PNWD-3800

Lower Monumental Reservoir Juvenile Fall Chinook Salmon Behavior Studies

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FINAL REPORT

July 2007

Prepared for the
U.S. Army Corps of Engineers
Walla Walla District, Walla Walla, Washington,
Under Contract DACW68-02-D-0001 029

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
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Battelle–Pacific Northwest Division
Richland, Washington 99352

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Summary

This report documents a one-year study to assess interactions between migratory behavior of juvenile fall Chinook salmon and water circulation patterns that developed in Lower Monumental Reservoir between June and September 2006. The study was conducted for the U.S. Army Corps of Engineers, Walla Walla District, by Battelle–Pacific Northwest Division and the Fish Ecology Division of the Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration.

Autonomous acoustic receivers and sensors monitoring hydraulic conditions were deployed before 15 June and maintained through 25 September. Actively migrating subyearling Chinook salmon (N = 1949) were surgically implanted with both acoustic and passive integrated transponder (PIT) tags. Ten groups of study fish were collected at Little Goose Dam, tagged, held overnight, and then released 5 km downstream of Little Goose Dam. Releases occurred between 16 June and 19 July. The probability of a tagged fish being detected was $\geq$ 99% at six of the seven detection lines within Lower Monumental Reservoir.

The following list presents each research objective, followed by our key results and observations:

1. **Characterize fish movements and hydraulic conditions from June through September.**

   - Throughout the study period, 44% (N = 852) of the study fish did not pass downstream of Lower Monumental Reservoir. The distribution of the fish that did not pass the reservoir was weighted toward the lower half of the reservoir, as illustrated in Figure S.1.

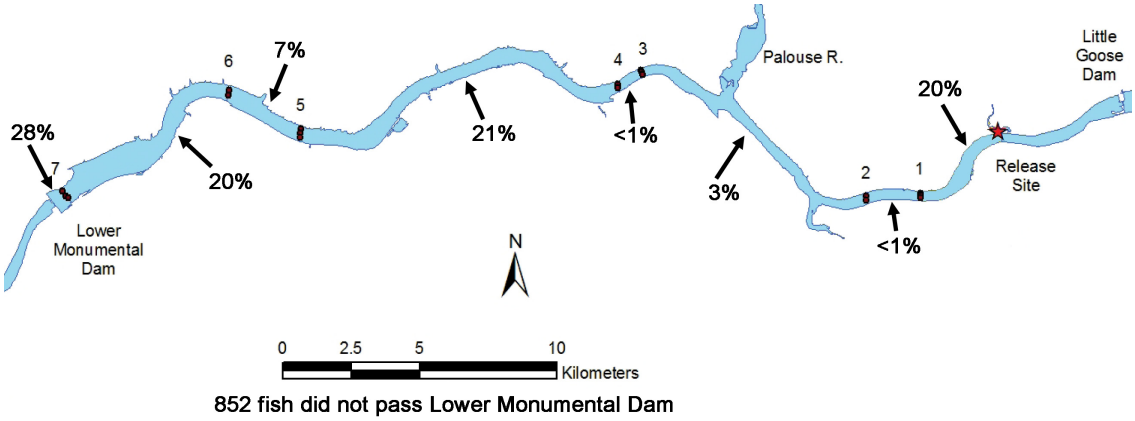

Figure S.1. Last Detection Locations of Study Fish Expressed as a Percentage of the Total That Did Not Pass Lower Monumental Dam

   - Detection probabilities were unchanged throughout the season and were not sensitive to seasonal changes in river discharge and reservoir stratification.

   - Daily-average discharge from Lower Monumental Dam decreased from more than 100 kcfs in early June to less than 20 kcfs in September. Superimposed on the seasonal trend, daily oscillations in powerhouse discharge occurred through late July. Powerhouse discharge was steady during August. The spillway was operated until 30 August. Voluntary spill ceased on 1 September.

- In the upper half of the reservoir, the water column was approximately isothermal throughout the study. The lower half of the reservoir stratified in early July. Below-equilibrium temperature releases from Little Goose Dam (influenced by hypolimnetic releases from Dworshak Reservoir) produced underflow hydraulic conditions in Lower Monumental Reservoir, and a plunge line was observed near the midpoint of the reservoir between 14 July and 15 September.

2. **Compare fish distribution with density gradients and wind effects that influence reservoir circulation, and assess the correlation between fish movements and hydraulic conditions.**

- Wind direction followed orientation of the river (i.e., topographic steering) during the study. The prevailing wind directions were either upstream or downstream, relative to the orientation of the reservoir, and winds oriented sideways to the flow of the river were rarely observed.
- Upstream-directed water motions in the top 6 m of the water column frequently occurred in the stratified lower half of the reservoir (Figure S.2). Motions were predicted to occur intermittently between 1 and 14 July and frequently after 14 July. These motions were in response to wind orientation and speed, although the response of the water was not instantaneous to changes in the wind. Upstream-directed water motions did not occur in the isothermal upper half of the reservoir.
- The majority (N = 647; 76%) of the fish that ceased downstream migration did so in the stratified portion of the reservoir and upstream of Lower Monumental Dam. Most of the fish that stopped in the isothermal zone (N = 170; 20% of the fish that did not emigrate from the reservoir) were never detected at any acoustic telemetry arrays, and we attribute the loss of these fish to predation near the release site (supported by mobile tracking data). Excluding these fish, only a small number (N = 35; 4%) stopped in the isothermal portion of the reservoir. The isothermal portion of the reservoir includes the confluence zones of the Tucannon and Palouse rivers.
- The number of fish in each release group that ceased migrating within the reservoir varied over time, with fewer fish migrating from the reservoir as time progressed. The number of fish that were detected downstream of Lower Monumental Dam are summarized in Table S.1. The detection probability of the tailrace array was 89% overall. Note that the sum of the Not Detected column totals 911 and includes 59 study fish that were detected at other downstream locations.

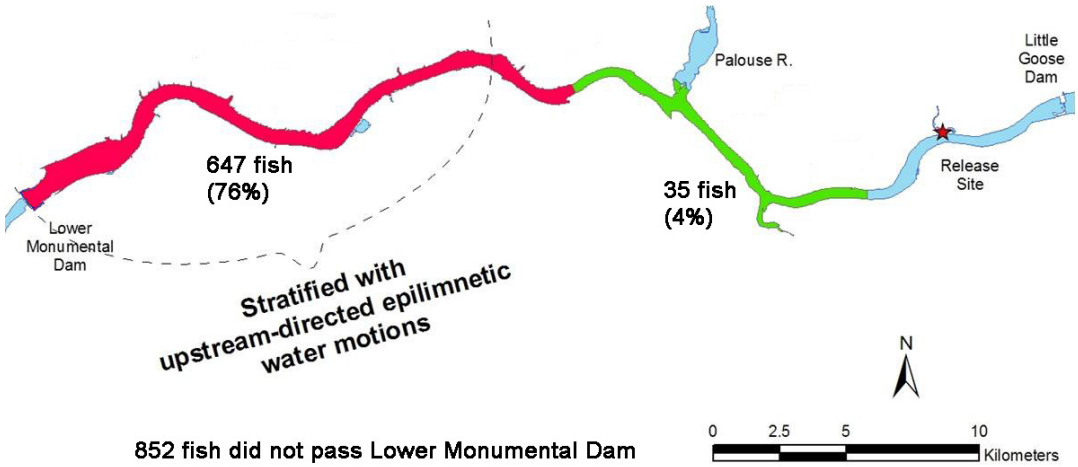

Figure S.2. Last Detection Locations of Study Fish and General Region Where Stratification with Underflow Conditions Developed in the Reservoir

Table S.1. Number of Study Fish Per Release Group Detected at the Lower Monumental Dam Tailrace Array

	Lower Monumental Dam Tailrace Array		
Release Date	Detected	Not Detected	% Not Detected
16 June	142	53	27%
21 June	147	48	25%
24 June	135	60	31%
27 June	156	39	20%
1 July	160	35	18%
4 July	117	78	40%
7 July	115	79	41%
11 July	47	145	76%
14 July	5	193	97%
19 July	14	181	93%

- Hydraulic conditions were examined at the time and location each fish was detected in the reservoir. Study results show a statistically significant correlation between the date and location at which downstream migration ceased in many of our study fish and the presence of thermal stratification with underflow hydraulic conditions. However, numerous physical and biological conditions changed throughout the study period, potentially confounding this relationship.

3. Document fish movement and assess mortality from temperature or predation.

- The median travel time of study fish from release site to the forebay of Lower Monumental Dam varied over the study. A progressive increase in the median travel time over the study period was not observed.
- The median travel times for fish that ultimately left the reservoir were faster than were travel times for fish within the same release cohort that remained in the reservoir. However, trends in travel time for fish that ultimately left or remained are confounded by the fact that more fish left the reservoir early in the study period when discharge was higher.
- Although water temperatures in the upper (isothermal) half of the reservoir were above 20°C for several of the release groups, large numbers of study fish were observed to migrate from the release site to the middle of the reservoir. The lowest estimated joint probability for survival and passage from release point to the middle of the reservoir was 78% (11 July release).
- Fish surgeries to implant the tags were successful, even at warm water temperatures (up to 22°C). Only a single post-surgery overnight mortality occurred during the study.
- Predators (primarily smallmouth bass) were generally located closer to shore than were the juvenile fall Chinook salmon. However, there was a high degree of overlap between the two. The sampling method (mobile tracking) did not allow for precise positioning of the tagged fish.

4. Document if fish residualize or continue movement downstream through the study period.

- Once the study fish ceased to migrate, they did not restart downstream movement during the study period (i.e., prior to 25 September).

- The last study fish to leave the reservoir and be detected using the acoustic telemetry receivers did so on 3 August (19 July release).
- The last PIT tag detection of any study fish was on 25 July at Lower Monumental Dam and 4 August at McNary Dam. The PIT tag detectors were active at Lower Monumental Dam until 30 September and at McNary Dam until 28 November.

In summary, thermal stratification and underflow conditions in the lower half of the reservoir were observed from early July through September. High proportions of study fish that ceased migration did so at times when the reservoir was stratified and in locations where underflow conditions were also present. However, this relationship does not imply causation because confounding factors (e.g., possible changes in the origin/release location of study fish and decrease in fish size through time) also were present.

Based on the results of this project in 2006, we recommend studies be considered for increasing the understanding of interactions between migrating juvenile fall Chinook salmon and environmental factors that develop in Lower Monumental Reservoir during the summer months. These include the following:

- With the intent of increasing the understanding of fate of subyearling Chinook salmon that fail to emigrate from Lower Monumental Reservoir, increase the number of acoustic receivers placed in the lower half of the reservoir and Lower Monumental Dam forebay.
- Assess how other biological factors (e.g., abundance of ichthyoplankton, fish source, smolt quality, predator fish distribution) could influence 'motivation' to migrate and/or ultimate fate of subyearling Chinook salmon passing through lower Snake River reservoirs. Document how these biological factors change over time when juvenile fall Chinook salmon are present in the lower Snake River. Determine if there is a relationship between these biological factors and cessation of downstream migration.
- Hydraulic conditions (e.g., water velocity and water temperature) in the reservoir and atmospheric parameters that affect hydraulic conditions (e.g., wind speed and direction, air temperature) should be documented in conjunction with emigration and fate measurements of subyearling Chinook salmon.

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1.0 Introduction

This report documents a one-year study to assess interactions between migrating juvenile fall Chinook salmon and water circulation patterns that develop in Lower Monumental Reservoir during the summer months. When Snake River fall Chinook salmon were listed under the U.S. Endangered Species Act in 1992, it was believed that most juvenile fall Chinook salmon within this evolutionarily significant unit followed a single life history. During the spring and summer after hatching, juvenile fall Chinook salmon would begin migration toward the ocean at age-0 (Connor et al. 2005, NMFS 1995). Not all juvenile fall Chinook salmon spend their first winter in the ocean as many have been documented migrating the following year at age-1 (Durkin et al. 1971, Williams et al. 2005). While the typical fall Chinook salmon life history involves seaward migration at age-0, referred to as ocean-type, fish that winter in fresh water and migrate to sea the following year are referred to as reservoir-type (Connor et al. 2005). Additionally, recent evidence indicates that individuals that leave the Snake River Basin at age-0 may not spend their first winter in the ocean, but instead spend their first winter in the brackish waters of the Columbia River Estuary (Hinrichsen and Van Holmes 2006). Growth rates, which are related to water temperatures during incubation and rearing as well as primary productivity of natal waters, have been linked to life-history in Snake River fall Chinook salmon. Salmon that spawn in warmer and more productive waters are thought to be more likely to produce ocean-type juveniles, while fry hatched and reared in colder and less productive areas are likely to delay seaward migration until age-1 (Connor et al. 2005). Durkin et al. (1971) reported that juvenile fall Chinook salmon were more likely to adopt this extended freshwater rearing strategy in Brownlee Reservoir on the Snake River during years with higher water levels and low (and 'disoriented') reservoir velocities.

The research discussed in this report was conducted for the U.S. Army Corps of Engineers, Walla Walla District, by Battelle–Pacific Northwest Division and the Fish Ecology Division of the Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration. The scope of the project was to address four research objectives:

1. Characterize fish movements and hydraulic conditions from June through September.

2. Compare fish distribution with density gradients and wind effects that influence reservoir circulation, and assess the correlation between fish movements and hydraulic conditions.

3. Document fish movement and assess mortality from temperature or predation.

4. Document if fish residualize or continue movement downstream through the study period.

In this report, Chapter 2 details the methods used to tag the juvenile salmon and predator fishes with acoustic tags, and to deploy, maintain and retrieve the acoustic receivers (nodes), water temperature and water velocity sensors, and meteorological stations. This chapter also discusses application of a two-dimensional hydrodynamic and water quality model to the reservoir. Chapter 3 documents the results of the study. This includes estimates of the joint probability of survival and passage of the juvenile salmon, characterization of the water temperature and water velocity patterns over the study period, and the meteorological conditions directly above the reservoir. We also document results generated by linking, over both space and time, the hydraulic and the fish passage/survival results. Chapter 4 presents a discussion of the study results, and Chapter 5 presents conclusions and recommendations.

2.0 Methods

2.1 Juvenile Salmon Collection and Microtransmitter Implantation

Juvenile fall Chinook salmon were obtained from the juvenile fish bypass facility at Little Goose Dam on the Snake River between 14 June and 17 July 2006. Fish were sorted to ensure that only juvenile fall Chinook salmon without previously implanted PIT tags were collected. A minimum of 195 fish were collected during each collection day and held without food for 24 hr prior to surgery in two 84-L tanks with freshly circulating ambient-temperature river water. Holding tanks were located in a covered trailer (2.7 m wide and 6.1 m long) designed specifically as a mobile fish surgery unit.

Surgeries to implant microtransmitters were performed on 10 dates from 15 June through 18 July. About 195 fish were implanted on each tagging day (Table 2.1). Length data of subyearling Chinook salmon measured by the Smolt Monitoring Program (SMP) every Sunday from 11 June to 16 July were assumed to be representative of the population and coincided with the dates of our study (Figure 2.1). Juvenile salmon tagged for our study (mean fork length (FL) = 111 mm, SE = 0.17) were longer than fish collected by the SMP (mean FL = 104 mm, SE = 0.28) ($t_{3248} = 23.48$, $P < 0.0001$). However, we did not tag fish less than 95 mm long, which comprised 11.2% of the subyearling Chinook salmon collected by the SMP.

Fish were anesthetized in 80–100 mg/L tricaine methanesulfonate (MS-222) prior to surgery for about 3–4 minutes until equilibrium was lost (i.e., fish could no longer hold themselves upright). Each sedated fish was then transported in a 1-L pitcher containing anesthetizing water to a technician who measured fork length (mm) and weight (g). One PIT tag (Destron-Fearing, Model TX1411ST; 12.5 mm × 2 mm) and one acoustic tag (Sonic Concepts, Model E101; 17 mm × 5.5 mm weighing 0.63 g in air and 0.35 g in water; Figure 2.2) were placed in the pitcher containing the corresponding fish and delivered to one of three surgeons. Acoustic microtransmitters were programmed to emit an individually encoded signal every 10 seconds, and expected battery life was 60 days. Tag life was evaluated in a separate study (Figure 2.3).

Each fish was placed on the surgery table ventral side up, a silicon tube was inserted into the mouth, and freshly oxygenated water was continuously supplied from two gravity-fed buckets positioned above the surgeon. One bucket contained a maintenance dose of 40 mg/L MS-222 and the other bucket contained water. Surgeons ensured the proper sedation level by controlling the valves on each bucket. An incision approximately 8 mm long was made about 3 mm from and parallel to the mid-ventral line between the pectoral and pelvic girdles. The PIT tag was inserted into the incision followed by the acoustic transmitter, which was placed with the battery toward the anterior portion of the fish. The acoustic transmitter was inserted following the PIT tag to reduce the possibility of the PIT tag passing out through the incision. Both tags were positioned parallel to the long axis of the fish. The incision was closed using two simple, interrupted sutures (Ethicon 5-0 absorbable coated Vicryl sutures with a C-3 needle). Fish were placed in a 120-L recovery bucket with flow-through river water and supplemental oxygen following surgery and were monitored to ensure that they recovered equilibrium before being transferred to the holding and release tank.

Table 2.1. Descriptive Statistics by Release Date of Juvenile Fall Chinook Salmon Tagged at Little Goose Dam and Released in the Lower Monumental Reservoir of the Snake River, 2006.

		Length (mm)				Weight (g)			
Release Date	N	Mean	SE	Min	Max	Mean	SE	Min	Max
16 June	195	109	0.6	95	136	12.4	0.2	8.2	25.7
21 June	195	110	0.6	97	135	13.1	0.2	8.6	24.5
24 June	195	113	0.6	97	135	14.3	0.2	9.1	23.9
27 June	195	114	0.6	99	132	15.0	0.2	9.6	24.6
1 July	195	115	0.4	105	136	15.4	0.2	12.1	27.3
4 July	195	112	0.4	103	135	13.9	0.2	9.7	27.4
7 July	194	109	0.4	96	130	13.3	0.2	8.8	21.5
11 July	192	107	0.4	94	126	13.4	0.2	8.8	21.4
14 July	198	110	0.5	96	135	15.7	1.0	9.8	28
19 July	195	113	0.6	97	132	15.8	0.2	9.9	25.1

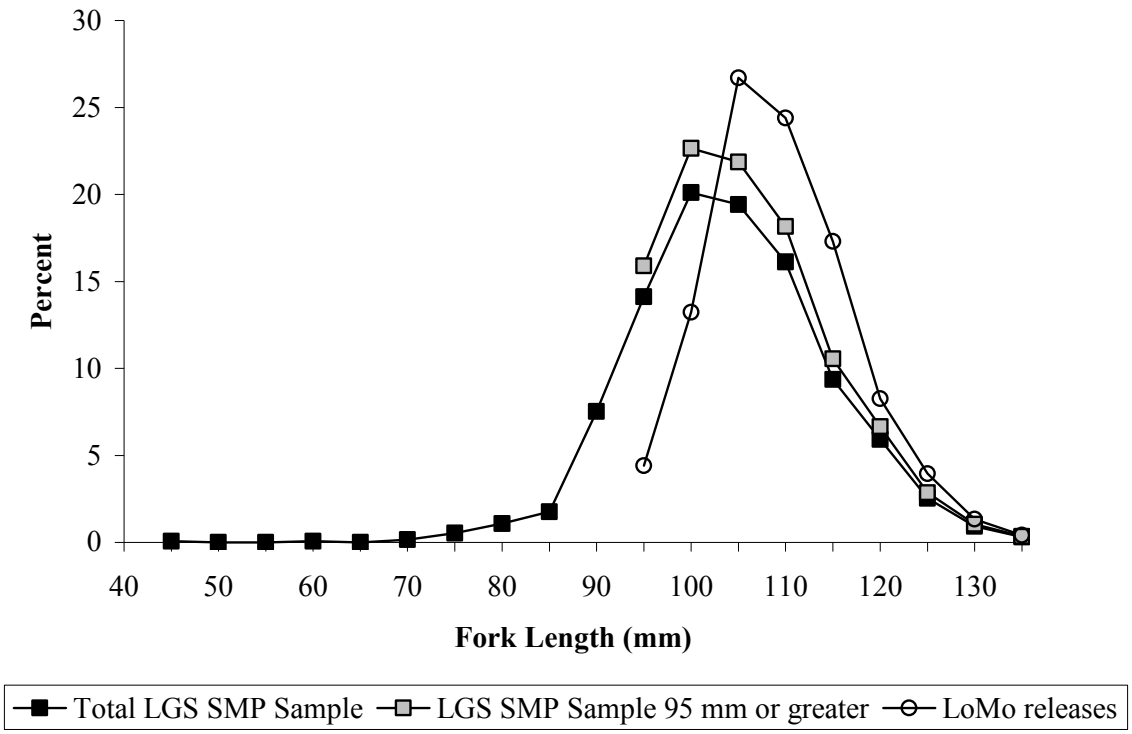

Figure 2.1. Length-Frequency Distribution of Subyearling Chinook Salmon Tagged with Acoustic Transmitters and Released in the Little Goose Tailrace (open circles) Compared with All Subyearling Chinook Salmon Collected by the Smolt Monitoring Program at Little Goose Dam (black squares) and Those 95 mm or Longer (grey squares; 11.2% of the total sample was < 95 mm). Data collected by the SMP are from Sunday samples only. Length data are grouped into 5-mm-length bins.

Figure 2.2. JSATS Microacoustic Transmitter Used in Subyearling Chinook Salmon Released Downstream of Little Goose Dam in 2006

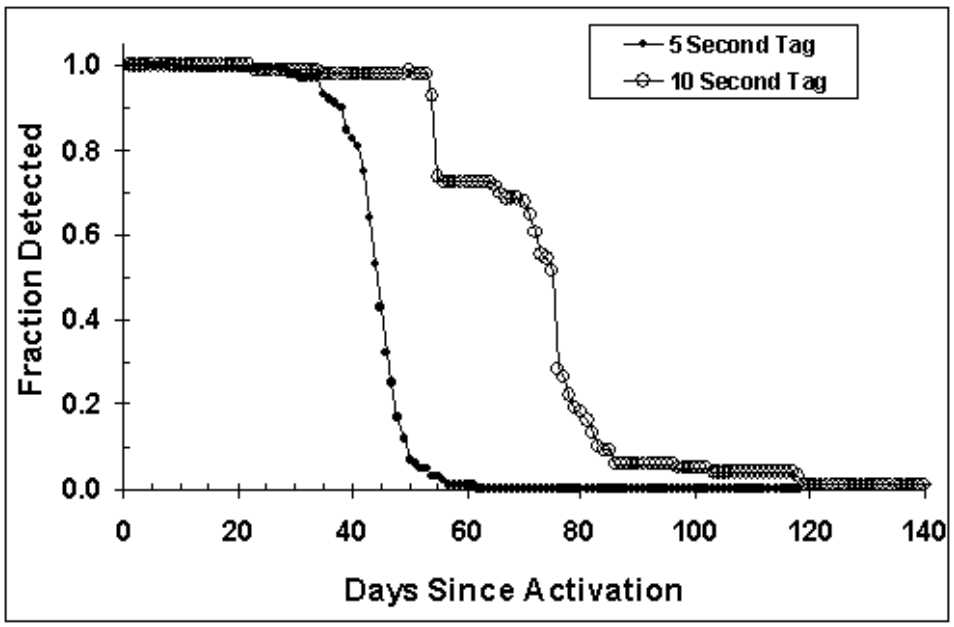

Figure 2.3. Cumulative Tag Life of 2006 JSATS Microacoustic Transmitters (*N* = 100 5-second and *N* = 100 10-second tags). The fraction of expected transmissions is plotted versus days since the tags were activated. The 10-second tags were used in the subyearling Chinook salmon released downstream of Little Goose Dam in 2006.

Following surgery, the juvenile Chinook salmon were held overnight in a truck-mounted holding tank (1,039 L) to assess tagging mortality and to allow fish to recuperate from surgery before being released into Lower Monumental Reservoir. Only one (0.05%) post-surgery overnight mortality occurred during the study. Salmon were released from the transport tank on the north shoreline 5 km downstream of the Little Goose Dam (river kilometer [rkm] 630.2). The release truck was backed into the river and the fish were released directly from the tank, through a 4-m-long PVC pipe. The river depth at the point of release was approximately 1 m.

2.2 Predator Collection and Tagging

Fifty predators (smallmouth bass *Micropterus dolomieu*, walleye *Sander vitreus*, and channel catfish *Ictalurus punctatus*) were collected using hook-and-line or seine from 18–20 July. Sampling and tagging occurred in specific areas of the Lower Monumental Reservoir to correspond with the spatial distribution of juvenile fall Chinook salmon that had ceased migration. Predator tagging methods were similar to salmon tagging methods; however, a few modifications were necessary due to field conditions. All predators were anesthetized in a manner similar to that for Chinook salmon, and fork length was measured. Smallmouth bass were placed ventral side up in a surgery bath with anesthetic-free water, and gills were irrigated continuously. Smallmouth bass received a PIT tag and an acoustic transmitter (Table 2.2). Incisions were closed with two 2-0 silk sutures and an FS needle (26-mm reverse cutting needle with a 3/8 circle). Channel catfish and walleye were tagged with transmitters that were modified for external attachment (Figure 2.4). External tags were constructed by securing the microacoustic transmitter to a Floy T-bar anchor tag with epoxy and shrink tubing. We used a tagging gun to insert tags into the pterygiophore bones ventral to the dorsal fin. Ten external transmitters were originally constructed for use in channel catfish because of their propensity to expel internal tags (Marty and Summerfelt 1986); however, three external tags were not used for catfish and were externally attached to walleye using the method described above for catfish. All predators were monitored for at least 1 hr following surgery to ensure that they maintained equilibrium. Predators were then released at their point of capture.

Table 2.2. Descriptive Statistics of Predator Fishes Tagged in Lower Monumental Reservoir of the Snake River, 2006

Species	*N*	Length (mm)			
		Mean	SE	Min	Max
Smallmouth bass	40	263	8.3	200	460
Channel catfish	7	450	25.4	372	546
Walleye	3	420	31.9	377	482

Figure 2.4. Microacoustic Transmitter Affixed to Floy Tag, Externally Attached to Channel Catfish

2.3 Autonomous Receiving System Deployment and Servicing

Prior to deployment, each node was attached to an acoustic release (InterOcean Systems, Inc., San Diego, CA; Model 111) by a 0.9-m-long bridle made of 12.7-mm-diameter braided nylon rope (Figure 2.5). Each bridle end was terminated by a braided splice around a professionally braided 9.5-mm SeaDog nylon thimble. Three yellow buoys (Baolong BL-6, 16.5 × 12.4 cm, 1.45 kg buoyancy each) were threaded on the bridle between the node and release. Each acoustic release was shackled to a 35-kg anchor with a 1- to 3-m-long shock-corded mooring made from 125-mm braided nylon rope terminated by a 10-cm galvanized steel ring held by the acoustic release.

