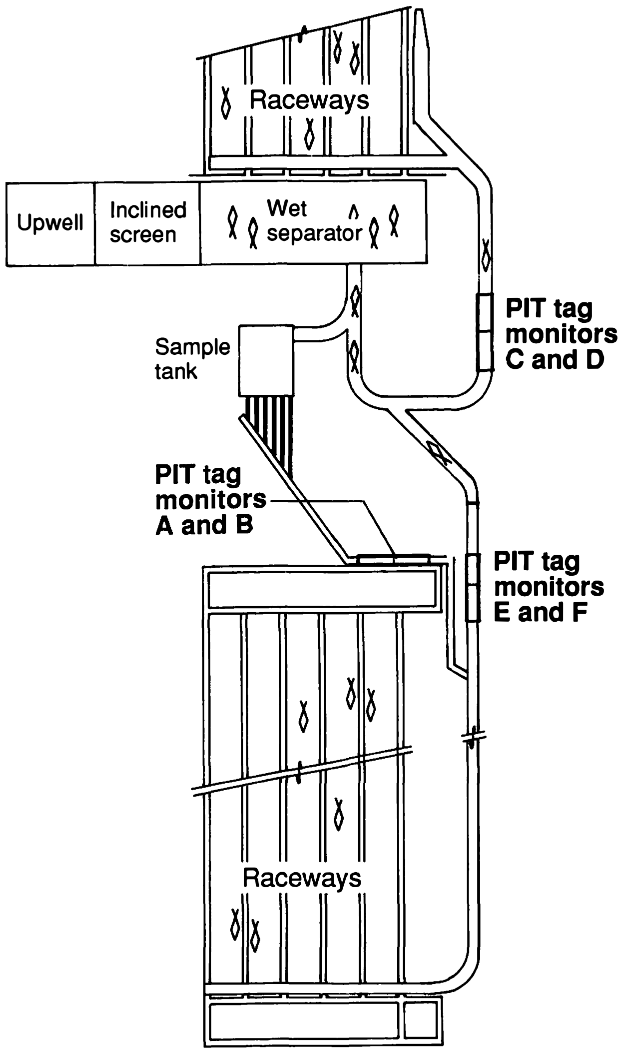


FIGURE 4.—Wet separator and PIT-tag monitoring system for juvenile salmonids at Lower Granite Dam.

troller, multiport, printer, and computer protect the system from becoming overloaded with information.

The system is designed to interrogate, decode, and process tag code information at rates in excess of one tag code per second (average), with peak rates of 10 codes/s for a maximum duration of 1 s. Signal interference can occur if two or more tags are present at the same time in the excitation field of the loop antenna. This situation may prevent either tag from being read. If a tag remains in the fringe reading range of the loop antenna for several seconds, an incorrect reading may occur. The DLAA, DE, LT, and dual filter are designed to operate in exposed conditions at temperatures of −20 to 50°C and at humidities of 0 to 100%. However, the controller, power supply, multiport, printer, and computer must operate in a protected environment.

Data Collection and Transfer

The computer in the PIT-tag monitoring system enables data to be stored in a specific format (ASC II) on electronic media and to be transferred via telephone lines. DoubleDos software allows concurrent operation of a PIT-tag monitoring program and a communication program (ProComm) that can send data to a central data-processing site. A program developed by the NMFS formats data received from the monitor controllers, and it