Nodes were placed at 31 locations in the Snake River from Little Goose Dam to just upstream of the confluence with the Columbia River (Figure 2.6; Table 2.3). Twenty-five of these locations were arranged in five gates, and each gate had a three-node primary array positioned upstream of a two-node secondary array. Nodes were spaced equidistant on cross-sectional lines to maximize detection probabilities and spatial redundancy among the nodes. Other arrays were three nodes in the forebay of Ice Harbor Dam, five nodes in the Ice Harbor Dam tailrace, and four individual nodes deployed near sites for capture and release of salmonid predators (bass, walleye, catfish). One of the predator nodes (deployed in the reach between the release site and LMN 1) was not recovered.

Most of the nodes within Lower Monumental Reservoir (Lake Herbert G. West) were deployed 12 June 2006, although nodes immediately upstream (forebay) and downstream (tailrace) of Lower Monumental and Ice Harbor dams had been deployed to support another study and were in place beginning in mid April.

Figure 2.5. Autonomous Acoustic Telemetry Receiver (top), Acoustic Release (middle), and Anchor (bottom left) Rigged as Deployed in the Snake River

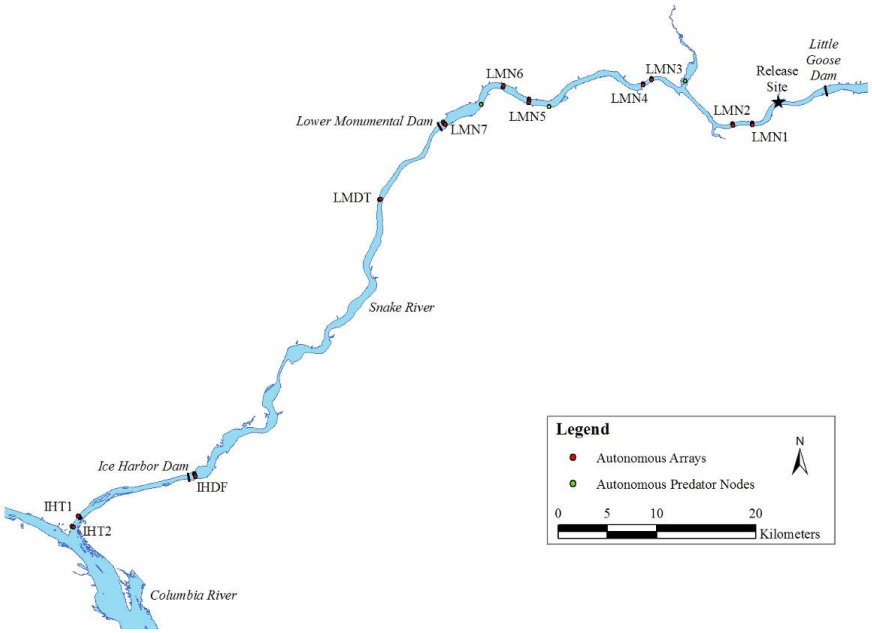

Figure 2.6 Autonomous Node Deployment Locations on the Lower Snake River Between Little Goose Dam and the Columbia River Confluence During Spring and Summer 2006

Table 2.3. Name, Location, and Deployment and Recovery Dates of Acoustic Telemetry Arrays in the Snake and Columbia River Systems Used To Detect Acoustic-Tagged Juvenile Chinook Salmon Released in 2006

Array Code	Snake Rkm	Columbia Rkm	Physical Description	Date In	Date Out
LMN1	104.7		LMN Res, Line 1, ds of TX Rapids	13-Jun	25-Sep
LMN2	102.7		LMN Res, Line 2, us of Tucannon R	13-Jun	25-Sep
LMN3	92.3		LMN Res, Line 3, ds of Palouse R	12-Jun	25-Sep
LMN4	91.2		LMN Res, Line 4, mid LMN Pool	12-Jun	25-Sep
LMN5	78.2		LMN Res, Line 5, ds of Ayers	12-Jun	25-Sep
LMN6	75.1		LMN Res, Line 6, ds of Skookum Cyn	12-Jun	25-Sep
LMN7	67.5		LMN Res, Line 7, BRZ (~0.5 km from dam)	26-Jul	25-Sep
LMDT	56.8		LMN tailrace, ds of Windust	12-Apr	26-Sep
IHDF	16.4		IHR forebay BRZ (~0.5 km from dam)	11-Apr	26-Sep
IHT1	3.5		IHR tailrace primary, at Hwy 12 Br	10-Apr	26-Sep
IHT2	2.3		IHR tailrace secondary, at RR Br	10-Apr	26-Sep
JDAE		339.2	JDA Egress, us of Maryhill State Park	12-May	5-Jun
JDA1		325.6	JDA tailrace primary, us of Celilo	10-May	20-Sep
JDA2		324.2	JDA tailrace secondary, Celilo	10-May	20-Sep
JDA3		312.4	JDA tailrace tertiary, ds of Horsethief Lake	10-May	20-Sep
TDA1		275.6	TDA tailrace primary, Bingen Marina	12-May	16-Sep
TDA2		238.4	TDA tailrace secondary, ds of Bridge of the Gods	8-May	6-Sep
TDA3		236.4	TDA tailrace tertiary, ds of TDA2, us of TDA4	8-May	6-Sep
TDA4		235.2	TDA tailrace quaternary, us of BON spillway	1-Jun	7-Aug
BONC		235.1	BON spillway cabled array	3-Jul	7-Aug
BON1		208.8	BON tailrace primary, Rooster Rock State Park	2-May	21-Sep
BON2		204	BON tailrace secondary, Reed Island	2-May	21-Sep
BON3		193.8	BON tailrace tertiary, Lady Island	2-May	21-Sep
EST1		8.3	Estuary primary, E. Sand Island	17-Apr	27-Sep
EST2		2.8	Estuary secondary, between N and S Jetties	17-Apr	27-Sep

2.4 Mobile Tracking Surveys

An omnidirectional hydrophone was placed on the end of a 2-m-long PVC pipe and secured vertically against the side of the boat; the hydrophone tip was positioned approximately 1 m below the surface of the water. The pipe with the hydrophone was raised when the boat was traveling at speed. A portable node (Model N202, Sonic Concepts) was connected to the hydrophone and a laptop computer to record detections. A Global Positioning System (GPS) unit (Garmin eTrex) was connected to the laptop to obtain locations throughout the tracking. Node graphical user interface (GUI) software (Sonic Concepts v1.2.1) was used to collect and store acoustic transmitter detections. The program was set to record detections of tag codes from only fish released for this project. An audible sound alerted the operator when a tag code from the list was detected. The software recorded the tag code, receive signal strength indicator, date, time, and the latitude and longitude from the GPS at the point of each detection. In addition, a stopwatch feature counted, to one-tenth of a second, the time interval between successive detections so the operator could assess the time frame between individual detections and help determine whether successive hits from a specific code were received on multiples of 10 seconds (the ping rate of the tags). The start and stop times for when the hydrophone was in the water and listening for tag codes were recorded on data sheets.

If a tag code was detected at least three times within 3 minutes, it qualified as a positive detection of that fish in that area. When this occurred, the omnidirectional hydrophone was unplugged and a directional hydrophone plugged into its place. The directional hydrophone detected tag signals within a 30-degree cone stretching outward horizontally for about 150 m. Because of this, the directional hydrophone was tilted slightly downward to aim the detection cone down from the surface of the water. The device was rotated in approximately 30-degree increments to listen in a full 360-degree arc around the boat. The bearing at which the hydrophone was facing when a tag was detected was recorded for that specific record.

During preliminary mobile tracking surveys and several initial systematic surveys, the boat that was used had a two-stroke outboard motor. This was found to cause electromagnetic interference with the hydrophone and therefore had to be turned off when the hydrophone was listening for tags. An electric trolling motor was used on several occasions to remedy the interference problem. For most of the surveys, however, an inboard jet boat was used, which did not cause interference with the hydrophone when it was operating.

2.5 Autonomous Node Data Processing Methods

Data collected by the autonomous nodes were recorded as text files on CompactFlash cards. These text files were transferred to a laptop computer when the nodes were serviced during the season or when recovered at the end of the season. Physical data were written to file every 15 seconds. Physical data recorded included date, time, pressure, water temperature, tilt, and battery voltage. Detections of transmitters were recorded in real time as they were received. They were written to media with TagID (individual code of transmitter), time stamp, receive signal strength indicator, and RxThreshold (a calculated measure of noise). Data files from all nodes were coded with the node location and stored in a database developed specifically for storing and processing acoustic telemetry data (TagViz). To filter out false positives (detections of TagIDs that did not meet criteria to be considered a valid detection), a post-processing program was implemented. This program was composed of a sequence of steps that included comparing each detection to a list of tags that were released (only tags that were released were

kept), then comparing the detection date to the release date (only tags detected after they were released were kept). Finally, a minimum of four detections in 120 seconds was required; the time spacing between detections was analyzed and only detection events with the correct time spacing were kept in the valid detection file.

2.6 Survival/Passage Analyses

The probability of survival was estimated based on detection histories using the CJS single release model (Cormack 1964; Jolly 1965; Seber 1965) as implemented in SURPH (Smith 1994). Detection histories were created for each individual fish by assigning a 1 if detected or a 0 if not detected at each possible Snake and Columbia River acoustic telemetry transect (Table 2.3). PIT tag records were used to determine whether any fish were placed in barges, and if so, they were removed them from the survival analyses. An assumption of the model states that all tagged fish have similar probabilities of survival to, and detection at, a detection location. This assumption may have been violated, especially by the later release groups, because not all fish moved downstream past all detection arrays during the study period. It may be more appropriate to think of these as estimates of the joint probability of survival and passage.

Survival estimates were calculated for all release groups to various points within Lower Monumental Reservoir and points downstream. Detection histories of daily release groups were partitioned into 12 periods (reach or project) to obtain survival estimates for each period. Additionally, survival from release to selected locations was estimated using the product(s) of the pertinent periods. Standard Errors for the individual period estimates as well as the overall Release-to-Estuary estimate were obtained from the full CJS model output. Standard Errors for the product-estimates to selected locations were obtained from the results of fitting a reduced model (i.e., subset of the full model) that pooled all detections below the location of interest. Due to observed strong temporal trends in survival/migration, the daily release groups, and survival estimates, were pooled into three time periods. Confidence intervals for pooled survival estimates were of the form

$$\left(x - z_{0.05} \times SE,\ x + z_{0.05} \times SE\right)$$

where x was the pooled estimate, $z_{0.05}$ was the z-value for $\alpha = 0.05$ (i.e., 1.96), and SE was the standard error of the pooled estimate.

Generally, the single-release survival estimation procedure is accompanied by a suite of assumption tests (Burnham et al. 1987), assessing the homogeneity of detection probabilities for tagged fish with varying previous detection histories. We did not conduct these tests for two reasons. First, the estimated detection probabilities are very high (at or near 100%) at most detection locations (particularly more upstream) resulting in very low or empty cell counts in most of the pertinent contingency tables used for the tests. This renders these tests incalculable or, at best, minimally informative. Second, these tests were designed in a mark-recapture scenario where detected fish experience different conditions than undetected fish (e.g., for PIT-tagged fish that must be guided into a bypass system and returned to the river via pipes). For telemetry studies, fish are not "captured" in any physical way and nearly the entire river is covered by the detection arrays, so there is no expectation that previous detection history will affect subsequent detection probabilities.

2.7 Movement, Behavior, and Fate Analyses

Median travel times (days) of subyearling Chinook salmon from release to subsequent downstream arrays in Lower Monumental Reservoir and tailrace were calculated for each release group and for fish that left or stayed in the reservoir. The first detection of an individual fish on an array was used for travel time calculations to determine when a fish arrived at an array. Median travel rates (kilometers per hour) were calculated for each release group from release to LMN 7. Residence times (length of time detected at an array) were also calculated at LMN 7.

Autonomous array detections of fish that did not pass Lower Monumental Dam were analyzed for their behavior patterns in an attempt to understand the fate of these fish. Because we did not want to include fish that were potentially in a predator's gut, a cutoff of more than 2 days between the first and last detection on any array was used (estimated gut evacuation time of a subyearling Chinook salmon in a smallmouth bass was about 19 hr at 20°C). Detections of each tag meeting these criteria ($N = 81$) were summarized by event (if a tag was not heard for more than 2 minutes on a single array, any subsequent detections were counted as being in a new event), and the start and end times for each event were assigned a number (e.g., start = 1, end = 0). These data were plotted, creating a graph that looks like a bar code for each fish, where the different colors represent different arrays. Detection patterns that had large (e.g., a week) gaps on a single node were thought to be indicative of fish that were alive. A sample of 10 microacoustic transmitters was placed in the water on 25 October and an autonomous node was deployed in that area for 2 weeks to collect detection information on tags known to represent dead or stationary fish resting on/in the fine sediment on the bottom of the reservoir in 20 to 30 m of water.

2.8 Meteorological Stations: Deployment and Data Acquisition

Four micrometeorological stations were set up at sites along Lower Monumental Dam (for locations, see Table 2.4). All stations included a 3-m metal tripod, Model CR10X data logger (CSI, Logan, Utah), cup and vane anemometer (CSI Model CS-800), air temperature and relative humidity (RH) sensor. Original factory specifications for accuracy were 0.1 m/s, or 1.5%, for wind speed and ± 3 degrees for wind direction. Vanes were checked in the field at time of installation for manual rotation to north and south positions, yielding results of 0 and 180 degrees, respectively. Vane alignment was matched to magnetic north. Cup anemometers were checked to ensure that all cups were present and the cup assembly rotated freely with no appreciable bearing drag. Air temperature and relative humidity (RH) were measured with a CSI Model CS-500 sensor. The RH sensor accuracy was ± 3% below 90% and ±5% above. Accuracy of the air temperature sensor varied with temperature; however, it was within 1.0°C over the air temperature range measured during the study. A predeployment test of the temperature and RH sensors used at meteorological sites 1 and 2 showed excellent agreement ($R^2 > 0.99$). Linear equations fit to these data indicate that the sensors differed in an offset of 0.2 and 0.9 units for air temperature (ºC) and RH (%), respectively, less difference than their manufacturer-stated accuracy. The anemometer and wind direction sensors were located 3 m above the ground, and the air temperature and RH sensors were installed at 2.5 m. A fiberglass instrument box attached to the tripod housed the data logger and 12-V battery. A solar panel was positioned flat on the ground to provide the small amount of power needed.

Data were collected at all four sites between 16 June and 24 October 2006. The data logger sampled at 10-second intervals, storing 15-minute and hourly averages for retrieval at approximately monthly intervals. The air and RH data were collected as simple averages, and the wind speed and direction data were generated by CSI wind vector output instruction contained in the data logger instruction set.

Siting criteria included locating near the shoreline, limited accessibility to minimize disturbance, uniform fetch with respect to the nearby surrounding landform, spatially dispersed between the dams, and for the sites to be in river sections with different prevailing river course direction. Review of satellite images and digital elevation model (DEM) results suggested general areas for sites, which were confirmed by onsite evaluation at the time of station installation.

The typical vegetation cover at each site can be seen in the site pictures in Figure 2.7. The early season vegetation is predominantly cheatgrass with sparse rabbitbrush at Site 3 and approximately 0.7-m-tall weedy forbs by the end of the season at Sites 1 and 3.

The meteorological station air temperature and RH data agreed quite well, with the lowest correlation found between the two sites with the greatest geographical separation (see Table 2.6). As expected, wind speed data show much less correlation, with R^2 values ranging between 0.67 and 0.47.

Figure 2.7. The Four Meteorological Sites

Table 2.4. Coordinates of the Four Meteorological Stations

Meteorological Site Name	Latitude	Longitude
Met 1	46.569154979	−118.097645430
Met 2	46.604469798	−118.319298925
Met 3	46.588253492	−118.426532816
Met 4	46.565486420	−118.524027522

Table 2.5. Air Temperature and Relative Humidity Correlations Between the Meteorological Sites

	Linear Relationship	R^2
Air Temperature	Met 2 = 0.971 * Met 1 + 0.9917	0.97
	Met 3 = 0.9517 * Met 1 + 1.9071	0.98
	Met 4 = 0.9132 * Met 1 + 2.6086	0.93
Relative Humidity	Met 2 = 0.9363 * Met 1 + 6.6549	0.93
	Met 3 = 0.9189 * Met 1 + 4.255	0.94
	Met 4 = 0.9196 * Met 1 + 5.0174	0.86

2.9 Water Temperature Measurements

Two types of instruments were used during the study to measure water temperature: self-contained temperature loggers and a portable conductivity-temperature-depth (CTD) probe. The Hydrolab-Hach MiniSonde 4a CTD probe had an accuracy of ±0.10°C within the temperature range of −5°C to 50°C. The pressure sensor on the probe had a maximum depth range of 100 m water depth and was accurate to ±0.3 m. The specific conductance sensor was accurate to within ±1% of reading ± 0.001 mS/cm. Calibration of the specific conductance sensor was checked and/or recalibrated each day we were in the field.

Most of the temperature loggers used in the study were Onset Computer Corporation HOBO Water Temp Pro v2 loggers. These loggers have a stated accuracy of ±0.2°C within the temperature range −20° to 70°C. The accuracy of all loggers was confirmed to be within the manufacture's specification using a constant temperature water bath both before and after deployment. High-accuracy SeaBird SBE39 temperature and pressure loggers were also used in the study. SBE39 temperature loggers were calibrated by the manufacturer to be accurate within ±0.002°C between −5°C to 35°C. These loggers were equipped with pressure sensors accurate to within 0.1 m.

At each site, loggers were suspended vertically in the water column. The deployment method shown in Figure 2.8 was used at all sites except at the mouth of the Tucannon River, where a single-weight string was used. The two-weight system was necessitated due to the shipping barge traffic, which have a maximum draft of 4.3 m (14 ft). The thalweg weight, with a subsurface buoy attached, was deployed at the deepest point in the cross-section. SBE39 loggers were mounted near the weight and the subsurface buoy. Throughout the deployment, the SBE39 logger on the subsurface buoy monitored vertical movement of the buoy, which can occur if drag forces on the buoy/logger line are large enough to counteract the positively buoyant force of the buoy. Negligible vertical movement occurred throughout the study, and at no time were subsurface buoys submerged by drag forces by more than 1 m. A connecting line was attached from the thalweg weight to a second weight positioned out of the navigation channel. This weight was attached also to a line that went up to a surface buoy. It was confirmed by multiple CTD probe transects across each open-water site that lateral temperature differences between the subsurface and surface buoy were negligible. To simplify reporting, data collected by the surface temperature loggers have been reported at the horizontal location of subsurface buoy.

Figure 2.9 summarizes the location of each temperature measurement site. The total number and type of logger (either Onset or SBE39) used at each site also are presented. Coordinate locations for the sites and a graphical summary of the measured temperatures can be found in Appendix A.

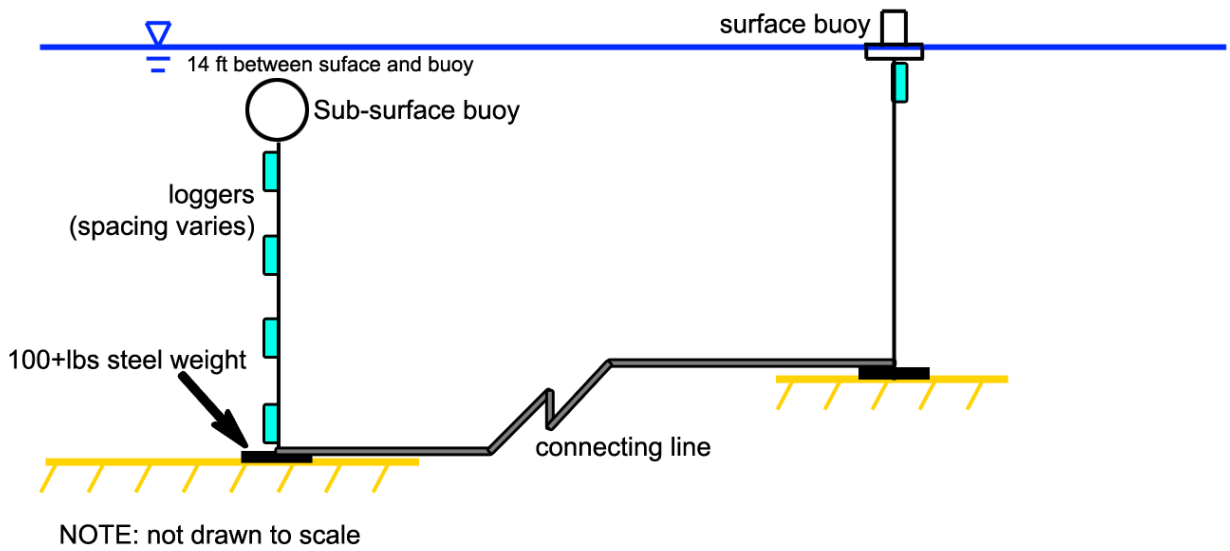

Figure 2.8. Open-Water Temperature Logger Deployment

2.10 Water Velocity Measurements

Vertical profiles of three-dimensional water velocity vectors (i.e., both magnitude and direction) were collected using both bottom-mounted (i.e., fixed position) and boat-mounted mobile acoustic Doppler current profilers (ADCPs). Before the ADCPs were used, internal system diagnostic tests were performed to confirm the unit was functioning properly. These tests included checks of the CPU, internal memory, and the receiving and transmitting boards and sensors. Additionally, the flux-gate compass was calibrated for any local magnetic fields, including any influence from the internal battery pack when the ADCP was bottom-mounted. We corrected all ADCP data to true north by applying a local magnetic declination factor to the compass output. The magnetic variation used for this study was 17.5 degrees east and was computed using the nautical chart for the reservoir (NOAA 1998).

A 1200-kHz RD Instruments Workhorse ADCP collected all mobile ADCP measurements. The ADCP was programmed to collect information at depth increments of 1 m throughout the water column. Each velocity measurement collected by the ADCP was composed of several individual acoustic pings, which were combined to form an ensemble average. By averaging the pings together over time, the ensemble error standard deviation due to random Doppler error can be decreased. Twenty-two pings collected over 5 seconds were used to produce an ensemble velocity measurement with an associated Doppler uncertainty of 1.5 cm/s. Temperature profile measurements were obtained after each ADCP transect was completed. These measurements were collected at the midpoint of the cross section. At river bends and when the water column was stratified, two or more temperature profiles were collected to document tilt of the isotherms.

Between 15 June and 15 September, 113 ADCP transects were collected. Longitudinal transects were collected in regions of interest such as at the forebay boat-restricted zone (BRZ) and near the plunge line. Figure 2.10 displays a summary indicating location of all transects collected during the study. Because numerous transects over time were collected at the identical locations of interest, many of the transect lines in overlap.

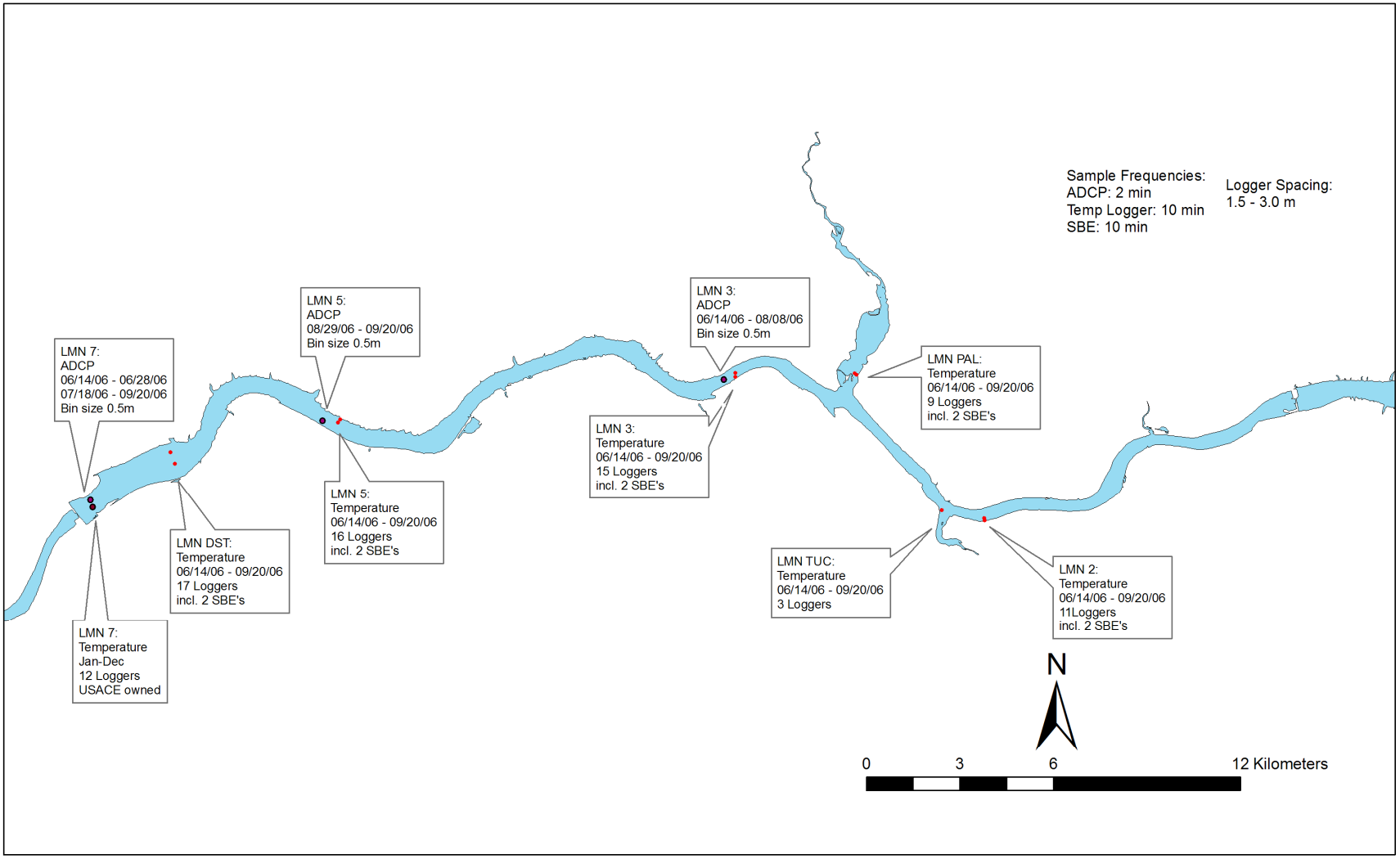

Figure 2.9. Bottom-Mounted ADCP Measurement Sites and Temperature String Locations

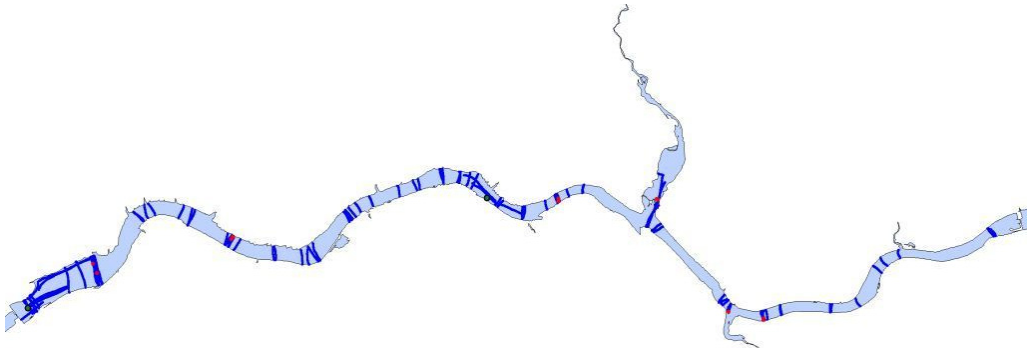

Figure 2.10. Mobile ADCP Measurements in Lower Monumental Reservoir

Figure 2.11 displays processed mobile ADCP data collected by transecting the river downstream of LMN 5. The middle portion of the figure displays color contours of water velocity magnitude, or speed. The color scale threshold maximum has been set to 0.3 m/s and is consistent throughout the report, so speeds for this transect, which was collected during a higher-than-average period, that are greater than 0.3 m/s are also colored red. Generally, the zone of greatest magnitude occurred in the center portion of the river, and in the upper half of the water column. Water directions were homogenous along the cross-section, and are oriented downstream. Water directional angle is relative to true north.

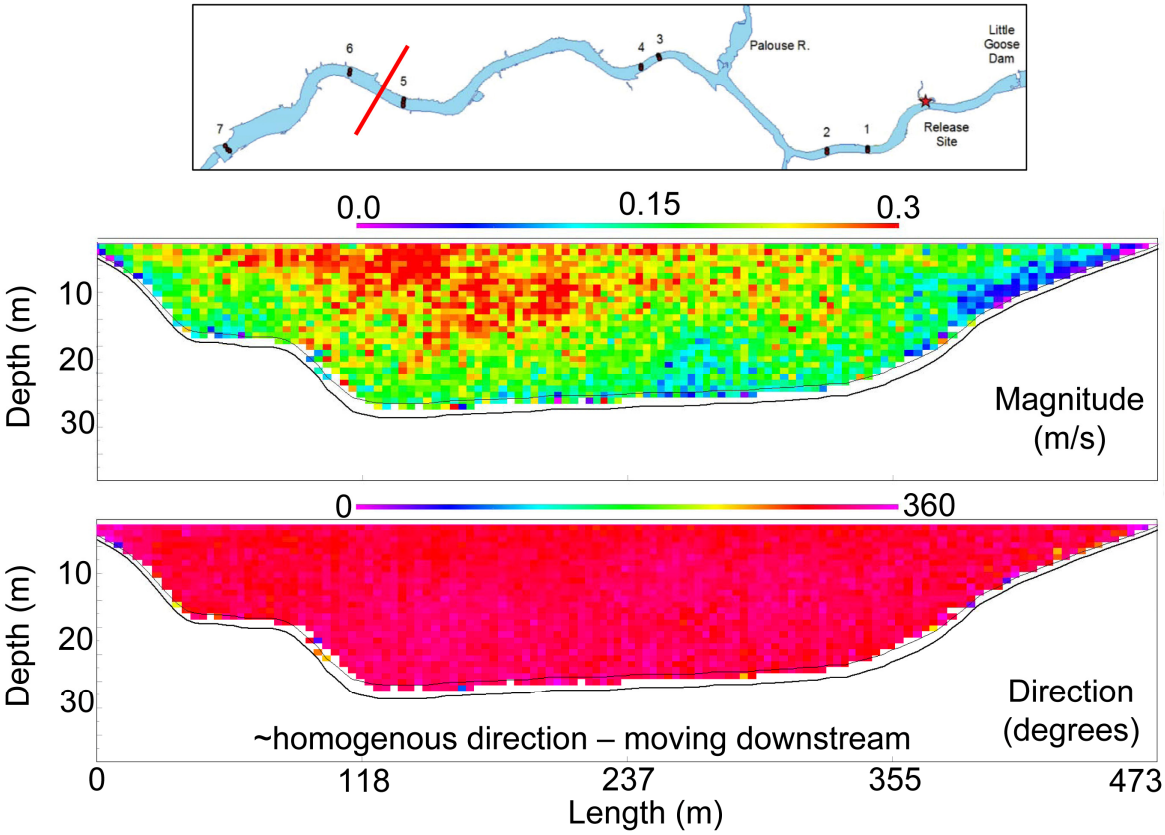

Figure 2.11. Cross-Sectional Mobile ADCP Measurement Near Site LMN 5 on 23 June at 5:04 pm. River discharge was approximately 59.4 kcfs.

Two bottom-mounted 600-kHz RD Instruments Workhorse ADCPs were deployed at three locations in the reservoir: near LMN 3, near LMN 5, and at LMN 7, which is at the upstream edge of the forebay BRZ (see Figure 2.12). One ADCP was deployed at LMN 7 during the entire study, while the second ADCP was deployed at either LMN 3 or LMN 5. The ADCPs were attached to a noncorrosive fiberglass mount via dual-axis gimbals that could compensate for small bathymetric irregularities (see Figure 2.13). The ADCP bottom-mount deployment was similar to the temperature logger string deployment, and the mount was retrieved via a surface buoy connected to a weight placed a short distance away and outside the beam swath of the ADCP. The bottom-mounted ADCPs collected an ensemble-averaged profile of three-dimensional water velocity every 2 minutes with a 0.5-m vertical resolution. Each velocity ensemble consisted of 40 pings with a resulting Doppler uncertainty of 1.26 cm/s.

Both ADCP units were also deployed near each other at LMN 7 on two occasions to measure lateral velocity differences at the upstream end of the BRZ. These measurements occurred in June and August, each for approximately 2 days. The locations of these deployments are shown in .

2.11 Numerical Modeling of the Reservoir

For this project, the two-dimensional hydrodynamic and water quality model CE-QUAL-W2 was selected. This particular model was selected for this study based on the outcome of the multi-agency group organized under Reasonable and Prudent Alternative 143 (RPA143) of the 2000 Biological Opinion (FCRPS 2000).

CE-QUAL-W2 assumes complete lateral homogeneity and is best suited for water bodies with negligible lateral gradients. The model solves the conservative form of the Navier-Stokes equations, and the hydrostatic pressure assumption has been applied to simplify the vertical momentum equation. Turbulence terms have been approximated using an eddy viscosity approach, although several methods are available for use. Complete details on the numerical scheme and water quality options can be found in the model documentation (Cole and Wells 2002; Wells 2005).

2.11.1 Numerical Representation of the River Bathymetry

A numerical grid was developed to approximate the bathymetry of Lower Monumental Reservoir. A large set of bathymetric data was collected from previous Battelle modeling of the reservoirs (Richmond et al. 2000), and these data were used to construct the CE-QUAL-W2 (W2) model geometry file. The methods used to construct the grid, including the incorporation of topographic shading coefficients, are described in Cook et al. (2006).

2.11.2 Boundary Conditions

Project operations data at Little Goose and Lower Monumental dams were used to create the time series inflow and outflow input files for the numerical model of Lower Monumental Reservoir. These data were obtained via personal communication with T. O. Wik (USACE, Walla Walla District) in 2007.

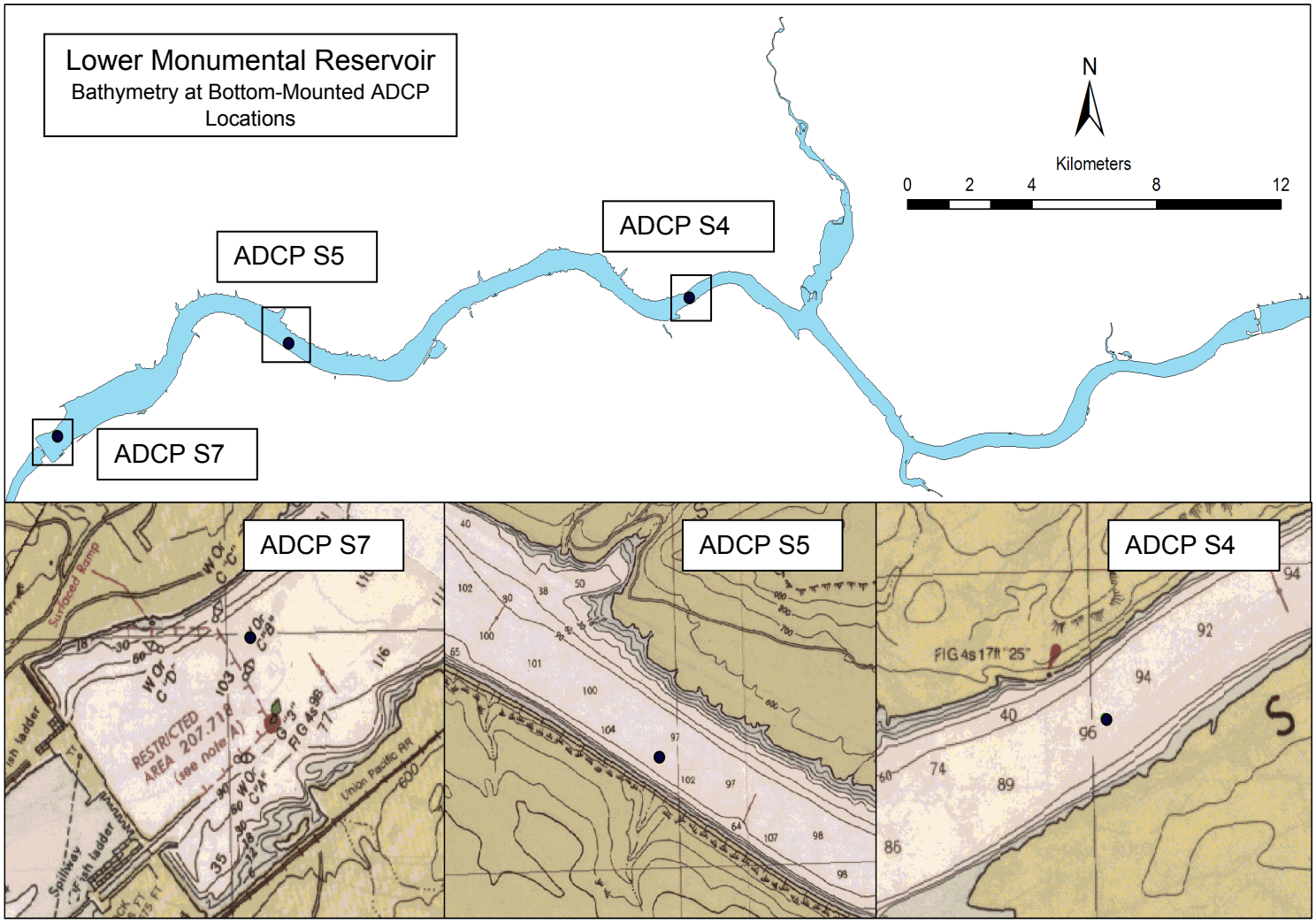

Figure 2.12. Bathymetry at Bottom-Mounted ADCP Measurements Sites

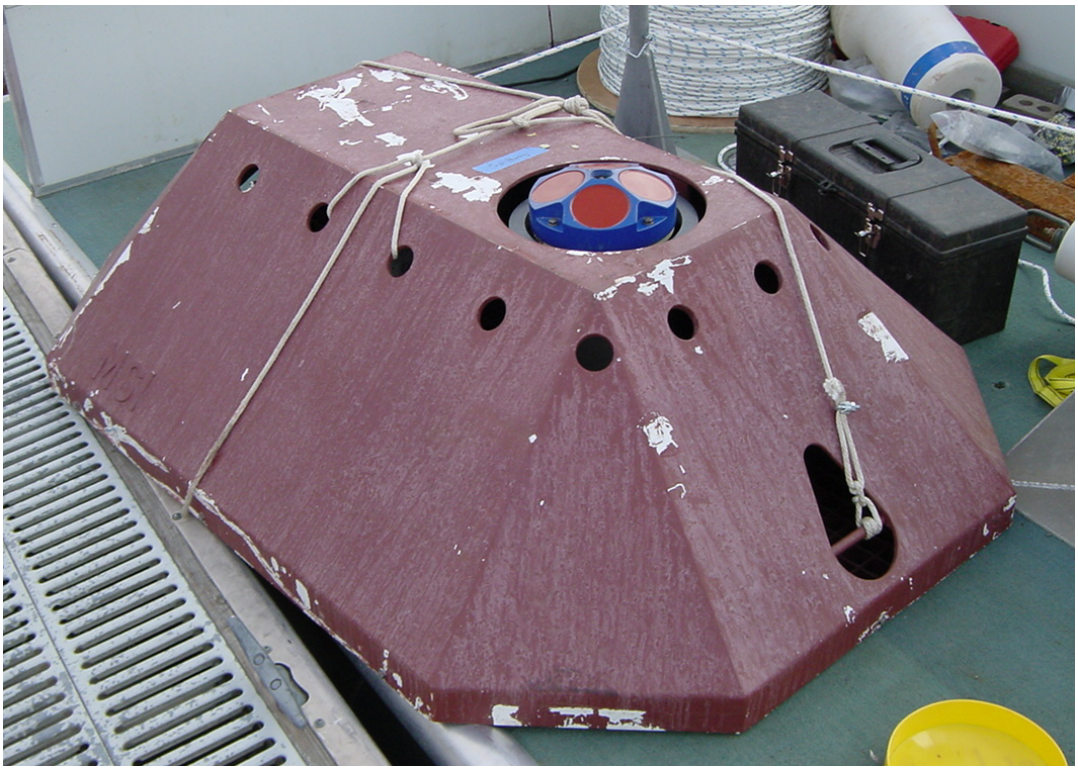

Figure 2.13. Acoustic Doppler Current Profiler Installed in the Bottom Mount

Temperature data collected in the tailrace of Little Goose Dam were obtained from USACE (2006) at a single depth between 4 and 7 m below the water surface. These data were used as the upstream temperature boundary conditions for the LMN reservoir model. It was assumed that flow below Little Goose Dam was sufficiently turbulent to remove any gradients in water temperature in the tailrace. Mobile ADCP and CTD data collected near the monitor support this assumption.

2.11.3 Model Development

2.11.3.1 Water Balance

Differences in mass conservation between reported upstream inflows and downstream outflows caused water surface elevations in the reservoir to deviate from observed values. This imbalance is caused by either slight inaccuracies in discharge measurements at the dams or groundwater accretions/depletions. To correct for these mass flow imbalances, the software "waterbalance" (Wells 2005) was used to adjust the inflow or outflow discharges. Water balance flows were specified at daily intervals and were small compared to the total river discharge. The average discharge adjustment was ±4.3 m^3/s (for comparison, average river discharge in August was >700 m^3/s).

Figure 2.15 shows the time series of computed versus observed water surface elevations at the Lower Monumental Dam forebay after the water balance adjustment was performed. Differences between the two time series can perhaps be more clearly determined using a Bland-Altman plot (Bland and Altman 1986). This type of plot displays the differences between the two data sets against their mean value. For

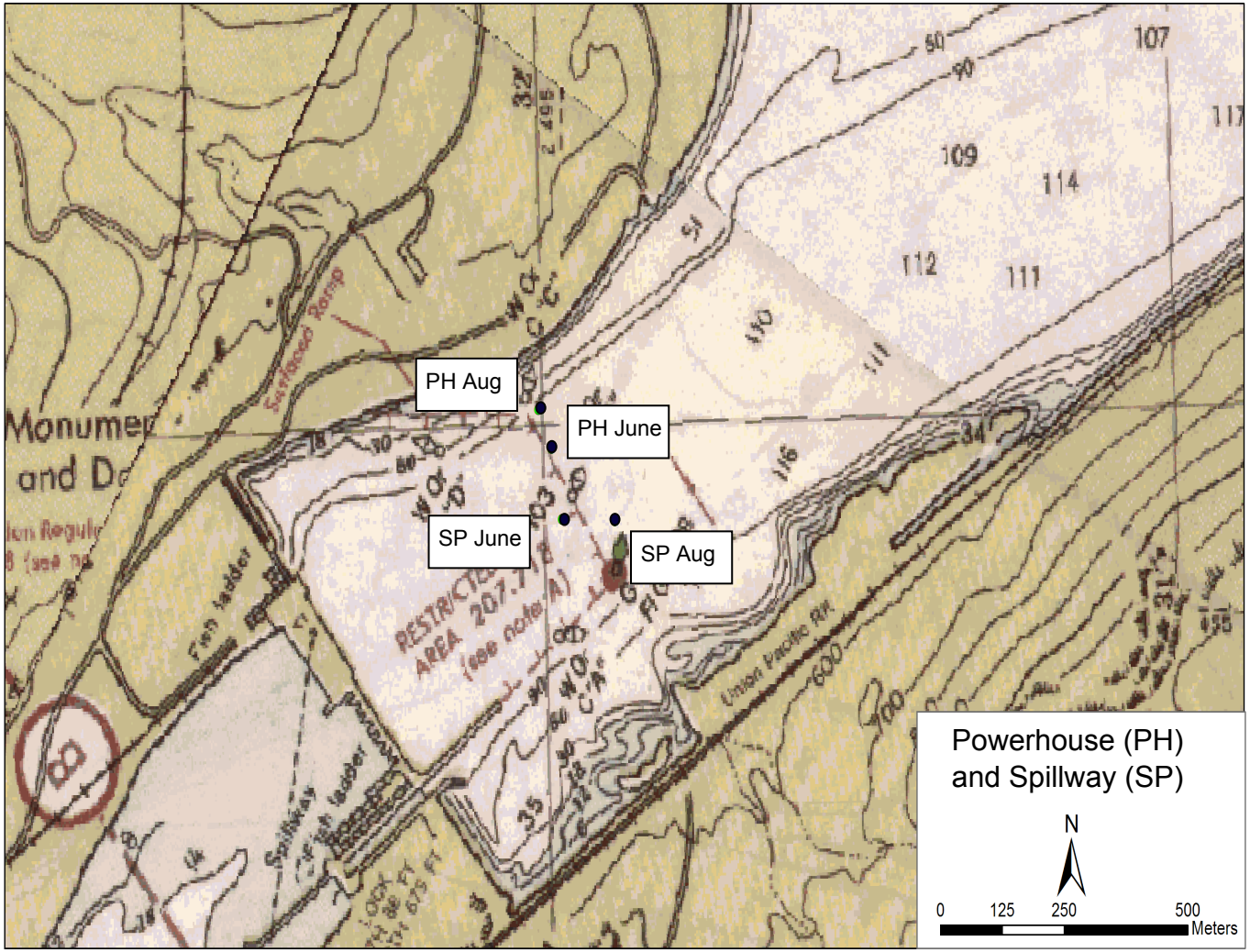

Figure 2.14. Bottom-Mounted ADCP at the LMN Forebay BRZ

the water surface elevation data set, Figure 2.16 was created by subtracting observed from simulated values. The mean difference over time was 0.03 m, and the so-called Bland-Altman limits of agreement (mean difference ± 2 times the standard deviation of the differences) were −0.09 and 0.15 m. Based on these results, we find that close agreement was achieved between the observed and simulated water surface elevations.

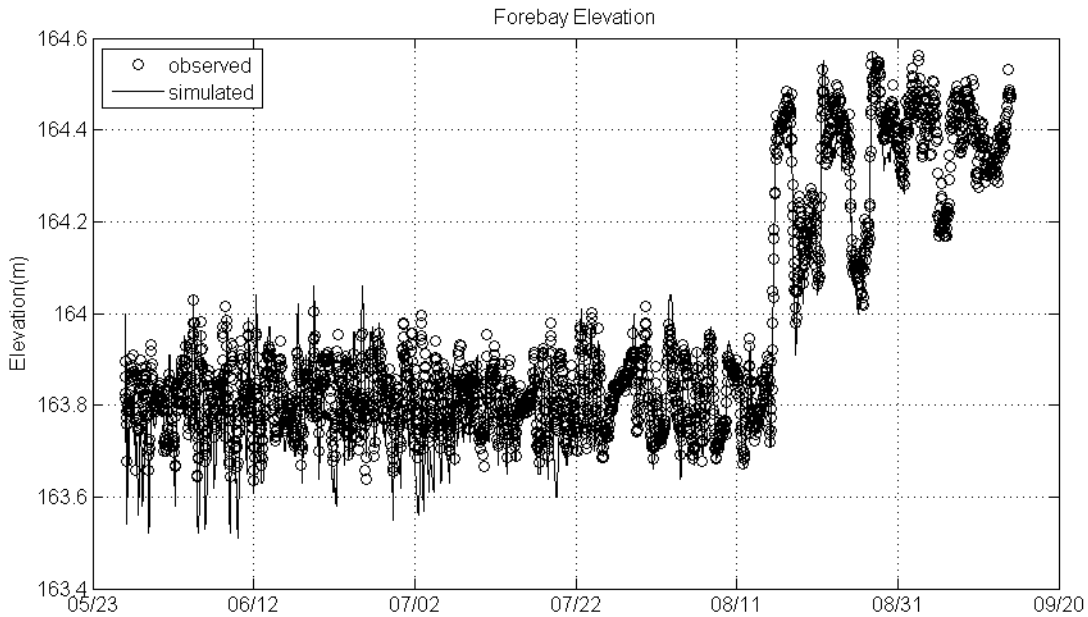

Figure 2.15. Observed and Simulated Water Surface Elevations During Part of 2006 at the Lower Monumental Dam Forebay After the Water Balance Adjustment Was Applied

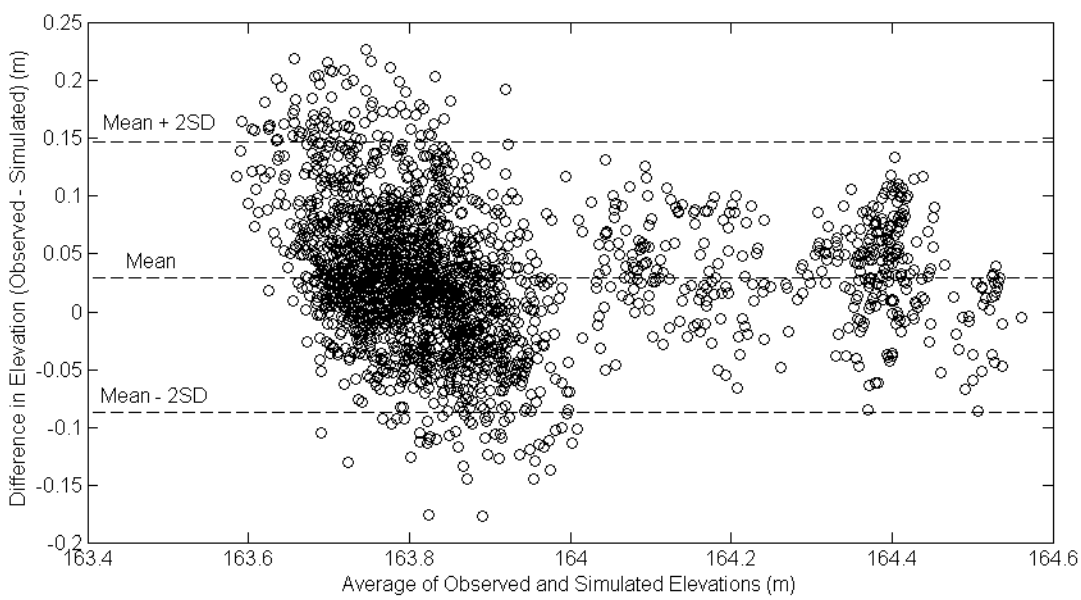

Figure 2.16. Observed Versus Simulated Differences in Water Surface Elevations

2.11.4 Sensitivity Analysis

A sensitivity analysis was conducted by changing various parameters in a systematic fashion to determine which parameters had the greatest overall impact on solution results. This included, but was not limited to, the following model parameters in various combinations:

Vertical and longitudinal eddy viscosity:

The vertical turbulence algorithm used to generate the final simulations results was the W2N method (W2 with mixing length of Nikuradse). Both the longitudinal and vertical eddy viscosity coefficients were adjusted.

Light extinction coefficient

The fraction of incident solar radiation absorbed at the water surface, BETA, was varied between 0.25 and 0.45.

Bottom roughness

A change to the model's bottom friction parameter impacted water levels, flow velocities and temperature.

Heat exchange and evaporation

Several parameters affect surface heat exchange and evaporation in the model. The variables AFW, BFW and CFW, which are equation coefficients for converting wind speed into surface shear stress, were systematically adjusted. These coefficients, which impact latent heat exchange at the water surface, had large impacts on short-term water temperature variations.

Segment length and height:

The calibrated model used segments (i.e., computational cell) lengths of 804 m (half-mile) and heights of 1 m. Sensitivity tests compared model results for month-long periods with segments that were 400 m and 200 m long. Cell heights were reduced to 0.5 m for both of the reduced-length grids. Simulation results produced using all three grids were approximately equal.

2.12 Linking Fish Passage and Hydraulic Condition

Data collected at the five water temperature sites shown in Figure 2.9 were averaged over each hour through the study season. These data were then linked to study fish tag detections at autonomous nodes (Figure 2.6) as shown in Table 2.6.

Study fish were classified based on their detection downstream of Lower Monumental Dam; they were classified as migrants if they were detected downstream of the dam or non-migrants if they were not. Additionally, study fish were summarized by the location of the array node farthest downstream in the reservoir and the first time they were detected at the node. This location and time were used to link fish to the hydraulic conditions that existed at the time and location at which they were last known to be in the reservoir. The hydraulic conditions were summarized by the Froude (Fr) index, which provides an estimate of the proportion of time conditions were right for thermal stratification and, possibly, upstream-directed epilimnetic water movements. The first time of detection at the farthest downstream node was used on the assumption that hydraulic conditions experienced by fish at the farthest downstream reservoir location best represent the conditions that triggered the behavioral response to continue or to cease

migration. Locations of farthest downstream detection for 1,779 study fish used in further analysis are summarized in Table 2.7 by array site and release group.

A mixed effects logistic regression model was fit taking release groups as a random effect with fork length and the Fr index as fixed effects. Fork length is another biological factor known to affect migratory behavior in juvenile salmon. The Fr index summarizes the thermal layering conditions in the vicinity of an array over a 24-hr period. The Fr index is a measure of the persistence of thermal stratification conditions increasing from 0 to 1 on a continuous scale. This modeling approach directly tests the influence of factors calculated from purely hydraulic metrics (e.g., Fr index) on fish behavior, after controlling for effects due to purely biological factors (e.g., release groups and fork length) and accounts for the strong correlations that exist between all predictor variables.