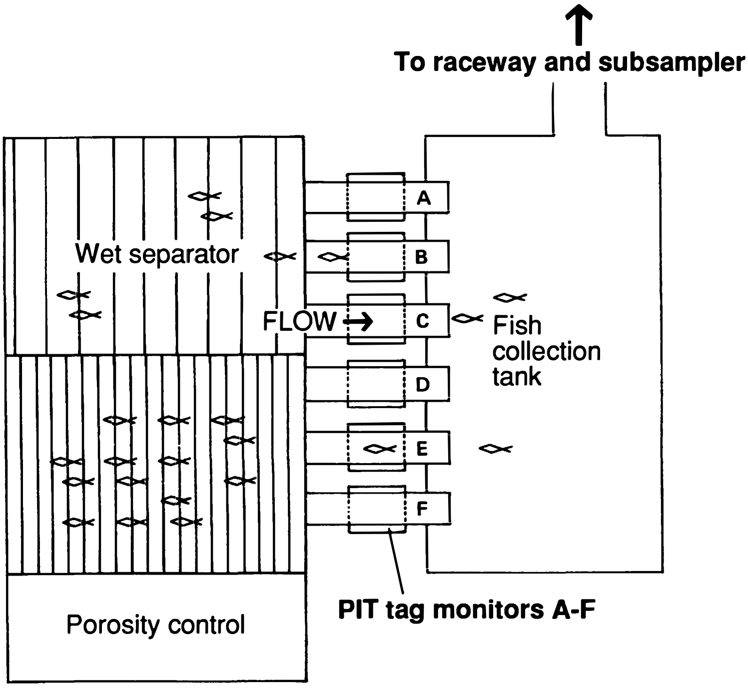


FIGURE 5.—Wet separator and PIT-tag monitoring system for juvenile salmonids at Little Goose Dam.

creates new files at 0000 hours every day. The title of the file and the time, date, and location of the monitoring system begin each entry. Hourly date–time stamps and tag-code information are added as tag codes come in.

At this time, PIT-tag monitoring sites at hydroelectric projects are queried daily for the previous day's files. The data-collection computer at the dam is accessed via telephone by a computer operator who transfers the files to a centralized computer in Seattle, Washington. A file from each of the monitoring sites is stored and edited for errors and system operation, and a processed file is generated. The processed file is available to users by 1200 hours on the day the file is received.

Hatchery Release Monitors

In some studies, there are waiting periods between tagging and release when tags are rejected or deaths occur. In such situations, it is important to identify the code of every PIT-tagged fish at the time of release so that losses during the waiting period are accounted for. Prentice et al. (1986, 1987) described a PIT-tag system for monitoring releases in hatchery raceways, which was tested at Dworshak National Fish Hatchery (DNFH) in 1986 (Figure 8). The monitoring systems at the dams and at hatcheries differed primarily in the size and number of their DLAAs and supporting electronic units (Table 1). At DNFH, there were four DLAAs, each consisting of a pipe 10.2 cm in diameter and 61.0 cm long. The four DLAAs were fitted to a raceway discharge so that all fish, tagged and nontagged, passed through the four DLAAs. The tag interrogation, decoding, and recording rate was about 20,000 fish/h (tagged and untagged combined) at a ratio of one tagged to four untagged fish. The tag-detection efficiency of this system was 93%, and the reading accuracy was over 99%.

Field Studies

Several of the PIT-tag monitoring systems for juvenile salmonids were evaluated in a series of field tests conducted in 1985 and 1986. We determined the tag-reading efficiency of monitors at Lower Granite and McNary dams for migrating yearling chinook salmon *Oncorhynchus tshawytscha*, underyearling chinook salmon, and steelhead *O. mykiss* (formerly *Salmo gairdneri*). In each test, PIT-tagged fish were released into a wet separator upstream from the tag monitors (Table 2). Tag-detection efficiency ranged from 95 to 100%, and tag-reading accuracy (correct code recognition) exceeded 99%. The monitoring equipment remained active up to 7 months with-

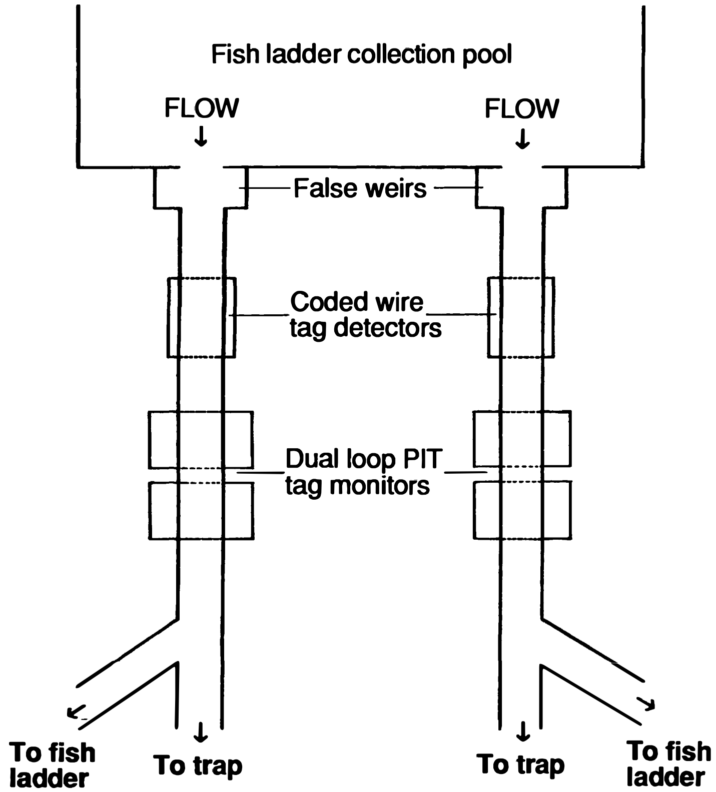


FIGURE 6.—Fish trap and PIT-tag monitoring system for adult salmonids at Lower Granite Dam.

TABLE 1.—Components required for PIT-tag systems used to monitor juvenile and adult salmonids at dams and hatchery raceways.[a]

Location	Monitor type	Size of DLAA (cm)	Number of DLAAs	Number of components required per DLAA				Number of components required per location			
				LT[b]	DE[b]	Filter[b]	DPS[b]	Controller[b]	Printer	Multiport[c]	Computer
McNary Dam	Juvenile	15 × 46 × 122	4	2	1	1	1	3	2	1	1
		15 × 31 × 122	2	2	1	1	1				
		15 dia × 22	1	2	1	1	1				
Little Goose Dam	Juvenile	10 dia × 61	6	2	1	1	1	2	2	1	1
Lower Granite Dam	Juvenile	15 × 46 × 122	4	2	1	1	1	2	2	1	1
		25 dia × 122	2	2	1	1	1				
Lower Granite Dam	Adult	31 dia × 122	4	2	1	1	1	2	2	1	1
DNFH	Juvenile	10 dia × 61	4	2	1	1	1	2	2	1	1
NMFS	Juvenile (pump system)	15 dia × 122	2	2	1	1	1	1	1	1	1

[a]Abbreviations used: DLAA = dual loop antenna assembly; LT = loop tuner; DE = dual exciter; DPS = dual power supply; dia = diameter; NMFS = National Marine Fisheries Service; DNFH = Dworshak National Fish Hatchery.

[b]Model numbers for PIT-tag monitoring equipment from Destron-Identification Devices, Inc.: LT = 800-0069-01; DE = 800-0026-00; DPS = 800-0027-00; Filter = 761-0050-00; Controller = 800-0028-00.

[c]Model number and source of multiport: Multiport model 528-H from Bay Technical Associates, Bay Saint Louis, Mississippi.