Table 2.6. Acoustic Array Sites Associated with Water Temperature Sites

AT Array	Temperature Site
LMN 1	LMN 2
LMN 2	LMN 2
LMN 3	LMN 3
LMN 4	LMN 5
LMN 5	LMN 5
LMN 6	LMN DST
LMN 7	LMN 7
LMDT	-

Table 2.7. Farthest Downstream Array Site of Detection by Release Group

Array Site	Release Group										Totals
	1	2	3	4	5	6	7	8	9	10	
1	1	2	0	0	1	0	0	2	0	0	0
2	1	4	1	2	0	4	2	2	5	3	24
3	0	0	0	1	0	2	2	0	5	1	11
4	1	4	10	3	2	12	11	16	85	38	182
5	1	0	4	2	2	1	1	8	25	27	71
6	1	8	4	1	4	2	10	39	39	53	161
7	13	19	20	21	18	30	34	40	11	21	227
Below LMN Dam	174	158	141	161	160	120	117	47	5	14	1097
Totals	192	195	180	191	187	171	177	154	175	157	1779

3.0 Results

3.1 Survival/Passage

3.1.1 Detection Probabilities

Detection probabilities (the probability of a tagged fish being detected) of the arrays within the Lower Monumental Reservoir were generally high (Figure 3.1). On six of the seven arrays, detection probabilities were greater than 99% during the entire season. LMN 2 had a lower detection probability (mean of 82%) for the season due to a non-functioning node on this two-node array for part of the season.

3.1.2 Survival/Passage Estimates

Run-of-the-river subyearling Chinook salmon tagged and released downstream of Little Goose Dam survived at relatively high rates from the release point (rkm 108.5) to the first array in the reservoir (LMN 1; rkm 104.7) during the entire study period (Figure 3.2; Table 3.1). The largest reduction in joint probability of survival and passage through the reservoir occurred after 7 July in the area downstream of LMN 3 (mid-reservoir).

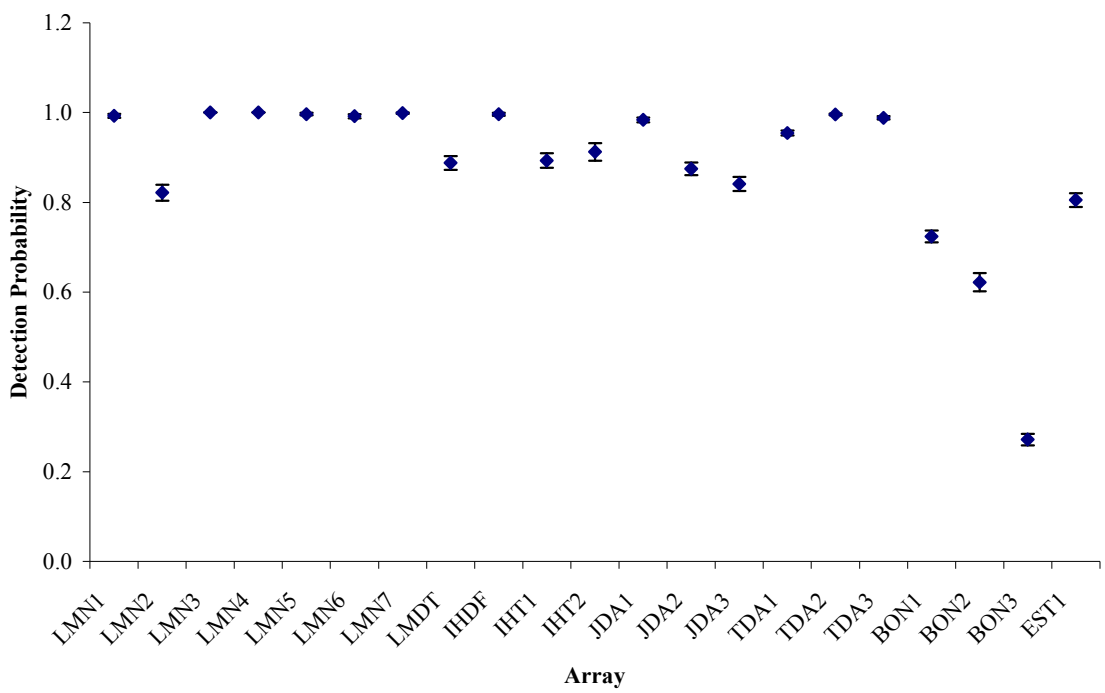

Figure 3.1. Detection Probabilities of Acoustic Arrays from Little Goose Dam Tailrace (LMN 1) to the Lower Columbia River Estuary (EST 1) in 2006 (see Figure 2.6 for map)

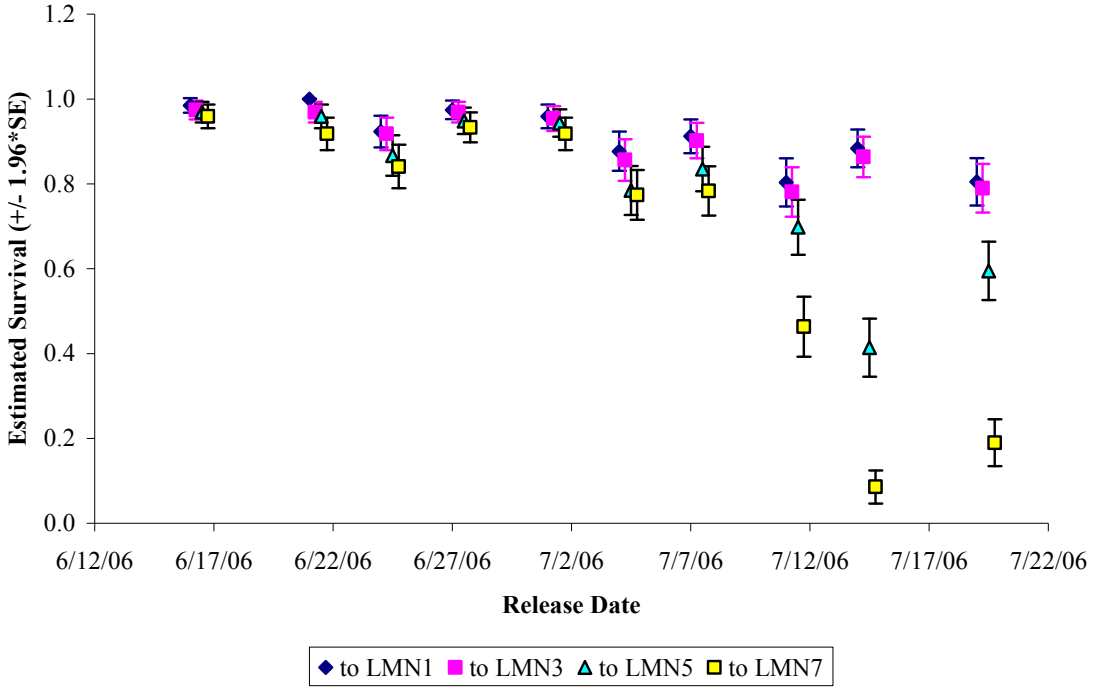

Figure 3.2. Estimated Joint Probability of Surviving and Passage (±1.96*SE) of Microacoustic-Tagged Subyearling Chinook Salmon Released Between 16 June and 19 July 2006 Downstream of Little Goose Dam on the Snake River (rkm 630.2) to Arrays in Lower Monumental Reservoir. Arrays, from upstream to downstream, are LMN 1 (rkm 104.7), LMN 3 (rkm 92.3), LMN 5 (rkm 78.2), and LMN 7 (rkm 67.5, 0.5 km from LMN Dam).

Tagged fish generally survived through the LMN Reservoir through the first week of July, when the joint probability of survival and passage decreased dramatically in the lower half of the reservoir. Survival/passage from release to the BRZ (LMN 7) dropped below 50% between 7 July and 11 July (Table 3.1). Reach survival also declined as the summer progressed, especially in the lower portions of LMN Reservoir (Table 3.2). Due to the different survival/passage results through the season, we grouped the first four release groups (16 to 27 June; considered 'actively migrating'), the middle three groups (1 to 7 July; considered 'transition period'), and the final three groups (11 to 19 July; considered 'non-migrant') (Table 3.3). The proportion of fish estimated to have survived and passed from the release site to the LMN tailrace (i.e., the proportion of fish that 'left' LMN Reservoir) declined from more than 80% prior to the end of June to less than 70% in early July and then finally to about 11% after 11 July (Table 3.3). Survival/passage from release to the first array (LMN 1) decreased later in the season, as water temperatures increased (Table 3.4). We suspect that the shoreline release location in an area where piscivorous fish were abundant resulted in the loss of a substantial number of fish from our study (170 of 1,949 (8.7%) fish were not detected on LMN 1.

Table 3.1. Estimated Joint Probability of Survival and Passage from Point of Release to Various Locations Downstream of Ten Groups of Subyearling Chinook Salmon Released Downstream of Little Goose Dam Between 16 June and 19 July 2006. See Table 2.3 for descriptions of the locations abbreviated in this table (NA = not applicable).

Release	Rel to LM1		Rel to LM3		Rel to LM5		Rel to LMN7		Rel to LMDT		Rel to IHDF		Rel to IHT1		Rel to JDA1		Rel to TDA1		Rel to BON1		Rel to EST1	
Date	Survival	SE	Survival	SE	Survival	SE	Survival	SE	Survival	SE	Survival	SE	Survival	SE	Survival	SE	Survival	SE	Survival	SE	Survival	SE
6/16/06	0.985	0.009	0.974	0.011	0.969	0.012	0.959	0.014	0.906	0.023	0.829	0.027	0.792	0.030	0.489	0.036	0.415	0.036	0.326	0.044	0.272	0.051
6/21/06	1.000	0.000	0.969	0.012	0.959	0.014	0.918	0.020	0.815	0.028	0.743	0.031	0.704	0.033	0.429	0.036	0.346	0.034	0.267	0.039	0.217	0.046
6/24/06	0.923	0.019	0.918	0.020	0.867	0.024	0.841	0.026	0.723	0.032	0.664	0.034	0.608	0.035	0.304	0.034	0.270	0.033	0.252	0.038	0.199	0.036
6/27/06	0.975	0.011	0.969	0.012	0.949	0.016	0.933	0.018	0.829	0.027	0.706	0.033	0.685	0.034	0.321	0.034	0.248	0.031	0.229	0.039	0.184	0.043
7/1/06	0.959	0.014	0.954	0.015	0.944	0.017	0.918	0.020	0.821	0.028	0.616	0.035	0.553	0.036	0.203	0.031	0.125	0.024	0.115	0.026	0.103	0.029
7/4/06	0.877	0.024	0.856	0.025	0.785	0.029	0.774	0.030	0.617	0.035	0.501	0.036	0.413	0.036	0.119	0.024	0.077	0.020	0.062	0.019	0.052	0.036
7/7/06	0.913	0.020	0.902	0.021	0.835	0.027	0.784	0.030	0.616	0.036	0.407	0.035	0.322	0.033	0.129	0.025	0.097	0.021	0.072	0.022	0.026	0.012
7/11/06	0.804	0.029	0.781	0.030	0.698	0.033	0.464	0.036	0.245	0.031	0.068	0.018	0.052	0.017	0.016	0.009	0.010	0.007	0.010	0.007	0.005	0.005
7/14/06	0.884	0.023	0.864	0.024	0.414	0.035	0.086	0.020	0.025	0.011	0.010	0.007	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7/19/06	0.805	0.028	0.790	0.029	0.595	0.035	0.190	0.028	0.072	0.019	0.041	0.015	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 3.2. Estimated Joint Probability of Survival and Passage by Reach of the Ten Groups of Subyearling Chinook Salmon Released Downstream of Little Goose Dam Between 16 June and 19 July 2006. See Table 2.3 for descriptions of the locations abbreviated in this table (NA = not applicable).

Release	Rel to LM1		LM1 to LM3		LM3 to LM5		LM5 to LMN7		LMN7 to LMDT		LMDT to IHDF		IHDF to IHT1		IHT1 to JDA1		JDA1 to TDA1		TDA1 to BON1		BON1 to EST1	
Date	Survival	SE	Survival	SE	Survival	SE	Survival	SE	Survival	SE	Survival	SE	Survival	SE	Survival	SE	Survival	SE	Survival	SE	Survival	SE
6/16/06	0.985	0.009	0.989	0.008	0.995	0.005	0.989	0.008	0.945	0.020	0.916	0.023	0.955	0.023	0.618	0.041	0.848	0.037	0.786	0.085	0.836	0.152
6/21/06	1.000	0.000	0.969	0.012	0.990	0.008	0.957	0.015	0.888	0.024	0.912	0.023	0.948	0.027	0.610	0.044	0.805	0.044	0.773	0.080	0.811	0.156
6/24/06	0.923	0.019	0.994	0.006	0.944	0.017	0.970	0.013	0.860	0.028	0.919	0.024	0.915	0.034	0.500	0.048	0.889	0.043	0.934	0.077	0.791	0.118
6/27/06	0.975	0.011	0.995	0.005	0.979	0.011	0.984	0.009	0.888	0.024	0.853	0.028	0.969	0.043	0.468	0.049	0.772	0.056	0.924	0.114	0.806	0.179
7/1/06	0.959	0.014	0.995	0.005	0.989	0.008	0.973	0.012	0.894	0.023	0.751	0.034	0.897	0.045	0.368	0.053	0.617	0.087	0.916	0.114	0.893	0.199
7/4/06	0.877	0.024	0.977	0.012	0.916	0.021	0.987	0.009	0.796	0.033	0.812	0.036	0.825	0.039	0.288	0.051	0.652	0.099	0.800	0.146	0.833	0.549
7/7/06	0.913	0.020	0.989	0.008	0.926	0.020	0.938	0.019	0.787	0.035	0.661	0.044	0.789	0.053	0.402	0.066	0.749	0.101	0.741	0.171	0.364	0.145
7/11/06	0.804	0.029	0.972	0.014	0.893	0.025	0.664	0.041	0.528	0.053	0.277	0.065	0.769	0.117	0.300	0.145	0.667	0.272	1.000	0.000	0.500	0.354
7/14/06	0.884	0.023	0.977	0.011	0.480	0.038	0.207	0.045	0.294	0.111	0.400	0.219	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7/19/06	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 3.3. Estimated Joint Probability of Survival and Passage from Point of Release to Various Locations Downstream of Ten Groups of Subyearling Chinook Salmon Released Downstream of Little Goose Dam in 2006. Data were pooled into three periods—16 to 27 June, 1 to 7 July, and 11 to 19 July. See Table 2.3 for descriptions of the locations abbreviated in this table.

Release	Rel to LM1		Rel to LM3		Rel to LM5		Rel to LMN7		Rel to LMDT		Rel to IHDF		Rel to IHT1		Rel to JDA1		Rel to TDA1		Rel to BON1		Rel to EST1	
Date	Survival	SE	Survival	SE	Survival	SE	Survival	SE	Survival	SE	Survival	SE	Survival	SE	Survival	SE	Survival	SE	Survival	SE	Survival	SE
6/16-6/27	0.971	0.017	0.958	0.013	0.936	0.023	0.913	0.025	0.818	0.037	0.736	0.035	0.697	0.038	0.386	0.044	0.319	0.038	0.268	0.021	0.218	0.019
7/1-7/7	0.916	0.024	0.904	0.028	0.854	0.047	0.825	0.046	0.685	0.068	0.508	0.060	0.429	0.067	0.150	0.027	0.100	0.014	0.083	0.016	0.060	0.022
7/11-7/19	0.831	0.026	0.812	0.026	0.569	0.083	0.246	0.113	0.114	0.067	0.040	0.017	0.024		0.005		0.003		0.003		0.002	

Table 3.4. Estimated Joint Probability of Survival and Passage by Reach for the Ten Groups of Subyearling Chinook Salmon Released Downstream of Little Goose Dam in 2006. Data were pooled into three periods—16 to 27 June, 1 to 7 July, and 11 to 19 July. See Table 2.3 for descriptions of the locations abbreviated in this table.

Release	Rel to LM1		LM1 to LM3		LM3 to LM5		LM5 to LMN7		LMDF to LMDT		LMDT to IHDF		IHDF to IHT1		IHT1 to JDA1		JDA1 to TDA1		TDA1 to BON1		BON1 to EST1	
Date	Survival	SE	Survival	SE	Survival	SE	Survival	SE	Survival	SE	Survival	SE	Survival	SE	Survival	SE	Survival	SE	Survival	SE	Survival	SE
6/16-6/27	0.971	0.017	0.987	0.006	0.977	0.011	0.975	0.006	0.897	0.018	0.898	0.016	0.944	0.012	0.556	0.038	0.828	0.025	0.839	0.043	0.818	0.009
7/1-7/7	0.916	0.024	0.987	0.005	0.945	0.023	0.966	0.008	0.830	0.034	0.743	0.044	0.847	0.032	0.349	0.034	0.666	0.039	0.857	0.051	0.715	0.167
7/11-7/19	0.831	0.026	0.977	0.003	0.699	0.122	0.431	0.027	0.462	0.068	0.318	0.085	0.667	0.111	0.214	0.110	0.667	0.272	1.000	0.000	0.500	0.354

3.1.3 Non-Migrant versus Migrant Characteristics

Out of 1,949 subyearling Chinook salmon released, 852 were not detected below Lower Monumental Dam. The average fork length of tagged fish increased until about 1 July after which the average declined. This coincided with a decline in the percentage of fish that were detected below Lower Monumental Dam (Figure 3.3). While fish that left the reservoir tended to be larger than fish that stayed within the reservoir (Figure 3.3), fish of all sizes were observed both leaving the reservoir and not leaving the reservoir throughout the season (Figure 3.4).

For fish not detected below Lower Monumental Dam, the locations of last detection were not evenly distributed within the reservoir. The numbers of fish in the lower reaches of the Lower Monumental Reservoir increased at a higher rate than in the upper reaches over the course of the season (Figure 3.5).

Median travel time from release to downstream acoustic arrays varied by release group and was generally slowest for the earliest (16 to 27 June) and latest (11 to 19 July) release groups and fastest for the intermediate release groups (1 to 7 July; Table 3.5; Figure 3.6). Travel times to LMN 1, LMN 3, and LMN 5 were similar between fish that stayed in or left the reservoir; however, median travel times to LMN 7 were slightly lower for fish that left the reservoir than those that stayed (Figure 3.6).

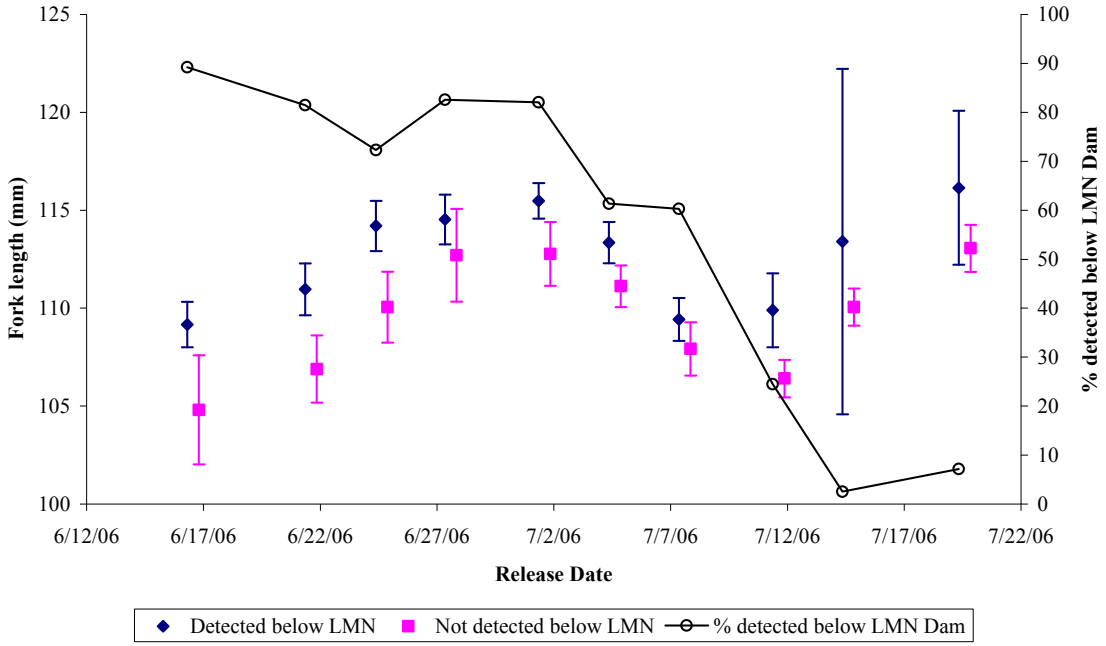

Figure 3.3. Average (± SE) Fork Length of Fish Detected Downstream of Lower Monumental Dam and Those That Were Not by Release Group, and the Percentage of Each Release Detected Downstream of Lower Monumental Dam

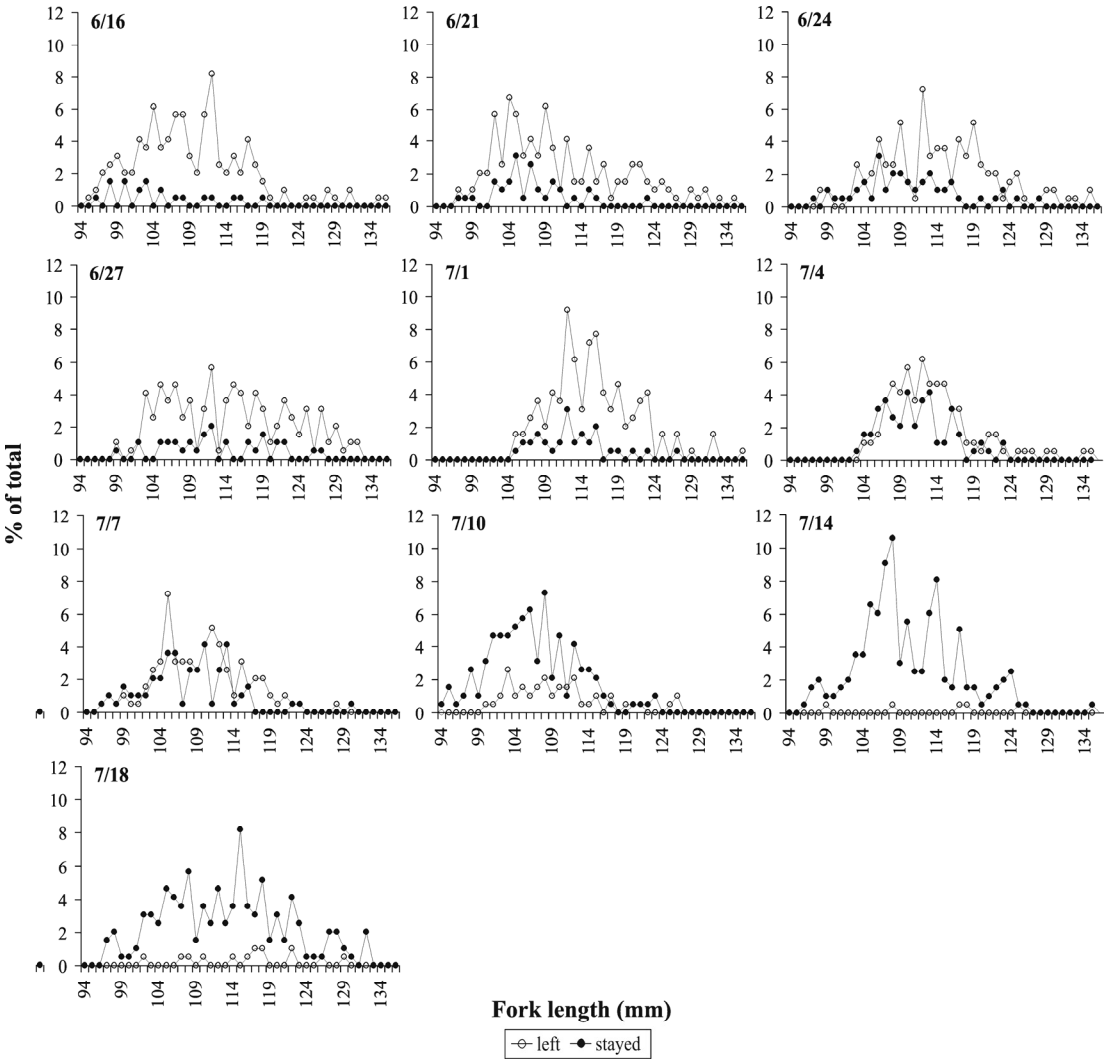

Figure 3.4. Distributions of Fork Length for Fish Detected Downstream of Lower Monumental Dam (left – open circles) and Those That Were Not (stayed – closed circles) for Each Group of Microacoustic-Tagged Subyearling Chinook Salmon Released in 2006. Total sample sizes are listed in Table 2.1.