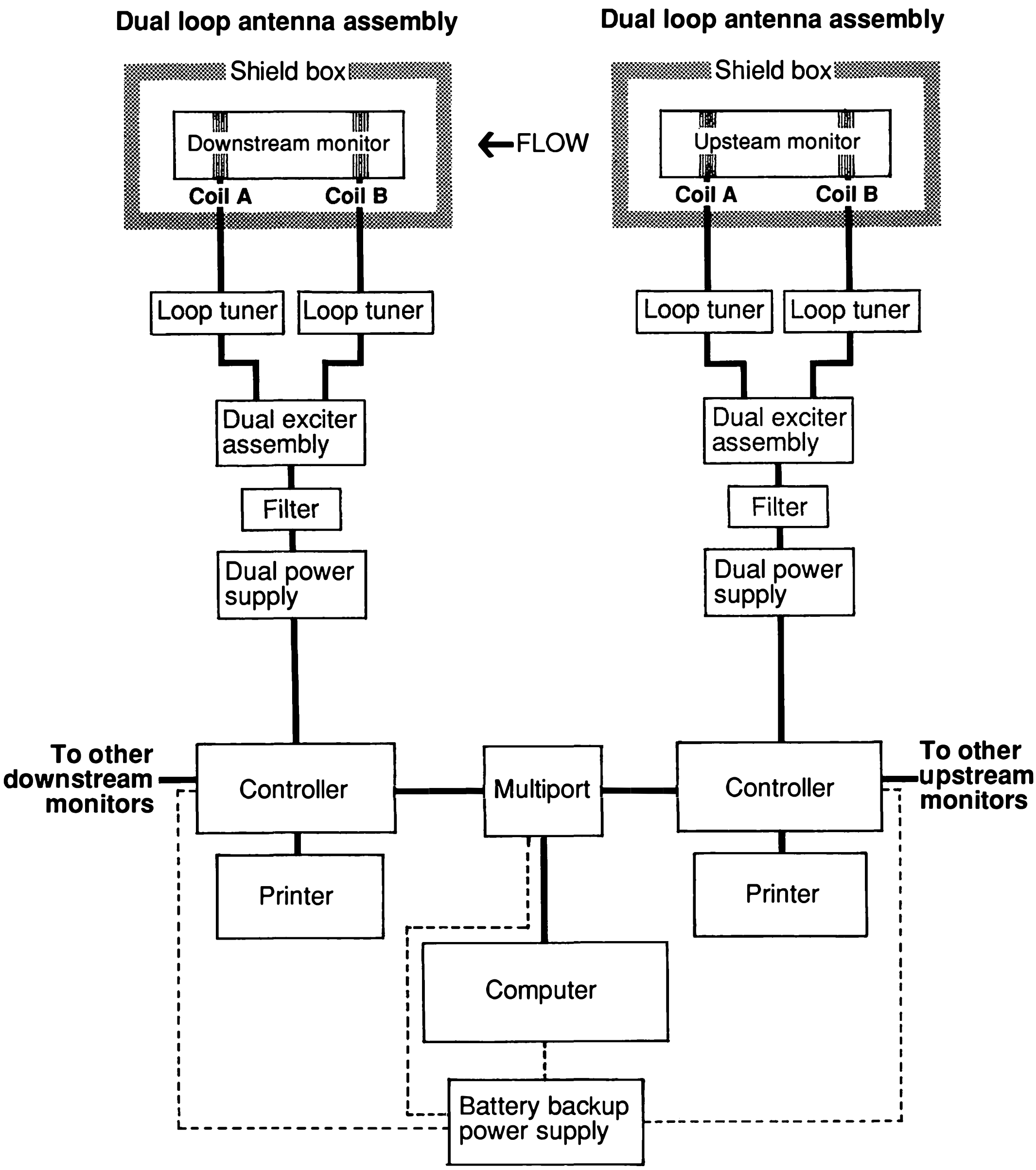
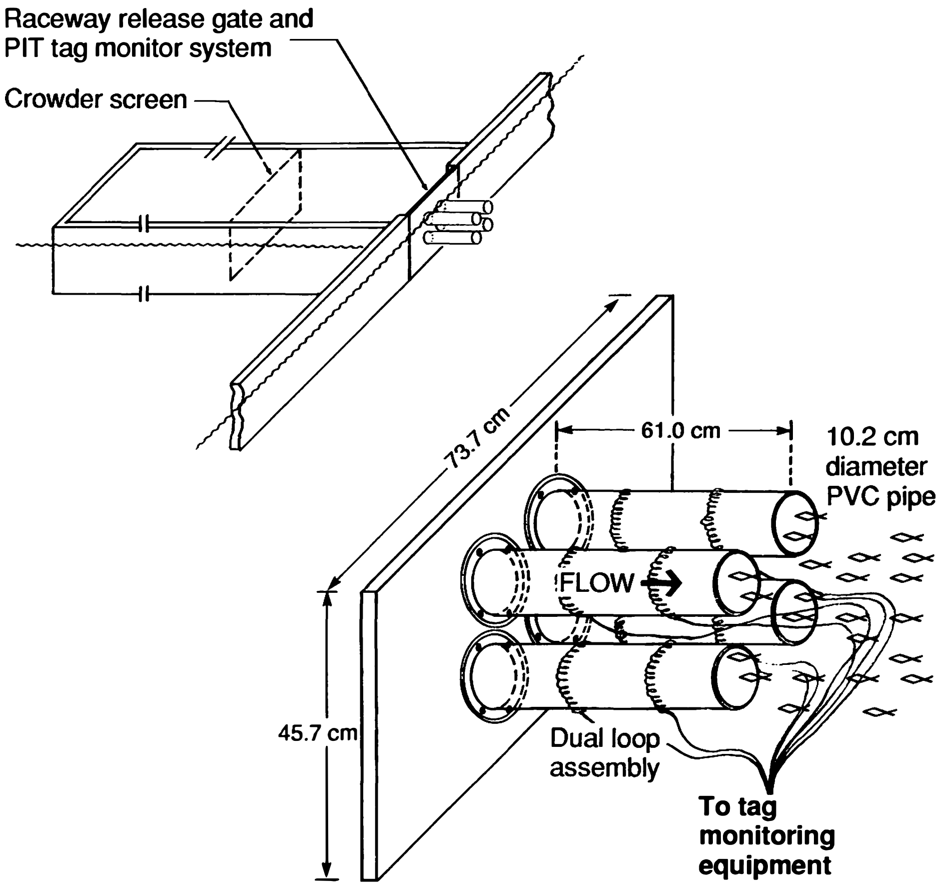


FIGURE 7.—Schematic of PIT-tag monitoring systems installed at Columbia and Snake river dams.

out major problems and proved to be reliable under field conditions.

To further evaluate the PIT-tag system, we compared it with freeze branding, a traditional marking method for juvenile salmonids. The migrations of juvenile salmonids in the Columbia Basin have been studied annually since 1964 (Raymond 1974). Usually, groups of fish are marked (either at the hatchery or in-river), released, and then sampled at collector dams—e.g., McNary, Little Goose, and Lower Granite. Freeze branding has been the traditional method used to identify these groups of fish (Park and Ebel 1974). At the dams, freeze-brand and PIT-tag data are acquired in fundamentally different ways. The PIT-tag detectors are deployed to interrogate all fish in the migrant bypass system. To obtain freeze-brand data, a subsample from the bypass population is examined for marks, which are then used in extrapolations to estimate the number of a partic-



Tag monitoring equipment

Description	Number
Dual power supplies	4
Exciter assemblies	4
Controllers	2
Multiport	1
Computer	1
Printers	2

FIGURE 8.—Diagram of PIT-tag system for monitoring releases in hatchery raceways.

ular marked group in the entire bypass system (Giorgi and Sims 1987). The methods also differ notably in the time required for data recovery. Detection of PIT tags are known to the second, whereas brands are pooled over a 24-h period and processed once a day.

Another drawback of the freeze-brand method is the amount of physical handling of many unmarked as well as marked individuals required to gather data. Because branded fish make up only a small portion of the outmigrants, hundreds of thousands of salmonids must be handled each year at the collector dams to obtain freeze-brand code information. The PIT-tag system alleviates this added stress on migrant salmonids.

For certain studies, the use of PIT tags in lieu of brands has the potential to produce statistically and biologically comparable results with a 90 to 95% reduction in the number of fish treated. In 1985 and 1986, we compared the collection ratios of freeze-branded and PIT-tagged chinook salmon and steelhead. The test groups were released into

TABLE 2.—Results of field tests that measured the ability of monitors to detect PIT tags in juvenile chinook salmon and steelhead at hydroelectric dams.

Year	Fish	Number of fish released	Tags detected (%)
	Lower Granite Dam		
1986	Yearling chinook salmon	340	98.5
1986	Steelhead	480	98.1
Subtotal		820	98.3
	McNary Dam		
1985	Yearling chinook salmon	584	97.9
1985	Age-0 chinook salmon	260	95.4
1986	Yearling chinook salmon	480	96.5
1986	Steelhead	480	96.0
1986	Age-0 chinook salmon	480	99.0
Subtotal		2,284	97.2
	Both dams		
Total		3,104	97.5

the reservoir of McNary Dam or released from Dworshak National Fish Hatchery and monitored at the juvenile fish collection facilities at McNary and Lower Granite dams (Table 3). Detection rates for PIT tags were as high as or higher than those for freeze-branded fish. Generally, PIT-tagged fish at McNary Dam were recovered in greater proportion than their freeze-branded counterparts (Table 3). Also, over a 5-d period, recoveries of serial releases of PIT-tagged and freeze-branded chinook salmon smolts at McNary Dam indicated that the PIT tag provided data with less statistical variation (Table 3).

The discrepancy in recovery data between PIT-tagged and branded fish suggests a bias may be associated with the recovery process. It may be an anomaly of the sampling mechanism or of the brand reading and transcription process. Personnel of the NMFS are conducting research to identify the source of this error.