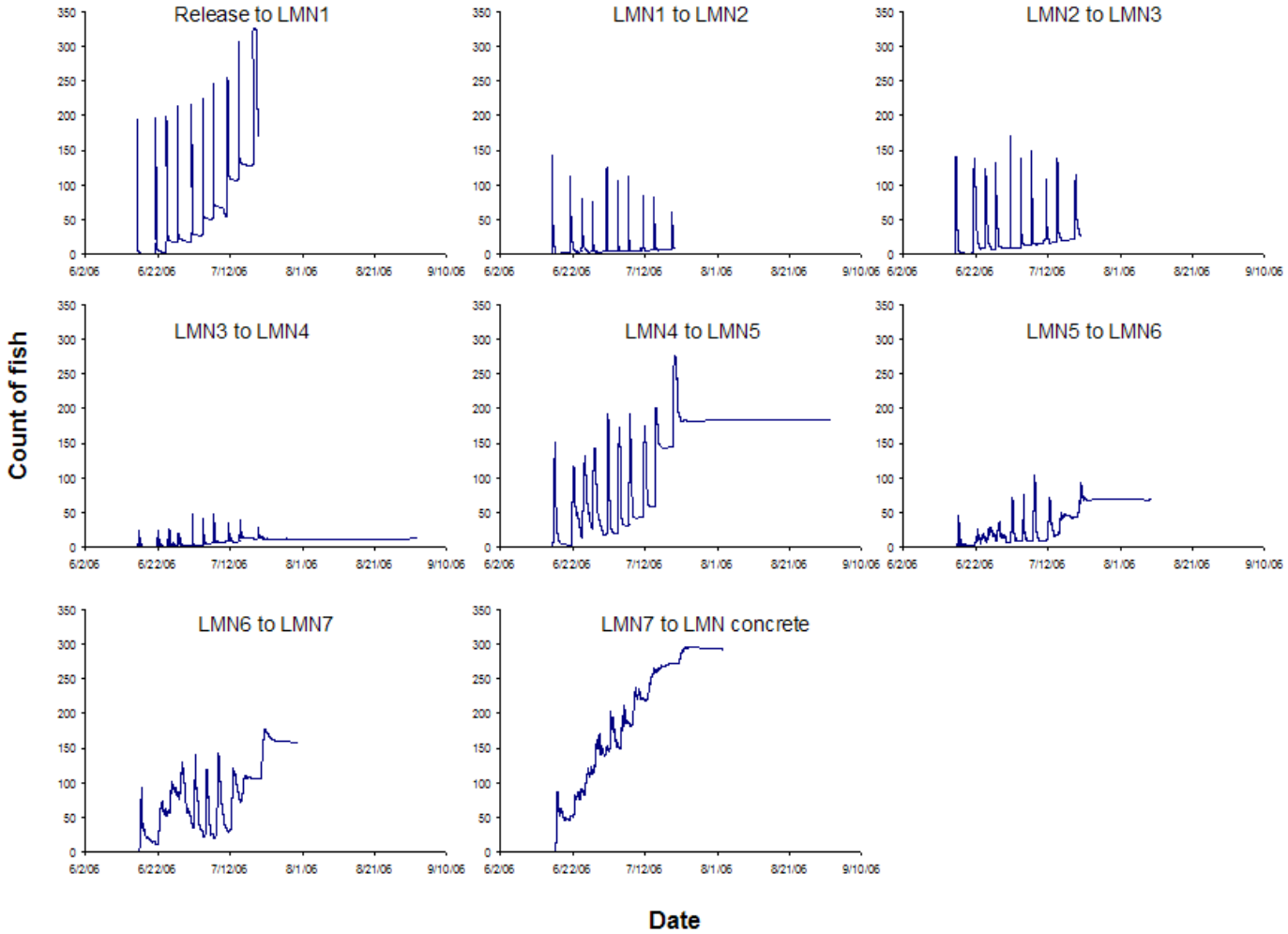

Figure 3.5. Counts of Tagged Fish Last Detected Between Each of the Acoustic Receiving Arrays in the Lower Monumental Reservoir over Time. Fish detected on LMN 7 and not detected on the LMN tailrace array were assumed to be upstream of the dam.

Table 3.5. Travel Time (days; median [5th–95th percentiles]) of Subyearling Chinook Salmon from Release Downstream of Little Goose Dam to Acoustic Arrays in Lower Monumental Reservoir and Tailrace

		Acoustic array							
Release date	Disposition	LMN1	LMN2	LMN3	LMN4	LMN5	LMN6	LMN7	LMDT
06/16/06	stayed	0.07(0.05-0.14)	0.11(0.09-0.14)	0.65(0.33-0.90)	0.69(0.37-1.02)	1.11(0.88-2.15)	1.23(0.97-2.47)	1.45(1.14-2.63)	N/A
	left	0.07(0.05-0.14)	0.11(0.09-0.26)	0.52(0.29-0.85)	0.59(0.31-0.92)	1.04(0.67-1.87)	1.11(0.76-2.10)	1.37(1.02-5.56)	1.86(1.29-7.95)
06/21/06	stayed	0.11(0.07-0.70)	0.18(0.11-0.62)	0.85(0.49-2.05)	1.00(0.52-2.13)	1.59(1.16-4.52)	1.98(1.26-4.97)	4.37(1.97-8.26)	N/A
	left	0.10(0.06-0.28)	0.16(0.09-0.58)	0.64(0.30-1.56)	0.70(0.31-1.63)	1.24(0.70-3.35)	1.33(0.89-3.69)	2.25(1.16-10.57)	3.41(1.35-12.39)
06/24/06	stayed	0.14(0.09-0.60)	0.25(0.13-0.63)	0.78(0.40-1.79)	0.89(0.44-2.05)	1.56(1.04-3.37)	1.84(1.10-3.92)	3.67(1.50-5.41)	N/A
	left	0.14(0.07-0.31)	0.22(0.12-0.46)	0.68(0.34-1.23)	0.73(0.35-1.28)	1.30(0.90-3.20)	1.41(0.98-3.37)	2.28(1.16-5.47)	2.92(1.36-6.21)
06/27/06	stayed	0.10(0.05-0.46)	0.20(0.08-0.68)	0.46(0.24-1.11)	0.56(0.25-1.21)	1.28(0.75-2.75)	1.34(0.95-3.09)	2.54(1.18-5.16)	N/A
	left	0.10(0.05-0.32)	0.16(0.09-0.41)	0.36(0.24-1.00)	0.40(0.25-1.02)	1.10(0.50-2.81)	1.19(0.60-2.94)	1.73(0.99-4.54)	2.20(1.25-6.05)
07/01/06	stayed	0.10(0.08-0.21)	0.14(0.10-0.25)	0.33(0.26-0.54)	0.35(0.28-0.58)	0.98(0.57-1.80)	1.09(0.69-1.97)	1.97(1.04-3.30)	N/A
	left	0.09(0.08-0.17)	0.12(0.10-0.20)	0.30(0.26-0.43)	0.32(0.28-0.46)	0.75(0.50-1.13)	0.94(0.56-1.35)	1.27(0.98-2.36)	1.62(1.13-2.88)
07/04/06	stayed	0.08(0.06-0.21)	0.11(0.08-0.27)	0.32(0.27-0.81)	0.34(0.28-0.83)	0.98(0.71-1.31)	1.13(0.91-1.59)	1.69(1.18-2.43)	N/A
	left	0.07(0.06-0.18)	0.11(0.08-0.21)	0.30(0.24-0.45)	0.32(0.26-0.49)	0.90(0.64-1.22)	1.02(0.89-1.49)	1.40(1.08-2.34)	1.86(1.23-3.24)
07/07/06	stayed	0.08(0.06-0.24)	0.12(0.09-0.21)	0.30(0.26-0.56)	0.32(0.27-0.60)	0.95(0.55-1.31)	1.22(1.02-1.71)	2.19(1.32-3.91)	N/A
	left	0.08(0.06-0.16)	0.10(0.08-0.19)	0.28(0.24-0.41)	0.30(0.26-0.43)	0.92(0.50-1.26)	1.16(0.86-1.54)	1.93(1.31-3.16)	2.25(1.60-3.91)
07/11/06	stayed	0.08(0.05-0.42)	0.12(0.08-0.50)	0.32(0.23-0.93)	0.34(0.25-0.97)	1.07(0.68-1.53)	1.30(1.00-2.22)	2.32(1.63-4.00)	N/A
	left	0.07(0.04-0.16)	0.10(0.07-0.21)	0.29(0.22-0.41)	0.31(0.23-0.43)	0.96(0.52-1.25)	1.16(0.83-1.88)	1.99(1.24-3.57)	2.33(1.40-4.30)
07/14/06	stayed	0.12(0.08-0.26)	0.16(0.12-0.43)	0.37(0.30-0.79)	0.39(0.31-0.92)	1.15(0.73-1.98)	1.37(0.92-2.67)	1.95(1.21-3.56)	N/A
	left	0.14(0.09-0.20)	0.17(0.13-0.26)	0.35(0.30-0.68)	0.36(0.31-0.75)	0.78(0.53-1.99)	1.08(0.73-28.35)	1.52(1.03-3.08)	1.89(1.26-7.87)
07/19/06	stayed	0.16(0.06-0.51)	0.22(0.10-0.56)	0.50(0.33-1.46)	0.53(0.34-1.49)	1.64(1.11-2.31)	1.83(1.28-2.41)	2.92(2.26-4.81)	N/A
	left	0.11(0.06-0.53)	0.17(0.10-0.58)	0.48(0.31-1.20)	0.49(0.32-1.23)	1.54(0.95-2.62)	1.75(1.27-3.03)	2.60(1.99-6.80)	3.19(2.19-13.61)

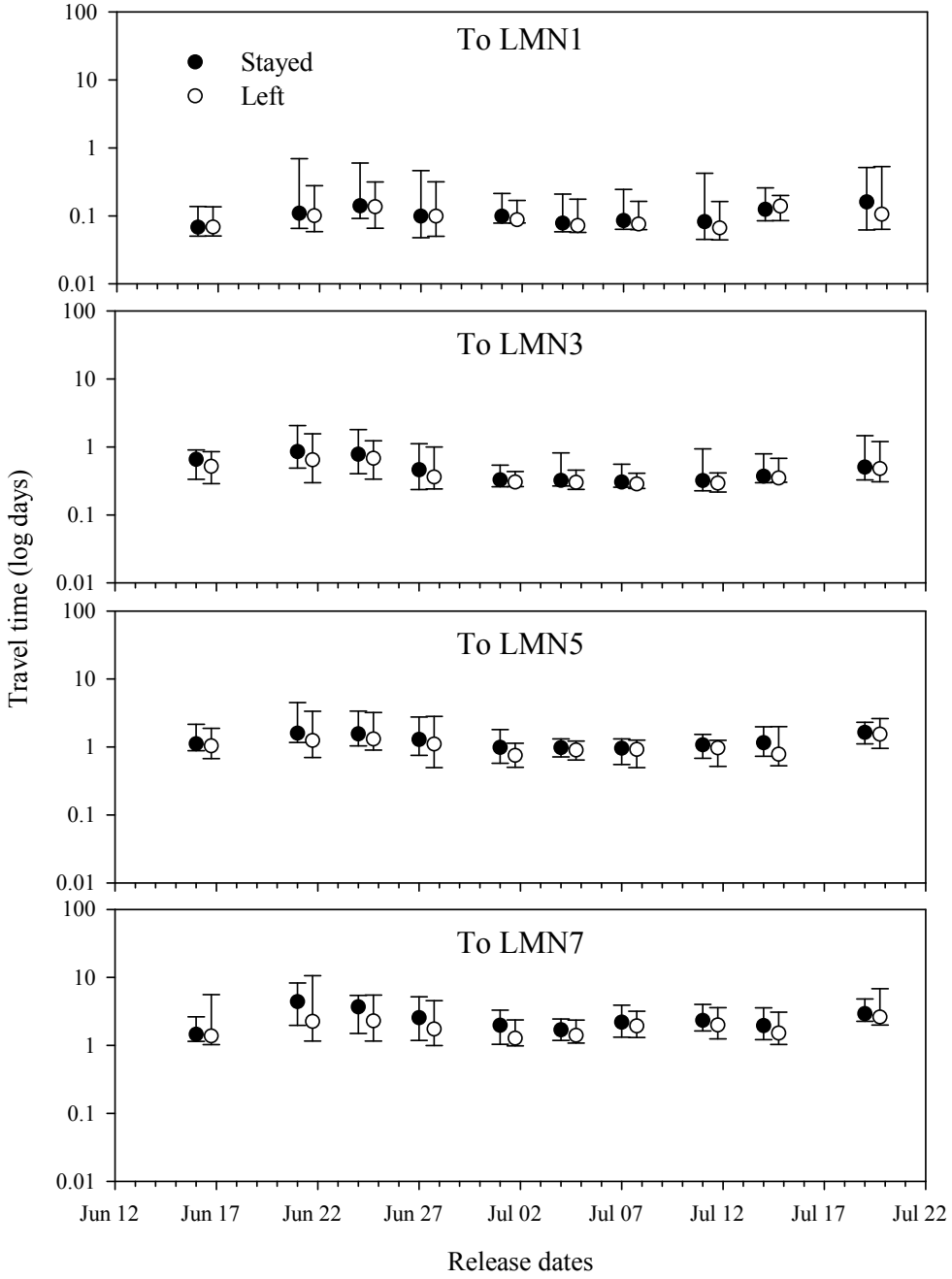

Figure 3.6. Travel Time in Days (median, 5th and 95th percentiles) of Subyearling Chinook Salmon That Stayed in Lower Monumental Reservoir (black) or Left the Reservoir (white) from the Release Site to LMN 1, LMN 3, LMN 5, and LMN 7

Fish that emigrated from the reservoir traveled at a faster rate than their counterparts that did not leave the reservoir (Table 3.6). However, the overall seasonal medians are confounded by the fact that more fish left during the earlier part of the study when discharge was higher.

Table 3.6. Travel Rate (kilometers per hour; median [range]) from Release to LMN 7 and Residence Time on LMN 7 (hours; median [range]) for Juvenile Fall Chinook Salmon Detected Downstream of Lower Monumental Dam (left) and Those That Were Not (stayed).

Release Date	Disposition	Travel Rate (km/hr)	Residence Time (h)	N
16-Jun	stayed	0.99 (0.42-1.49)	0.47 (0.09-1691.75)	13
16-Jun	left	1.25 (0.13-2.34)	0.96 (0.05-360.71)	168
21-Jun	stayed	0.39 (0.17-1.04)	16.24 (0.13-1075.88)	20
21-Jun	left	0.74 (0.11-1.81)	4.04 (0.05-916.31)	158
24-Jun	stayed	0.47 (0.22-1.36)	8.39 (0.31-147.88)	23
24-Jun	left	0.75 (0.19-1.89)	4.72 (0.02-71.86)	141
27-Jun	stayed	0.67 (0.28-2.00)	4.98 (0.09-116.78)	21
27-Jun	left	0.94 (0.13-1.89)	1.49 (0.02-66.50)	157
1-Jul	stayed	0.87 (0.46-1.70)	0.34 (0.08-12.72)	19
1-Jul	left	1.34 (0.42-1.89)	0.32 (0.04-42.25)	160
4-Jul	stayed	1.00 (0.55-1.68)	0.75 (0.09-42.63)	31
4-Jul	left	1.22 (0.52-1.68)	0.25 (0.04-129.81)	120
7-Jul	stayed	0.76 (0.40-1.61)	1.35 (0.05-71.86)	34
7-Jul	left	0.89 (0.43-1.47)	0.49 (0.04-453.50)	116
11-Jul	stayed	0.73 (0.20-1.15)	3.52 (0.11-1591.47)	38
11-Jul	left	0.85 (0.38-1.91)	1.81 (0.10-40.44)	46
14-Jul	stayed	0.86 (0.44-1.45)	0.86 (0.13-685.65)	12
14-Jul	left	1.13 (0.50-1.84)	0.99 (0.17-126.24)	5
19-Jul	stayed	0.57 (0.34-0.88)	1.00 (0.16-1157.78)	23
19-Jul	left	0.66 (0.15-0.88)	0.84 (0.25-77.23)	14
	stayed	0.74 (0.17-2.00)	2.15 (0.05-1691.75)	234
	left	1.00 (0.11-2.34)	0.88 (0.02-916.31)	1085

Fish that stopped migrating in the reservoir were not observed reinitiating migration while the acoustic arrays were in place (through 25 September), nor were they observed migrating through the PIT detectors, although the PIT tag detector at Lower Monumental Dam was operational only until 30 September (Table 3.7).

Table 3.7. Dates of Latest Detection on the LMN Tailrace Array and Latest PIT Detections (anywhere) for Each Group of Subyearling Chinook Salmon Released in the Little Goose Dam Tailrace in 2006

Release Date	Acoustic Array	Date	PIT Detector	Date
16-Jun	LMDT	7/3/06	JDJ	7/9/06
21-Jun	LMDT	8/2/06	JDJ	7/10/06
24-Jun	LMDT	7/5/06	JDJ	7/14/06
27-Jun	LMDT	7/11/06	JDJ	7/11/06
1-Jul	LMDT	7/5/06	JDJ	7/13/06
4-Jul	LMDT	7/12/06	JDJ	7/15/06
7-Jul	LMDT	7/29/06	JDJ	7/30/06
11-Jul	LMDT	7/17/06	MCJ	8/1/06
14-Jul	LMDT	7/23/06	LMJ	7/18/06
19-Jul	LMDT	8/3/06	MCJ	8/4/06
Overall		8/3/06		8/4/06

3.1.4 Fate Determination – Autonomous Array Data

Counts of each non-migrant fish that were detected on an array for at least two days ($N = 81$) were summarized by event (if a tag was not heard for > 2 min on a single array, any subsequent detections were counted as being in a new event), and the start and end times for each event were assigned a number (e.g., start = 1, end = 0). These data were plotted, creating a graph that looks like a bar code for each fish, where the different colors represent different arrays (Figure 3.7 through Figure 3.10). This was a relatively simple way to understand the spatial and temporal behavior patterns of subyearling Chinook salmon that remained in Lower Monumental Reservoir. This same method was also applied to data from tags that had been dropped onto the river bottom near the Lower Monumental Dam forebay, to serve as a reference for what detection patterns from a dead fish would look like (Figure 3.11).

In light of the data from the tags that were dropped to the river bottom, it appears impossible to know with certainty the fate of the majority of the 81 fish. This is especially true in the forebay where the river is wide, because if a fish moved back and forth across the river, within the 600 m detection zone of the nodes, it could appear to be stationary based on these plots. There is one good example of a fish that can definitively be classified as alive, at least until its tag died, because it moved far enough to be detected on multiple arrays over a period of almost 2 months (Figure 3.10, #5–6; G723df6ad). In addition, the fish with very long gaps (~> 1 week) between detections were probably alive, though we have no way to quantify or confirm this. The autonomous arrays covered an estimated 11.4% of the area between LMN 4 and LMN 7, where 76% (647/852) of the fish that did not leave the reservoir resided, so if a fish resided in an area where we could not detect it, then we had no way to determine its fate. A limitation of this approach is that fish had to move long distances (e.g., 7.6 km from LMN 7 to LMN 6) to be detected on multiple arrays; therefore, live fish that moved shorter distances or resided largely within the detection range of one node would not be classified as alive.

For a fish to be categorized as moving upstream, the shortest distance it had to travel was about 1 km. A total of 36 of the fish that did not leave Lower Monumental Reservoir were detected going upstream, while 27 of the fish that left the reservoir were detected also going upstream at some point prior to emigrating from the reservoir. The majority (44%) of these upstream movements happened in the 3.1 km reach between LMN 6 and LMN 5. Only three upstream movements occurred upstream of LMN 3.

3.1.5 Preliminary Tracking

A total of 120 tagged subyearling Chinook salmon were detected during preliminary mobile tracking efforts on 11 and 12 July. The tracking was initiated near the release site approximately 1 hr after the release of the tagged fish. Consequently, the majority of detections (91%) were of fish from the 11 July release group. However, two fish from 21 June, one from 24 June, three from 4 July, and five from 7 July releases were also detected.

Sixteen of the fish tracked in preliminary mobile tracking efforts were subsequently detected during the systematic mobile surveys. Of these, 11 made it to the forebay, and the other five were re-located near the release site. One fish was detected on 12 July at a location 25.8 km downstream of where it was detected one day earlier. Two weeks later, the same fish was detected 5.4 km farther downstream in the forebay, where it remained.

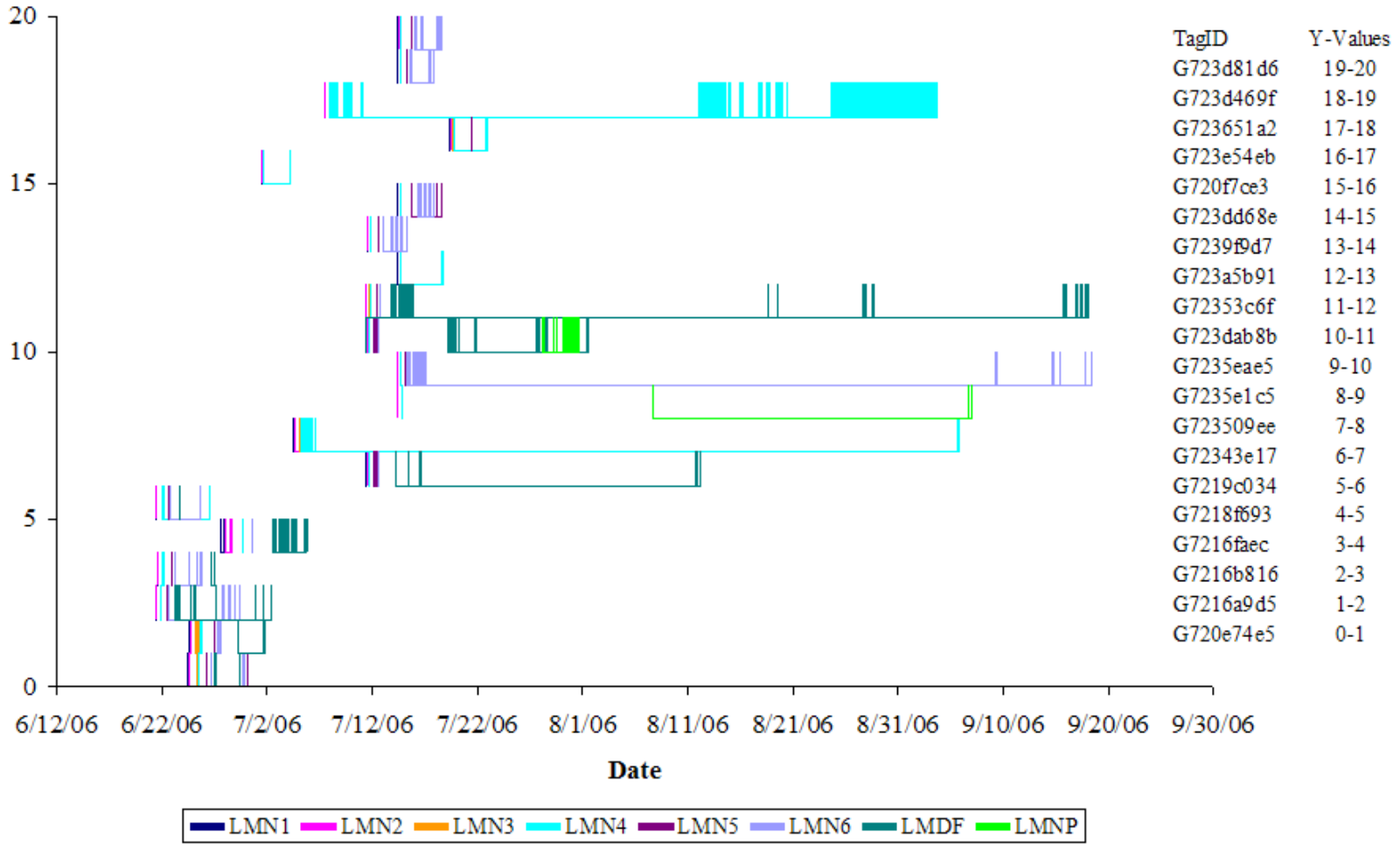

Figure 3.7. Detections of Fish Presence/Absence on the Autonomous Arrays in the Lower Monumental Reservoir. For a given fish, the lower *y*-axis value indicates absence and the higher *y*-axis value indicates presence. Dense bands of color indicate activity around an array.

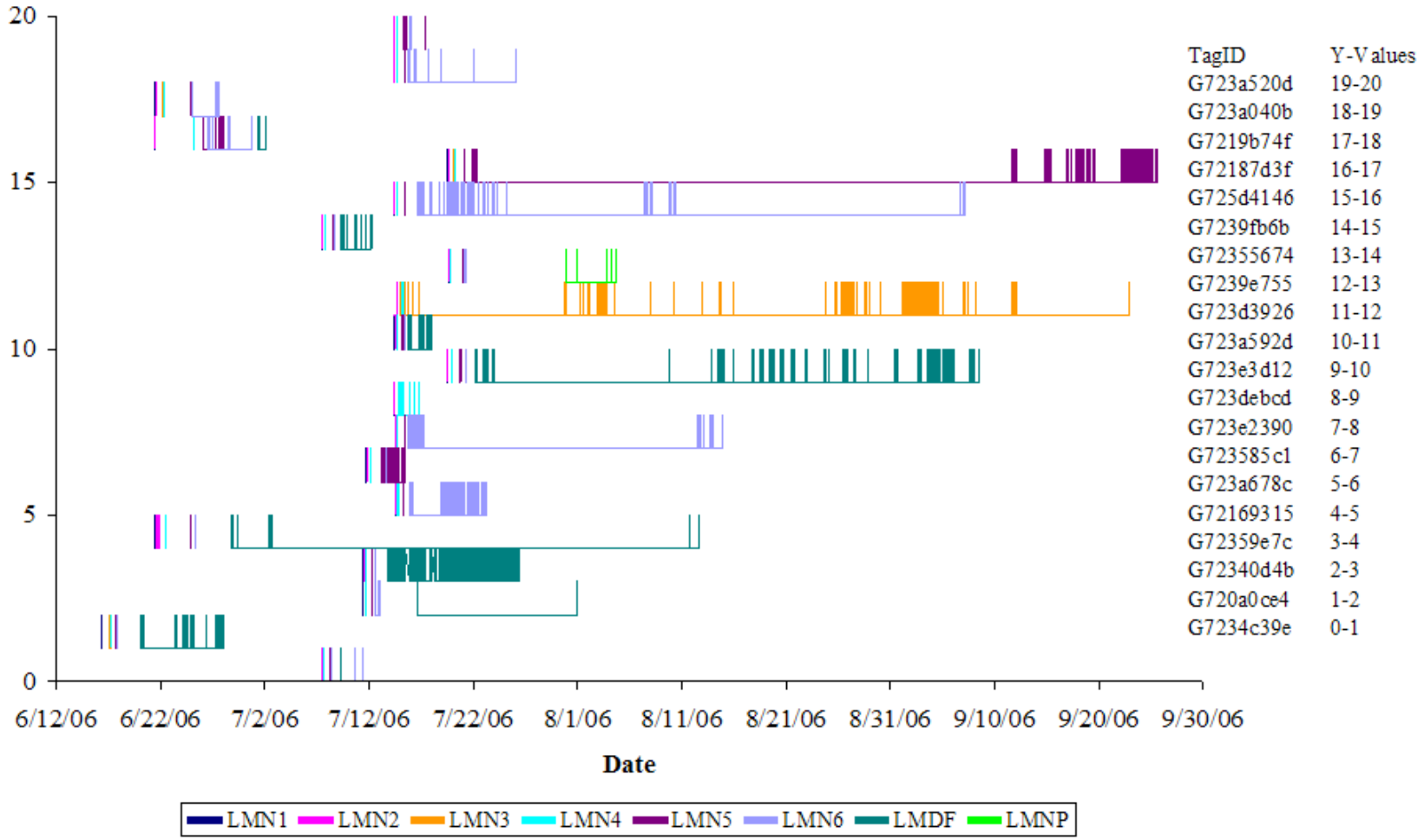

Figure 3.8. Detections of Fish Presence/Absence on the Autonomous Arrays in the Lower Monumental Reservoir. For a given fish, the lower *y*-axis value indicates absence and the higher *y*-axis value indicates presence. Dense bands of color indicate activity around an array.