Future PIT-Tag Monitoring Systems

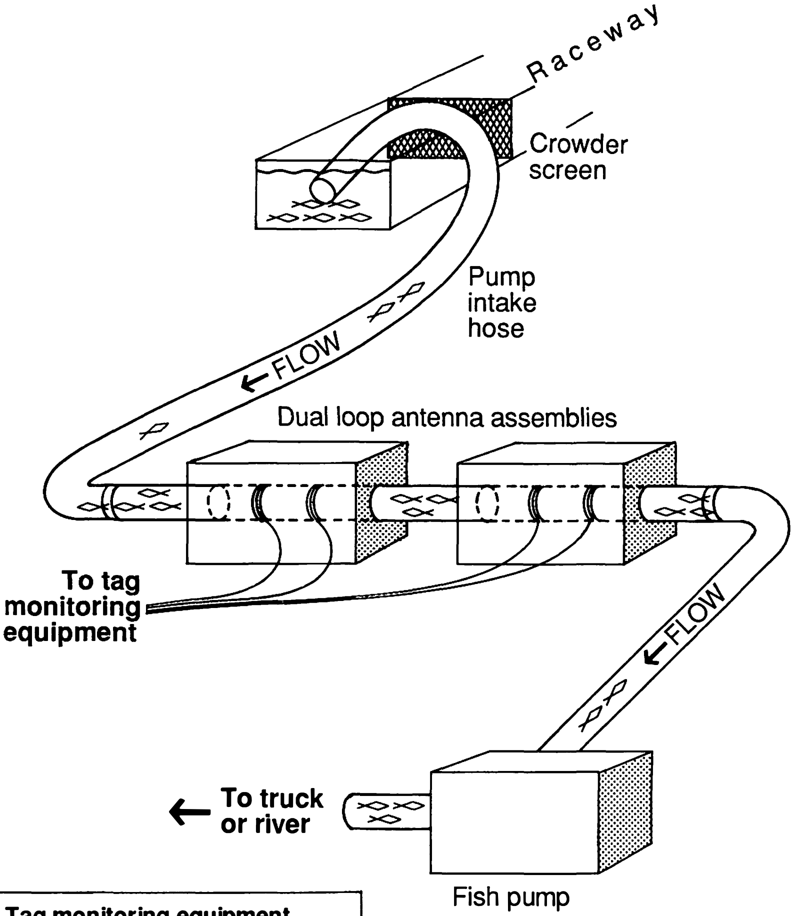
We are now evaluating a PIT-tag monitoring system that processes fish as they are pumped from fish hatchery raceways to transport trucks or barges. The system consists of two DLAAs, each 15 cm in diameter and 152 cm long, attached to the intake of a fish pump (Figure 9). The electronic components of the system are the same as for the PIT-tag monitoring systems previously described. Tag interrogation, decoding, and recording rate are being evaluated for different pumping rates and ratios of tagged to untagged fish.

A disadvantage of the PIT-tag monitoring systems is its range of detection, which is limited to a radius of about 18 cm. Future efforts will be directed at increasing this range. With an expanded detection system, it would be possible to

TABLE 3.—Detection of PIT-tagged and freeze-branded chinook salmon and steelhead released into the Columbia River system in 1985 and 1986.

Species (year)	Treatment	Number released	Number of groups	Tag detection[a]: Lower Granite Dam Observed	Lower Granite Dam %	McNary Dam Observed	McNary Dam % (SD)
			Releases from Dworshak Hatchery				
Yearling chinook salmon (1986)	Branded	40,675	1	4,659	11.5	3,402	8.9
	PIT-tagged	2,450	1	464	18.9	264	10.8
Steelhead (1986)	Branded	35,025	1	7,061	20.2	389	1.1
	PIT-tagged	2,424	1	928	38.1	45	1.8
			Releases into McNary Reservoir				
Age-0 chinook salmon (1985)	Branded	4,400	5			758	19.0 (9.0)
	PIT-tagged	400	5			64	16.0 (4.0)
Age-0 chinook salmon (1986)	Branded	5,000	5			1,371	27.4 (3.7)
	PIT-tagged	500	5			142	28.4 (1.6)
Yearling chinook salmon (1986)	Branded	5,000	5			2,101	39.6 (9.9)
	PIT-tagged	500	5			318	63.6 (2.5)

[a]Detection of freeze-branded fish is based on actual number of fish observed expanded by the prevailing sample rate, whereas the detection of PIT-tagged fish is based upon actual number of fish observed.



Tag monitoring equipment

Description	Number
Dual power supplies	4
Exciter assemblies	4
Controllers	2
Multiport	1
Computer	1
Printers	2

FIGURE 9.—Diagram of experimental system for monitoring PIT-tagged fish as they are pumped from raceways to release or transport points.

interrogate all the adult salmonids that migrate through fish ladders at hydroelectric dams.

Acknowledgments

We thank the Bonneville Power Administration for funding this project and the U.S. Army Corps of Engineers for allowing us to install and evaluate the PIT-tag monitoring systems at their facilities. We also thank Richard Frazier, Phillip Weitz, and their NMFS staffs for engineering services and installation of the PIT-tag monitoring systems.

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