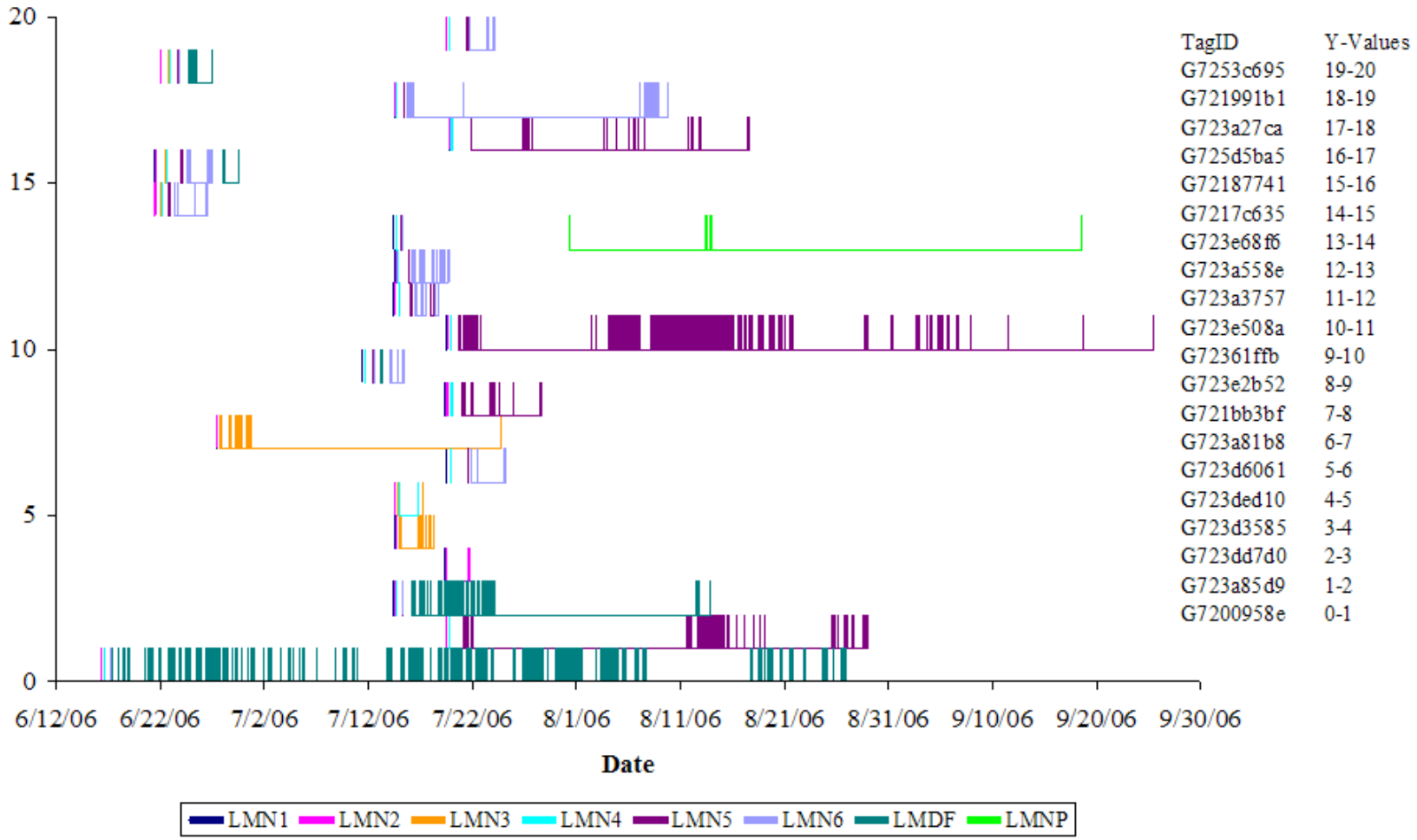

Figure 3.9. Detections of Fish Presence/Absence on the Autonomous Arrays in the Lower Monumental Reservoir. For a given fish, the lower *y*-axis value indicates absence and the higher *y*-axis value indicates presence. Dense bands of color indicate activity around an array.

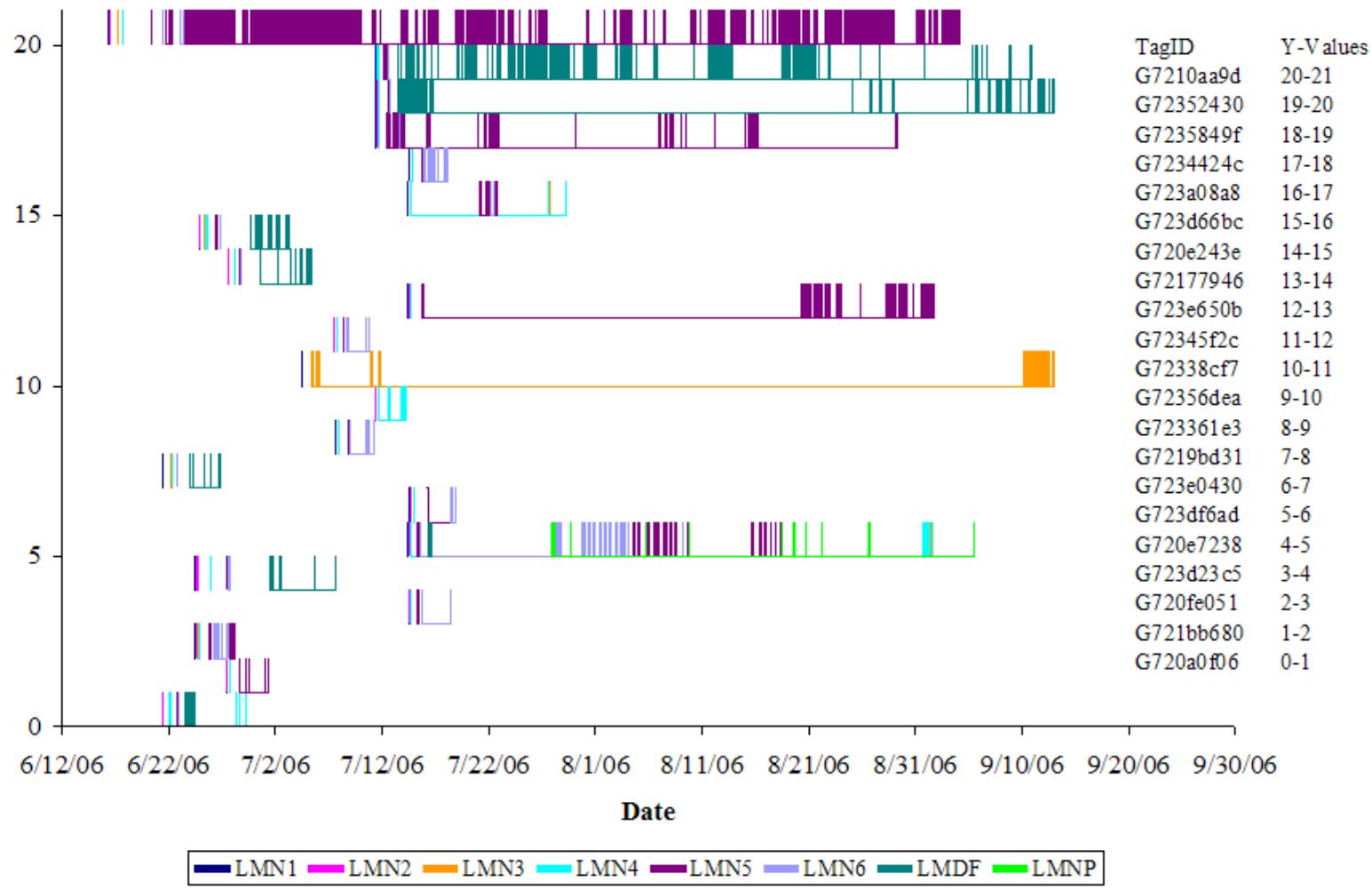

Figure 3.10. Detections of Fish Presence/Absence on the Autonomous Arrays in the Lower Monumental Reservoir. For a given fish, the lower *y*-axis value indicates absence and the higher *y*-axis value indicates presence. Dense bands of color indicate activity around an array.

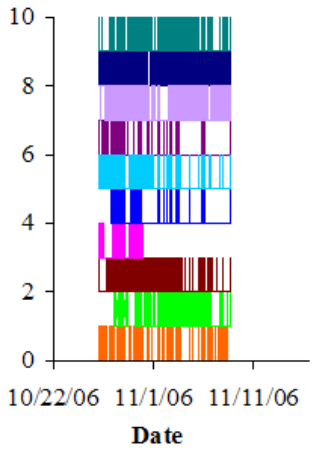

Figure 3.11. Detections of Tags Dropped onto the River Bottom near the Lower Monumental Dam Forebay. Each color represents a different tag. For a given tag, the lower *y*-axis value indicates absence and the higher *y*-axis value indicates presence. Dense bands of color indicate activity around the nodes. For comparison, this is on the same scale as Figures 3.8 through 3.10.

3.1.6 Systematic Mobile Tracking Surveys

The amount of area in the reservoir covered throughout the study by the mobile tracking effort is shown in Figure 3.12. The level of effort was measured by the amount of surface area that was covered within the estimated detection range of 150 m radius of the mobile tracking gear at each of the points surveyed throughout the mobile tracking study (Figure 3.12). This was compared to the total surface area of each reach determined in a GIS map. The areas between the release site and the first line of nodes (Rel-LMN1) and the area between node lines 6 and 7 in the forebay of the dam were covered much more extensively during the release area and forebay surveys, discussed below, where large numbers of the tagged fish ceased migration, as determined by autonomous array detections.

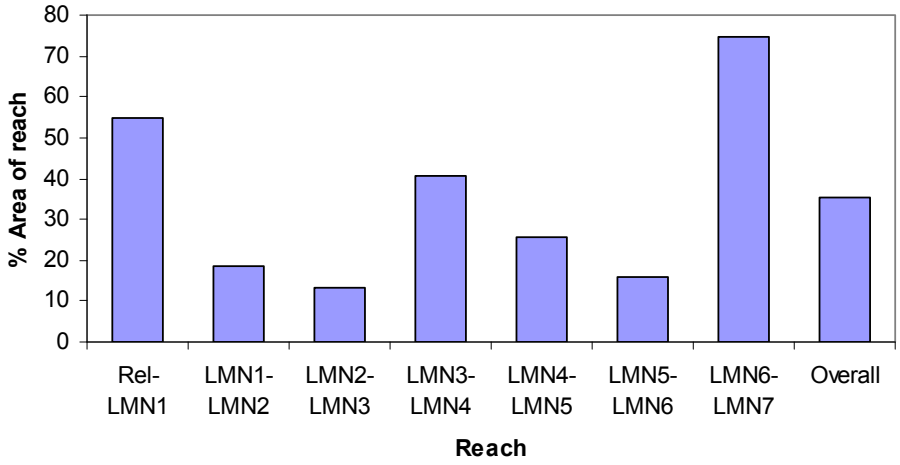

Figure 3.12 Estimated Percentage Surface Area of Each Reach from the Release Site to the Forebay of Lower Monumental Dam, Covered by the Mobile Tracking Efforts, Based on a Detection Radius of 150 m for the Mobile Hydrophone. Survey points used from 26 July to 21 September 2006 for the systematic, and the forebay and release area surveys are included.

A total of 5.3% (104/1949) of the tagged subyearling Chinook salmon were detected by the mobile tracking gear during the systematic surveys in the Lower Monumental Reservoir. Twenty-nine of the 40 (72.5%) smallmouth bass that were tagged and released were also detected. All three of the tagged walleye were detected early on in the surveys, but not found in the later part of the study (late August through the end of September). None of the tagged channel catfish was detected on the mobile tracking gear.

Of the 104 detections of subyearling Chinook salmon, 61 of these were detected on just a single survey at one point throughout the study period. The same was true for nine of the tagged smallmouth bass and one of the walleye.

Most (91%) of the subyearling Chinook salmon that were detected by mobile tracking were released on or after 4 July, whereas only nine fish were from earlier releases (Figure 3.13). Five of these fish from June releases were detected in the forebay area (between LMN 6 and the BRZ), and two were found near the release site.

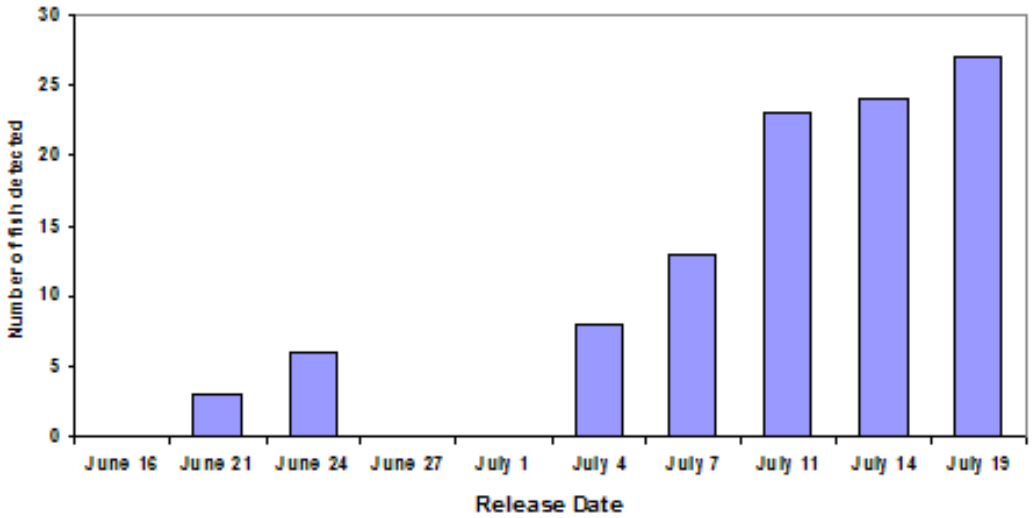

Figure 3.13. Numbers of Fish from Each Release Group Detected by Mobile Tracking Throughout the Reservoir Between 26 July and 21 September 2006

The majority (82%) of the tagged subyearling Chinook salmon located in the reservoir were found within 3 km of the release site or within 7 km of the BRZ in the forebay of Lower Monumental Dam (Figure 3.14).

Forty-three tagged subyearling Chinook salmon were detected in the reach between the release site and the first line of nodes (LMN 1) 3.8 km downstream (Table 3.8). Forty-two tagged Chinook salmon were detected in the forebay, from LMN 6 to the edge of the BRZ (LMN 7), 7.6 km downstream (Table 3.8).

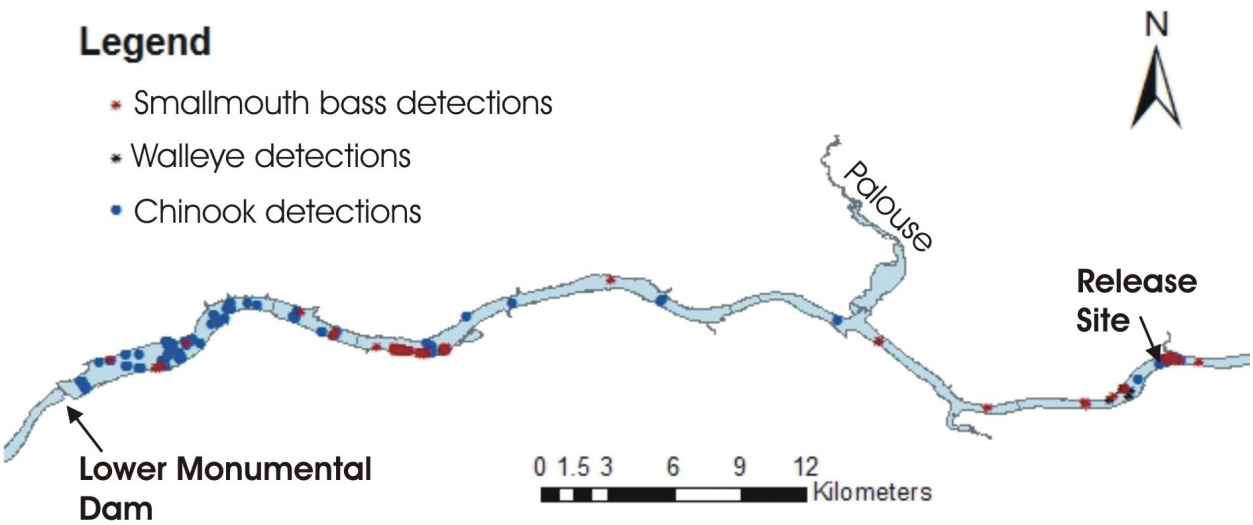

Figure 3.14. Distribution of Mobile Tracking Detections of Acoustic Tagged Fish Between 26 July and 21 September

Table 3.8. Mobile Tracking Detections of Acoustic Tagged Subyearling Chinook Salmon by Release Group and the Section of River (reach) in Which They Were Located

	Reach						
Release	Rel–LMN 1	LMN 1–LMN 2	LMN 2–LMN 3	LMN 3–LMN 4	LMN 4–LMN 5	LMN 5–LMN 6	LMN 6–LMN 7
16 June	0	0	0	0	0	0	0
21 June	0	0	0	0	0	0	3
24 June	2	0	0	0	2	0	2
27 June	0	0	0	0	0	0	0
1 July	0	0	0	0	0	0	0
4 July	6	0	1	0	1	0	0
7 July	9	0	0	0	0	0	4
11July	9	0	0	0	0	2	12
14 July	8	0	0	0	4	4	8
19 July	9	0	0	0	3	2	13
Total	**43**	**0**	**1**	**0**	**10**	**8**	**42**

3.1.7 Forebay Surveys

The subyearling Chinook salmon located in the forebay of Lower Monumental Dam were found fairly scattered throughout the area, with no clear specific region where the non-migrants congregated (Figure 3.15). Subsequent detections were typically in proximity to the previous location (Figure 3.15); indicating very little movement.

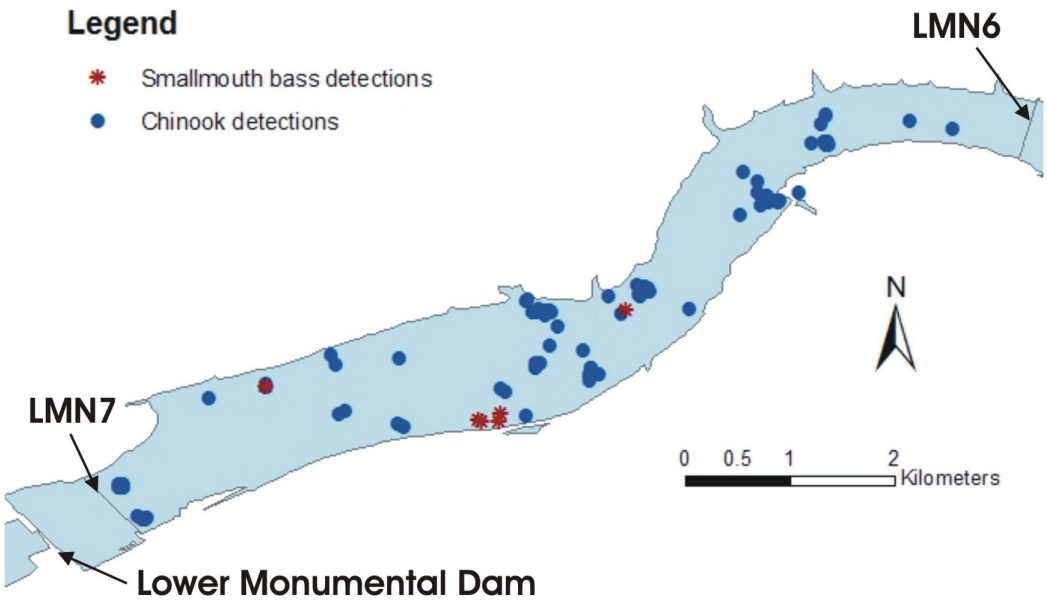

Figure 3.15. Locations of Acoustic Tagged Chinook Salmon and Smallmouth Bass Detected by Mobile Tracking in the Forebay of Lower Monumental Dam Between 26 July and 21 September

3.1.8 Release Area Surveys

Surveys throughout the release area detected 25% of the 170 tagged subyearling Chinook salmon that failed to reach the first line of autonomous nodes (LMN 1). The locations of both subyearling Chinook salmon and smallmouth bass detected in the release area were clustered in proximity (<200 m) to the point where they were released (Figure 3.16).

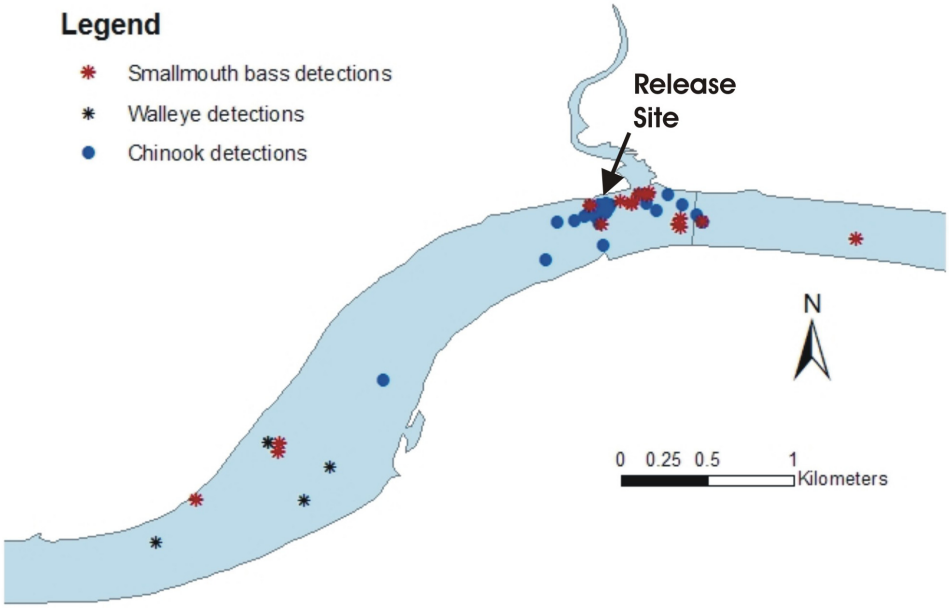

Figure 3.16. Locations of Acoustic Tagged Chinook Salmon, Smallmouth Bass, and Walleye Detected by Mobile Tracking in the Area Near the Release Site from 26 July to 21 September

3.1.9 Fish Proximity to Shoreline

Due to the omnidirectional nature of the hydrophone, precise locations of detected fish were not possible. The location of the boat, as the center of the detection radius of the hydrophone, was used as an approximate location of the fish being detected. Most detections of both smallmouth bass (99%) and subyearling Chinook salmon (84%) occurred when the boat was within 200 m of either shore (Figure 3.17). Only one smallmouth bass location occurred farther than 200 m from shore, and 75% of the tagged smallmouth bass were located within 100 m of shore. Because the river is fairly narrow (typically 300–500 m wide) until it nears the forebay, the subyearlings that were detected more than 250 m from either shore were located within the forebay area (Figure 3.14). Many of the subyearling Chinook salmon detections near shore were located near the release site (Figure 3.16).

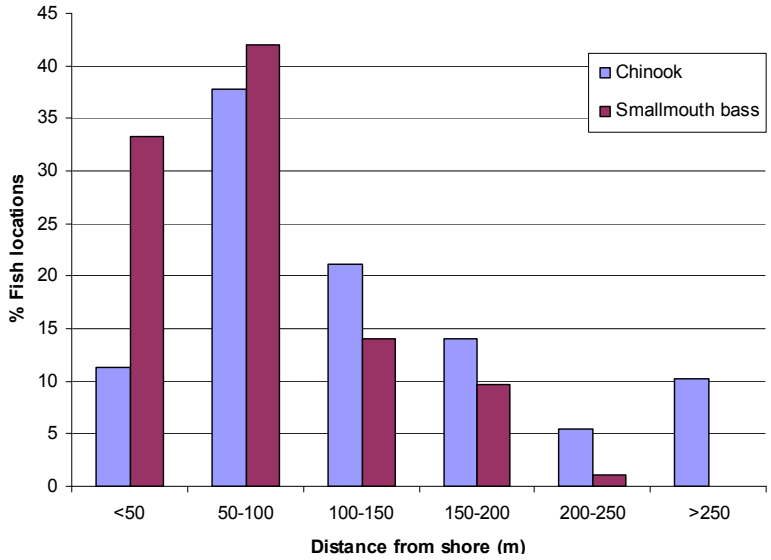

Figure 3.17. Distribution of Mobile Tracking Locations of Subyearling Chinook Salmon and Smallmouth Bass Based on the Distance to the Nearest Shoreline from Each Location

3.1.10 Subyearling Chinook Salmon Movements

None of the Chinook salmon detected during the mobile surveys resumed their downstream migrations to be detected later on node arrays downstream of the Lower Monumental Dam forebay (LMN 7).

The rate at which the fish detected by mobile tracking traveled from release to the autonomous array where they were last detected, was an average of 1.4 km/hr (33.8 km/day). These rates ranged from a minimum of 0.12 km/hr (2.9 km/day) to a maximum of 3.1 km/hr (74.4 km/day). Because the distance from release to LMN 7 in the forebay of the dam is approximately 41 km, the subyearling Chinook salmon that were detected by mobile tracking that made it past the first set of nodes often arrived at the locations where they were detected within the first day of their release.

Once detected by the mobile tacking surveys, the tagged subyearling Chinook salmon moved very little between subsequent detections. Only one tagged subyearling Chinook salmon located by mobile tracking was recorded as moving more than 100 m per day when it was detected on 11 August and 2.1 km upstream of its previous location from 3 days earlier.

However, due to the wide range in the number of days between detections, the distance per day measure used to summarize the tagged Chinook salmon movements somewhat skews the rate to smaller numbers. The mean number of days between successive locations was 12, with a maximum of 50; when one fish was located on 26 July, but not again until 14 September. The second detection of that fish was only 423 m from its first detection near the release site. In fact, four fish were not relocated for periods of 40 or more days. They all relocated within 500 m of their original locations; three near the release site and the fourth in the forebay.

3.1.11 Predator Movements

Although not detected with mobile tracking, two of the seven tagged catfish were detected in late July by a few of the autonomous nodes. One moved downstream 5.2 km from its release on 19 July to LMN 6 by 20 July, where it remained until its last detection on 22 July. The other catfish was detected on all three autonomous nodes on array LMN 7 along the edge of the BRZ from 19 to 20 July. It was then detected for the final time 2.6 km upstream on 30 July at the forebay autonomous predator node.

The tagged smallmouth bass exhibited a wider range of movements between successive detections on both the mobile tracking equipment and the autonomous nodes. These ranged from 0 m/day to over 13 km traveled in one day by a smallmouth bass that moved upstream from LMN 5 (10.5 km upstream of the dam) to LMN 4 (roughly mid reservoir, 24.2 km upstream of the dam). The mean daily movements (meters/day), although variable, tended to generally decrease as the season progressed (Figure 3.18). Although mobile tracking efforts ceased on 21 September, additional data up to 25 September were available from the autonomous nodes (Figure 3.18).

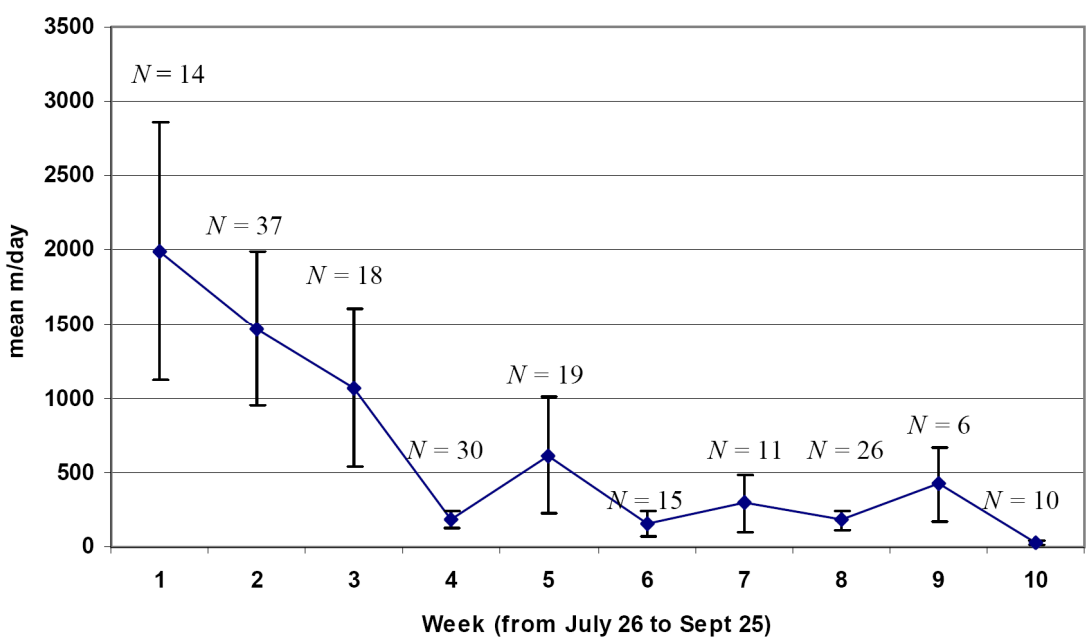

Figure 3.18. Mean Daily Distances (m/day, ± SE) Between Successive Locations of Acoustic Tagged Smallmouth Bass from Mobile Tracking and Autonomous Node Data from 26 July to 25 September. Sample size for each sample week is shown.

The number of days between successive locations (including release site) ranged from 1 to 62, with a mean of 8 days. The one smallmouth bass that relocated 62 days after its release was detected on the predator autonomous node, 450 m upstream of where it was released. Many relocations (62%) of the smallmouth bass occurred within each week.

3.2 Meteorological Station Results

Data collected at the four meteorological stations described in Section 2.8 were averaged over the hour to produce season-average summary statistics. More than 3185 measurements were collected between 13 June and 24 October. Figure 3.19 displays histograms of wind speed at the four stations; these are shown to provide the general range of wind speeds for the reservoir. Peak counts of wind speed were centered on 2 to 3 m/s, and wind speeds in excess of 8 m/s were generally rare.

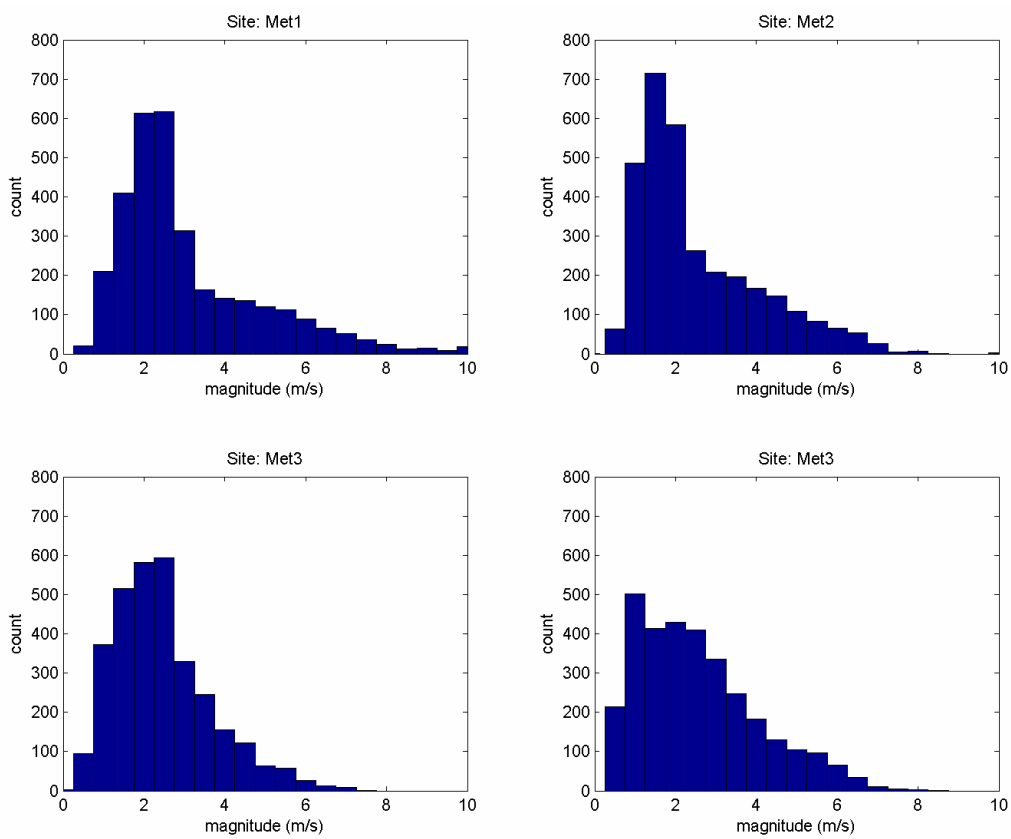

Figure 3.19. Wind Speeds at the Four Meteorological Station Sites During the Field Season (13 June to 24 October)

Figure 3.20 displays the angular histogram summary of winds at the four sites. Bars indicate the number of times a wind was blowing from a particular direction. At Met 1, Met 2, and Met 4, wind directions were generally bimodal; however, Met 3 was noted to deviate from this pattern and was trimodal. To put this information in context, these histograms were summarized using arrows to indicate wind direction in Figure 3.21. At Met 1, Met 2, and Met 4, the wind generally blows either upstream or downstream, and follows the river canyon. Winds at Met 3, which deviate from the bimodal pattern, are produced as a result of the large river bend downstream of the site and the opening in the river canyon near Lower Monumental Rock (river bend).

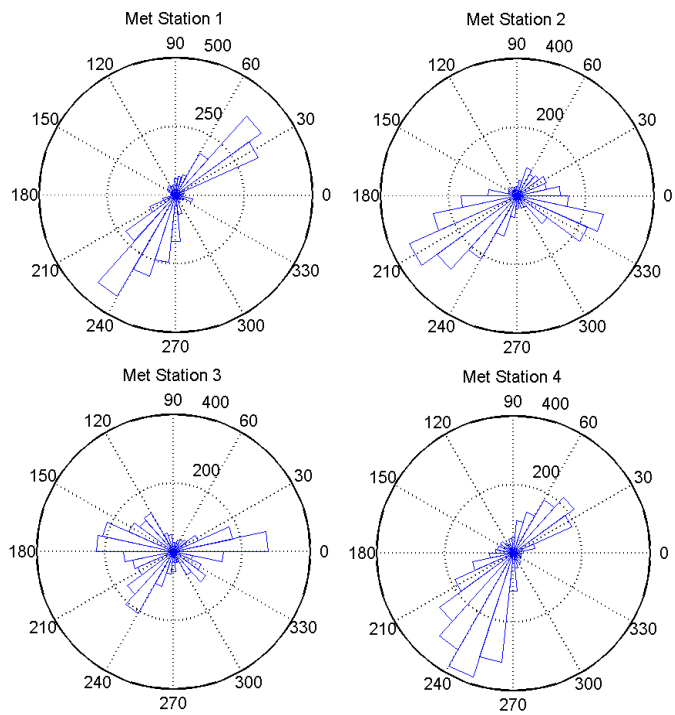

Figure 3.20. Wind Direction at the Four Meteorological Station Sites During the Field Season (13 June to 24 October). Directions represent the angle from which the winds are coming (see Figure 3.21).

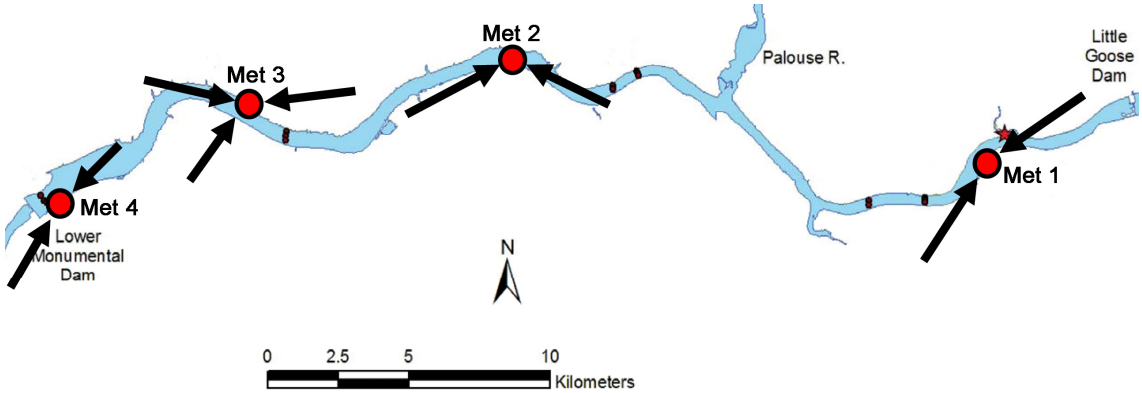

Figure 3.21. Observed Wind Directions Along Lower Monumental Reservoir. Arrows represent direction only and have not been scaled to represent magnitude.

A comparison of wind speed variations between the four meteorological stations was examined by first creating scatter plots (see Figure 3.22). These plots compare wind speeds at Stations 1 through 3 to speeds measured near Lower Monumental Dam (Station 4). As perhaps expected because of their location, more points lie off the line of equality for the Station 1 versus Station 4 plot than any of the others. The largest deviations from the line of equality occurred at high Station 1 speeds (i.e., > 4 m/s) and often differed by more than 2 m/s. Correlation coefficients are as follows: S4 and S3 = 0.80; S4 and S2 = 0.77; and S4 and S1 = 0.75.

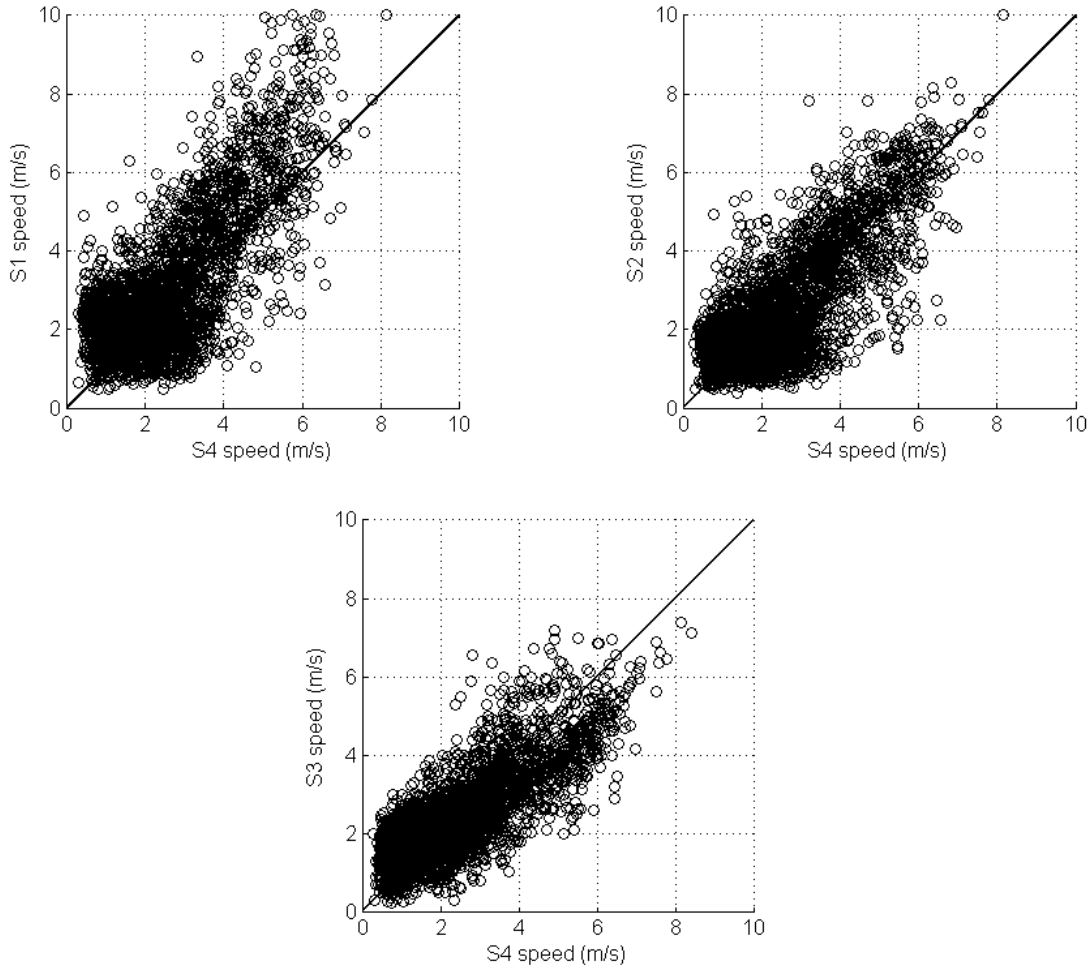

Figure 3.22. Wind Speed with Line of Equality

To further analyze the wind speed differences between the stations, Bland-Altman (1986) plots were created comparing differences in wind speeds between Station 4 (S4) and the other three meteorological stations. The Bland-Altman plot of S1 and S4, like the scatter plot comparing these two stations, clearly indicates that larger differences occur at higher wind speeds. The mean (S4–S1) difference was −0.5 m/s, and the Bland-Altman limits of agreement were 1.8 and −2.9 m/s. Mean differences dropped for (S4-S2), and was approximately zero (~0.6×10^{-04} m/s). Limits of agreement were 2.0 and −2.0 m/s. Although the mean difference was slightly higher at 0.1 m/s for (S4-S3), the limits of agreement were smaller at 1.9 and −1.7 m/s.

In summary, relatively good agreement in wind speeds was observed between Station 4 (near Lower Monument Dam) and the other three stations at low to moderate wind speeds. However, during periods when wind speeds were higher than 4 m/s at Station 1, wind speeds at Stations 2 through 4 were lower (Figure 3.23). Nevertheless, because of the relative similarity between Stations 2 through 4, the majority of the reservoir water column that experienced stratified conditions also experienced wind shear stresses of approximately the same magnitude.

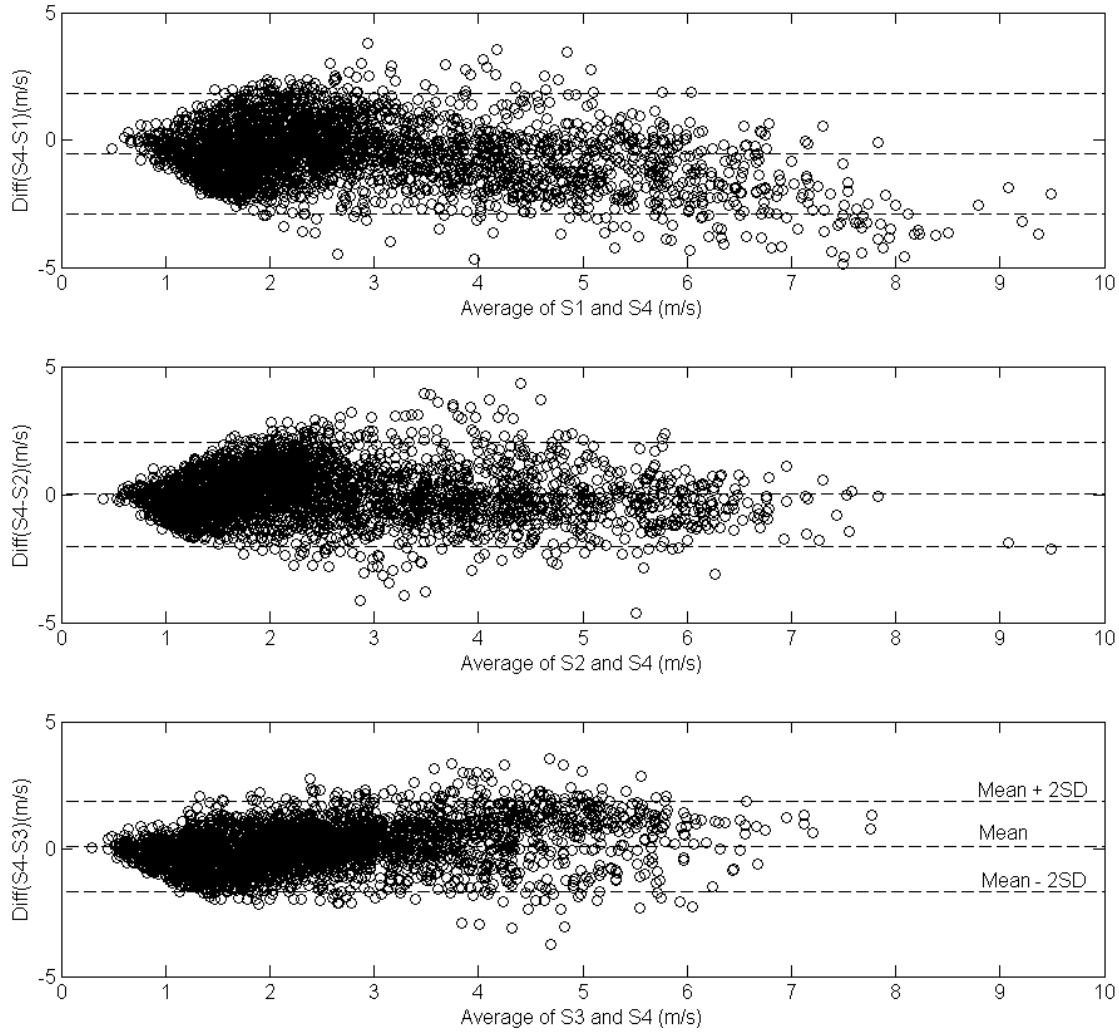

Figure 3.23. Wind Speed Differences Between Station 4 and the Other Three Meteorological Stations

3.3 Hydraulic Studies Results

At the onset of this project, relatively few vertical profile data sets of water velocity and water temperature had been collected in Lower Monumental Reservoir. During the summer months of 2003 and 2004, vertical strings of water temperature loggers collected data at mid reservoir and the upstream edge of the BRZ. Data from these loggers indicated that the water column stratified during the summer when flow augmentation from Dworshak Reservoir cooled releases from Little Goose Dam below equilibrium temperature. However, vertical temperature gradients were noted to be less at Lower Monumental Reservoir than those observed in both Little Goose and Lower Granite reservoirs (Cook et al. 2006). Numerical modeling results indicated the potential for underflow conditions to develop in Lower Monumental Reservoir during periods of stratification (Cook et al. 2006). However, these circulation patterns had not been verified with in situ measurements before this project.

Results presented in this section show that for the summer of 2006, an underflow condition developed in early July near the midpoint of Lower Monumental Reservoir. Stratified conditions extended downstream from the plunge line to the dam, and stratification persisted through September.

3.3.1 Vertical Temperature Gradients

Eleven to 17 loggers were deployed at each Snake River site (fewer were deployed in the Tucannon and Palouse rivers; see Figure 2.9), and results from all loggers can be viewed in Appendix B. To facilitate visualization of vertical gradients, figures in this section have been reduced to two loggers—one placed in the upper water column (although not the logger closest to the surface because diurnal variations may skew interpretation) and a second placed near the bottom of the water column.

At LMN 2, temperatures were approximately isothermal throughout the entire field season. Although daily temperature differences approached 1°C during August, there were periods during each day when differences vanished and the water column temperature became uniform. At LMN 3, the water column returned to an isothermal state each day until the end of July. Between the end of July and mid September, multi-day periods were observed when 24-hr-average temperature differences were approximately 1°C. It should be noted that these differences are relatively small compared to differences observed at sites downstream of LMN 3.

At sites LMN 5 and downstream, temperature differences between the upper and lower water column were routinely in excess of 1°C during all times of the day. At LMN 5, a difference greater than 1°C began on the morning of 30 June and persisted until the early morning of 7 July (see Figure 3.24). A more-weakly stratified period began soon afterward and persisted until midday on 13 July. Starting on 14 July, the water column again stratified, reaching a peak temperature difference of more than 3°C on 24 July when the upper water column temperature reached values higher than 24°C. Although temperature differences between the upper and lower water column decreased after the end of July, the water column remained stratified by more than 1°C until 15 September, except for a brief (<12-hr) mixing period during the night of 30 August that lasted until the early morning period of 31 August.

Water temperature patterns at LMN DST and LMN 7 (forebay BRZ) were similar to those at LMN 5 (see Figure 3.24). Slight differences between these three sites were noted during mixing events on 30 June and 7 July. The water column at neither LMN DST nor LMN 7 became isothermal during these events; however vertical temperature differences did decrease. It was noted that, on average, peak upper water column temperatures at LMN 7 were less than those at LMN DST and LMN 5. Therefore, although stratification was more persistent at the LMN 7 than LMN 5, temperature differences between the top and bottom of the water column were less.

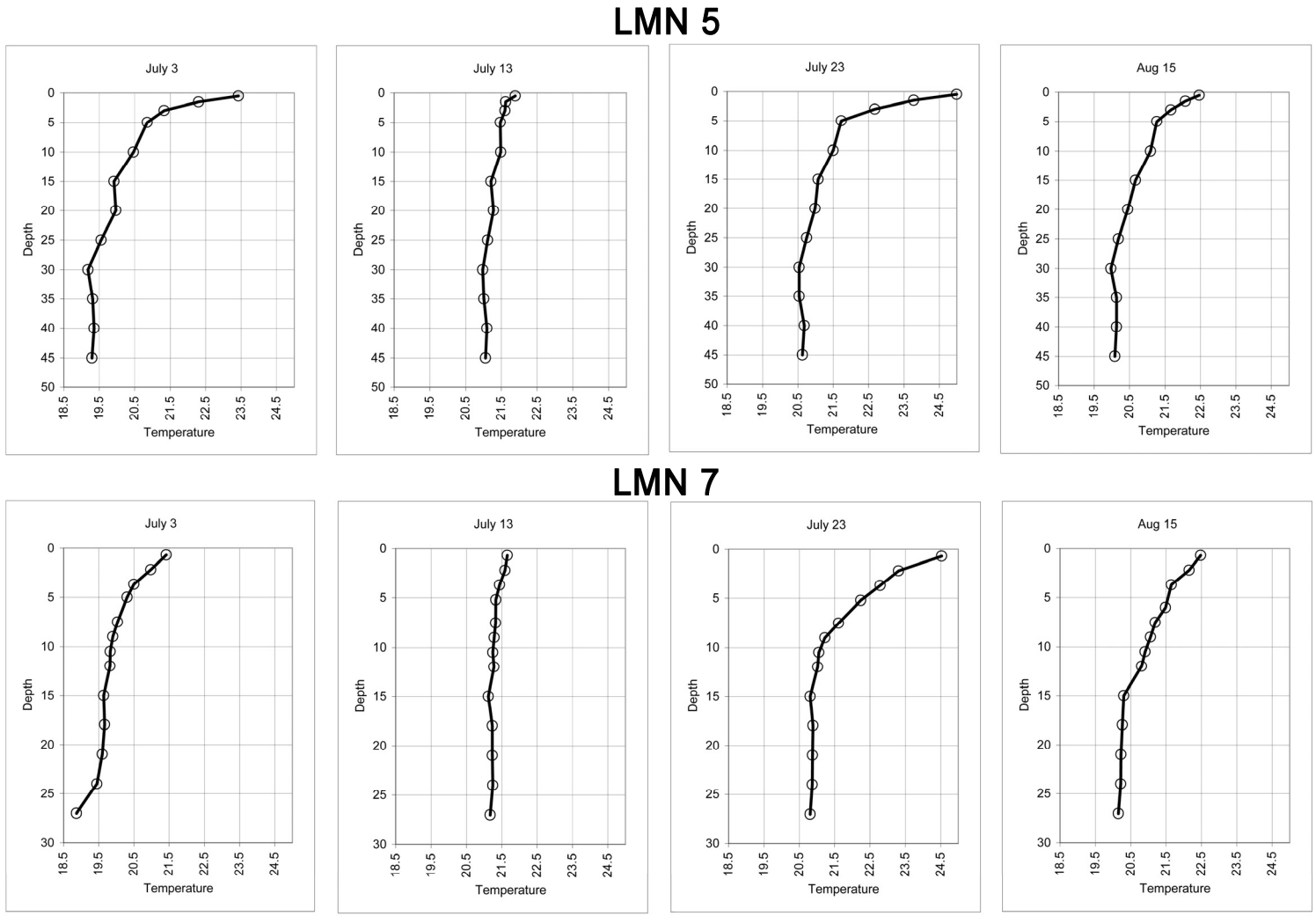

Figure 3.24. Representative Water Temperature Profiles at Sites LMN 5 and LMN 7 (see Figure 2.9)

3.3.2 Development and Persistence of Underflow Hydraulic Conditions

A river entering a reservoir will nearly always be at a different density than the surface water in the reservoir due to temperature, salinity, or turbidity differences. As the river water enters the reservoir, it will push the more stagnant reservoir water ahead of itself only until buoyancy forces have become sufficient to hold up the inflow. At that point, the inflowing water will either flow over the surface of the reservoir if it is lighter or plunge and flow submerged if it is heavier (Fischer et al. 1979). If the flow is heavier and the reservoir is sufficiently deep, the plunging underflow will entrain water and continue downward only until it is neutrally buoyant relative to the adjacent water in the reservoir (Imberger and Patterson 1990). At this point, the underflow will become a subsurface interflow (Wetzel 2001). Schematics of the three conditions are graphically depicted in Figure 3.25. The dynamics of these flows is a subject in itself, and details on each condition, including additional references, can be found in Imberger and Patterson (1990).

During the summer months of 2006, an underflow condition developed in Lower Monumental Reservoir as a result of flow augmentation (hypolimnetic releases) from Dworshak Reservoir. A schematic of this condition, once it had fully developed in Lower Monumental Reservoir, is provided in Figure 3.26. Flow entered the upper end of the reservoir from Little Goose Dam below equilibrium temperature. Water temperature and specific conductance measurements show that the water was of a uniform density at the upstream edge of the reservoir.

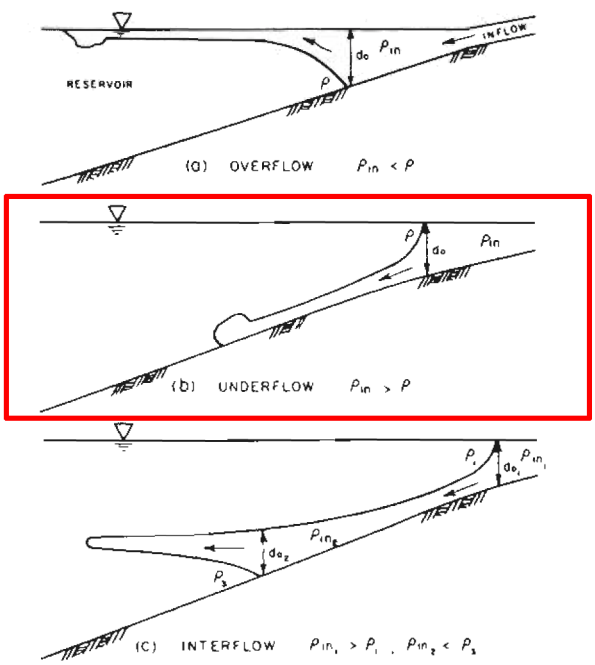

Figure 3.25. Inflow into Lakes and Reservoirs (Source: Wetzel 2001)

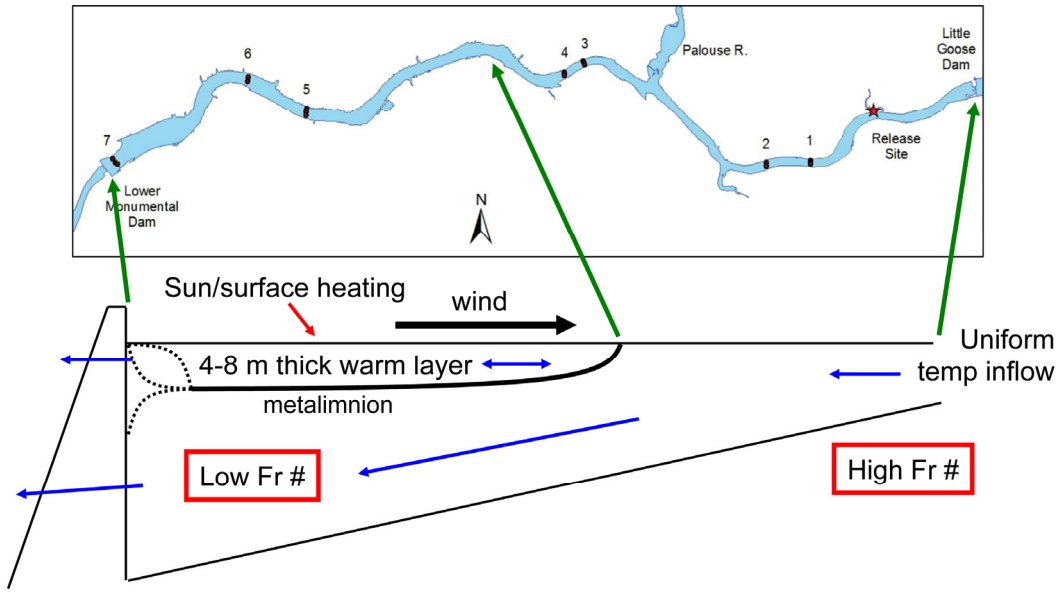

Figure 3.26. Lower Monumental Reservoir and Underflow Conditions That Developed During the Study Period

The plunge line was typically observed and monitored using the mobile ADCP. Between 14 July and 15 September, the plunge line was observed between LMN 4 and LMN 5, except for two periods—a reservoir-wide mixing event on 30 August (i.e., the line vanished) and between 28 July and 1 August. During the 28 July to 1 August period, the location of the plunge line moved upstream to LMN 3. This period corresponds to when the peak upper water column temperatures occurred during the study (see Figure 3.27). Movement of the plunge line upstream to LMN 3 was noted in records from both the temperature logger (e.g., stratification > 1°C) and ADCP time series (upstream motions detected; see Appendix C). Although this was the only period during which we measured upstream water motions between 14 June and 8 August (period of time the ADCP was at LMN 3), upstream motions at LMN 3 may have occurred later in August and September. These motions are suspected because densimetric Froude (Fr) values were small (i.e., below the Fr cutoff; see Section 3.3) on several occasions.

Between 30 June and 14 July, underflow conditions were developing in the lower-half of the reservoir, and this time should be considered a period of hydraulic transition for the reservoir. During this period, the lower-half of the reservoir experienced a full range of conditions: strong stratification (30 June–7 July), weak stratification (7–14 July), and isothermal (July 7). Placement of the plunge line, when it existed, is difficult to determine during the transition period.

Prior to 30 June, the reservoir was stratified only near the dam (LMN 7 and LMN DST temperature logger sites), and ADCP data collected at the upstream edge of the BRZ (LMN 7) indicates the entire water column was moving uniformly downstream except for a brief 6-hr period in the early hours of 27 June. Based on the data we collected, we were not able to determine whether a plunge line existed between LMN 6 and LMN 7 during the 15–30 June period, although temperature differences were >1°C at LMN DST (see Figure 3.27).

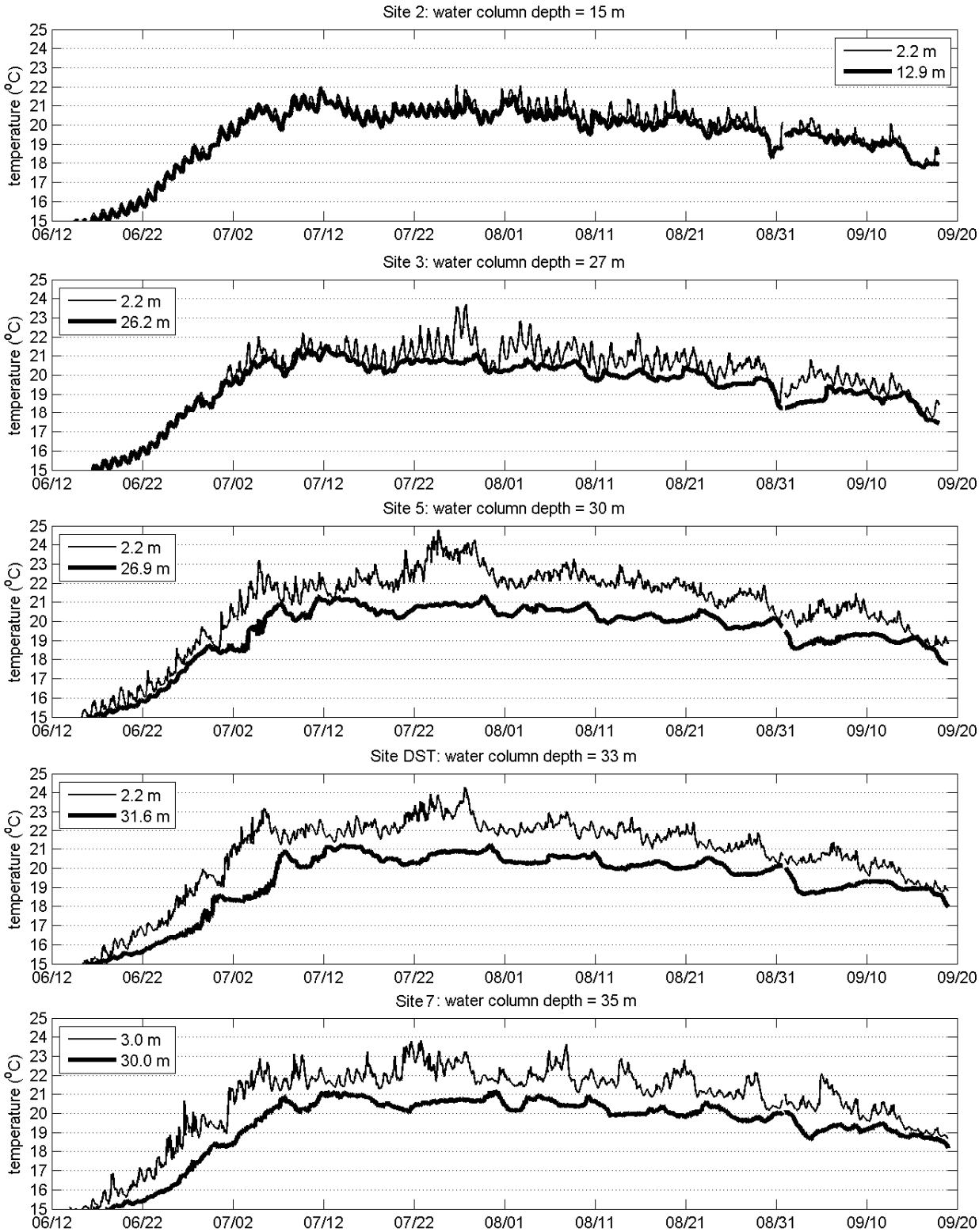

Figure 3.27. Near-Top and Bottom Temperature Logger Time Series Data at the Five Sites (see Figure 2.9). The maximum depth of the water column is noted in the title of each plot.

Downstream of the plunge line, the water column was stratified and water traveled both upstream and downstream in the upper portion of the epilimnion. The upstream-moving water was separated by a layer of almost zero velocity (i.e., a shear layer). The distance from the surface to the middle of the shear layer varied; however, it generally was 4 to 8 m. A typical transect of water velocity data collected in this zone is displayed in Figure 3.28. At the time these data were collected, the total temperature difference across the water column was 2°C, with most of this difference occurring in the shear layer zone (depths of 4 to 14 m).

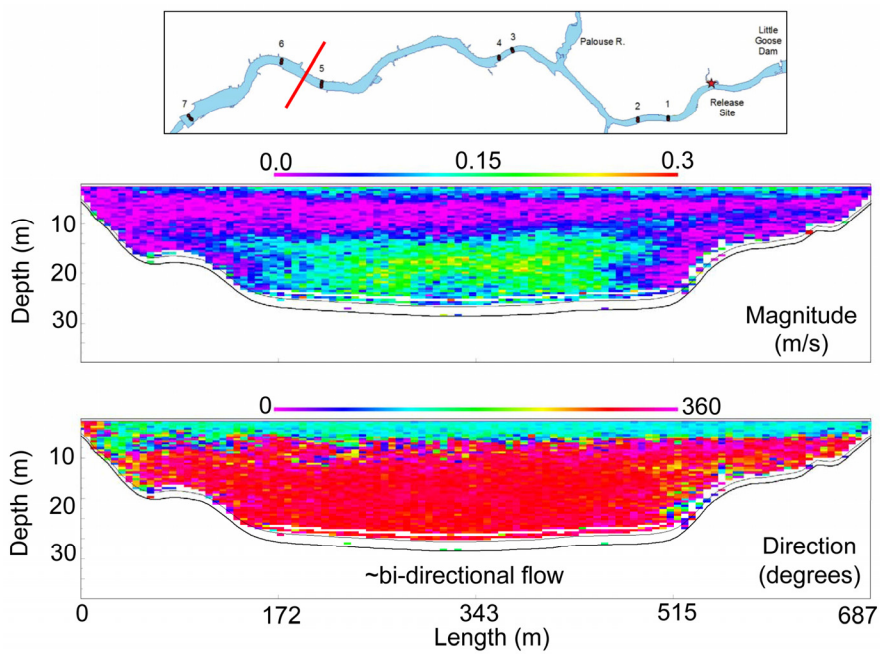

Figure 3.28. ADCP Transect on 1 August Between Sites LMN 5 and LMN 6. River discharge was 25.9 kcfs. The upstream moving layer (teal-colored directions) extends vertically downward from the surface to a depth of 6 m.

3.3.3 Characterization of the Water Column Using the Densimetric Froude Number

The densimetric Froude number (Fr) represents a balance between the inertial forces associated with the local flow and the gravitational forces induced by the density gradient. It is a nondimensional ratio, or index, and is commonly used to predict plunge line formation (Wetzel 2001), applicability of numerical modeling assumptions (Imberger and Patterson, 1990), and to generalize or classify conditions in stratified reservoirs (Fischer et al. 1979). The equation for the Fr as it was applied for this study is as follows:

$$Fr = \frac{Q/A}{\sqrt{g\frac{\Delta\rho}{\rho}D}}$$

where Q is the discharge through the reservoir, A is the cross-sectional area, g is gravity, ρ is the density of the inflow, $\Delta\rho$ is the density difference between the near-surface and bottom temperature logger (see Figure 3.27), and D is the depth. The appropriate depth to use in the Fr is not uniformly defined between

references. For this application, the absolute value of the Fr is not as important as the relative differences over time; hence, the value can be considered a scale factor. In Table 3.9, the hydraulic properties for each logger site are presented, determined using multiple ADCP transects at each location. Depth values used in the analysis were computed by integrating the bathymetric measurements across the cross sections. Interestingly, these average depth values and depth values computed by dividing the area (A) by the top width (T), as suggested by Fischer et al. (1979), are approximately equal.

Time series of Fr values, which were computed at all temperature logger sites, are shown in Figure 3.29. At LMN 2 and LMN 3, Fr values are very large, which is consistent with the nearly isothermal conditions, and hence small density differences, at the sites. Time series Fr values at LMN 5, LMN DST, and LMN 7 (forebay BRZ) drop rapidly as the lower half of the reservoir stratifies.

To put Fr values in context with physical phenomena occurring in Lower Monumental Reservoir, time series plots of Fr and ADCP water direction were created. Two examples are shown in Figure 3.30 and Figure 3.31; a complete set of figures presenting all bottom-mounted ADCP data is presented in Appendix C. At the forebay BRZ, the Fr values shown in Figure 3.30 decline rapidly as river discharges decline and water temperature differences increase in late June. Water directions both near the surface and bottom are unwavering, following a downstream path, except for a brief 6-hr period in the early hours of June 27. A time series of angular differences was computed and filtered based on the empirically determined Fr value at the site. Histograms of these filtered differences were then displayed at the bottom of each figure.

A cutoff Fr value was determined empirically using the bottom-mounted ADCP data sets. Whenever the Fr was greater than or equal to the cutoff, the entire water column was moving uniformly downstream. Because there is always some variation in velocity direction, especially at low speeds, angular differences of 60° or less were considered as moving in the same direction. It should be noted that whenever the Fr is less than the cutoff, water direction in the epilimnion is uncertain. Only when the Fr is above or equal to the cutoff is the direction of the epilimnetic water known. Defined in this way, a low Fr value is a necessary condition for epilimnetic water to be moving upstream. However, a low Fr is by itself not sufficient to know which direction the epilimnetic water is traveling.

Table 3.9. Hydraulic Properties at the Temperature Logger Sites Used To Compute the Densimetric Froude Number

Site	Location (RM)	Location (rkm)	Area (m^2)	Top Width (m)	Avg Depth (m)	A/T Depth (m)	Max Depth (m)
LGS tailrace	69.3	111.4	3,242	426	7.3	7.6	9.9
LMN 2	63.0	101.4	4,967	387	13.0	12.8	15.2
LMN 3–4	57.0	91.7	6,715	356	18.7	18.9	27.2
LMN 5	48.0	77.2	10,260	477	21.7	21.5	30.1
LMN DST	44.0	70.8	21,809	1,145	19.0	19.0	32.5
LMN 7	42.0	67.6	15,250	612	24.4	24.9	34.6

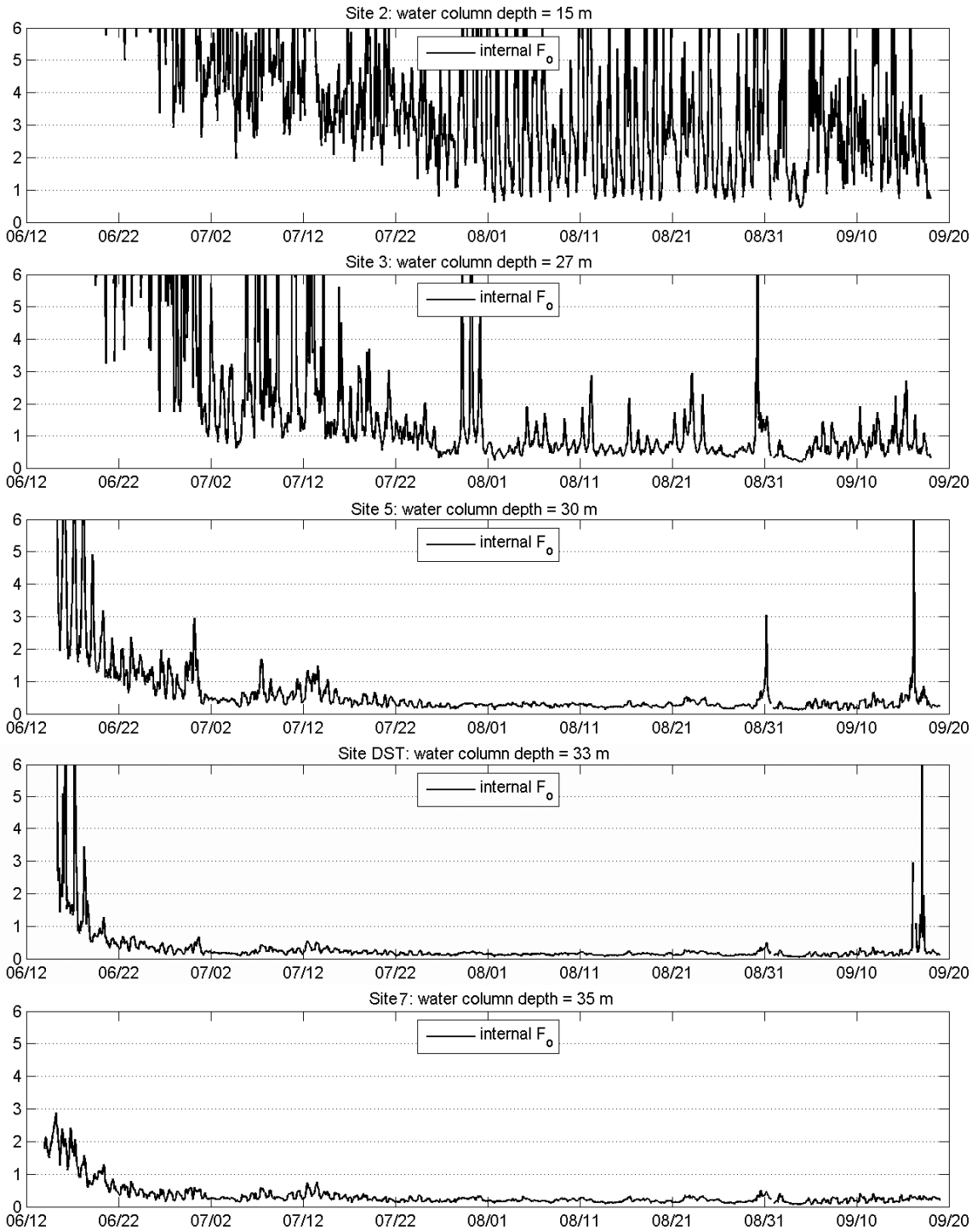

Figure 3.29. Densimetric Froude Number at the Monitoring Sites (see Figure 2.9)

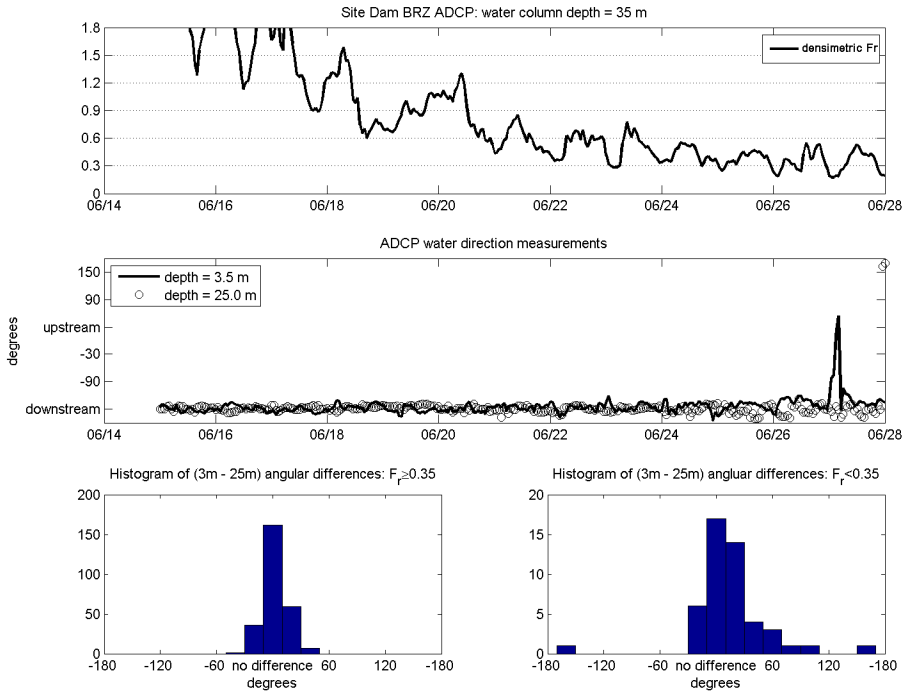

Figure 3.30. Time Series of Densimetric Froude Number and Water Directions at LMN 7 in June with Histograms of Angular Differences in Water Direction Both Above and Below the Fr Cutoff

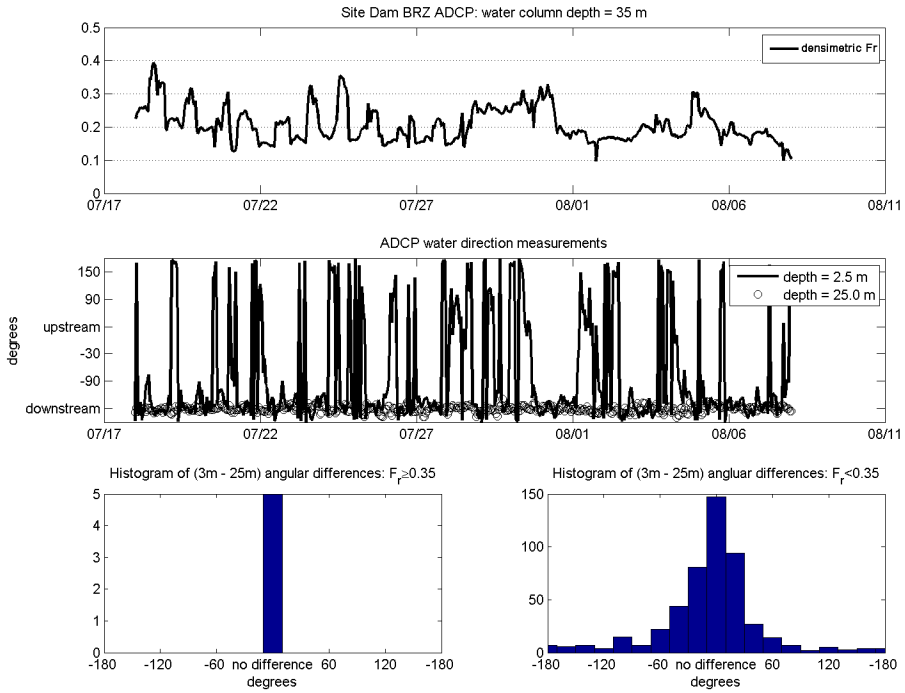

Figure 3.31. Time Series of Densimetric Froude Number and Water Directions at LMN 7 in Late July/Early August with Histograms of Angular Differences in Water Direction Both Above and Below the Fr Cutoff

Figure 3.31 presents ADCP data collected at the edge of the forebay BRZ (LMN 7) from the end of July until early August. Unlike the previous period, this period contains numerous incidents when the upper water column deviates from in the same direction as deeper in the water column. Using the identical Fr cutoff value as the previous period, the histograms show that, as predicted, whenever the Fr value is greater than or equal to the cutoff, the water is moving coherently downstream. Likewise, if the Fr value is less than the cutoff, the water can be moving upstream, downstream, or laterally.

Fr cutoff values were determined for each of the three sites where bottom-mounted ADCP data were collected (Table 3.10). Although the data collection periods at LMN 3 and LMN 5 were much less than at LMN 7, the data set at each site contained at least one period when non-downstream movements of the upper water column was observed. This allowed for the Fr cutoff to be empirically determined at each of the three sites.

Table 3.10. Densimetric Froude Number Cutoffs as Determined from Bottom-Mounted ADCP Data Sets

	Froude Number Cutoff
LMN 7	0.35
LMN 5	0.70
LMN 3	0.60

3.3.4 Velocity Profiles at the Upstream Edge of the BRZ (LMN 7)

Bottom-mounted ADCP time series data sets were collected continuously during the field study at the upstream edge of the BRZ (LMN 7). Two ADCPs were placed in this area on two occasions: 14 June and 8–10 August. These short-term data sets were used to investigate lateral variations in the flow field across the upstream edge of the BRZ. Outside these two periods, only a single ADCP was deployed at this site. Long-term time series data from this ADCP were used to understand how velocity profiles varied in response to changes in river discharge, dam operations, and vertical temperature gradients.

3.3.4.1 Lateral Variations in Velocity Profiles

3.3.4.1.1 14 June: High River Discharge

On 14 June, the Lower Monumental Project went from spilling 30% to 87% of the total river discharge for a brief 5-hr period. During this period, the total project discharge was held approximately constant between 104 and 109 kcfs. For this test, the two ADCPs were 120 m apart, with one being aligned with the centerline of the spillway and the other aligned with the centerline of the powerhouse (see). Profiles of velocity magnitude and direction, which were collected every 2 minutes, were averaged over 1 hr. The averaging period began only after project conditions had been held steady for more than 1 hr, which allowed the reservoir to adjust to the new project operations. The averaging period for the 30% spillway discharge extended from 0.5 to 1.5 hr, while the averaging period for the 87% spillway discharge extended from 3 to 4 hr.

Profiles of velocity magnitude and direction are presented in Figure 3.32. At both ADCP locations, and during both project operation scenarios, the water column was moving downstream. The change in current direction between the two project operations was less than 10° in the top 15 m of the water column and negligible below this depth. The vertical profile of velocity magnitude changed shape slightly with the changes in project operations, with slightly higher water speeds at depths between 20 to

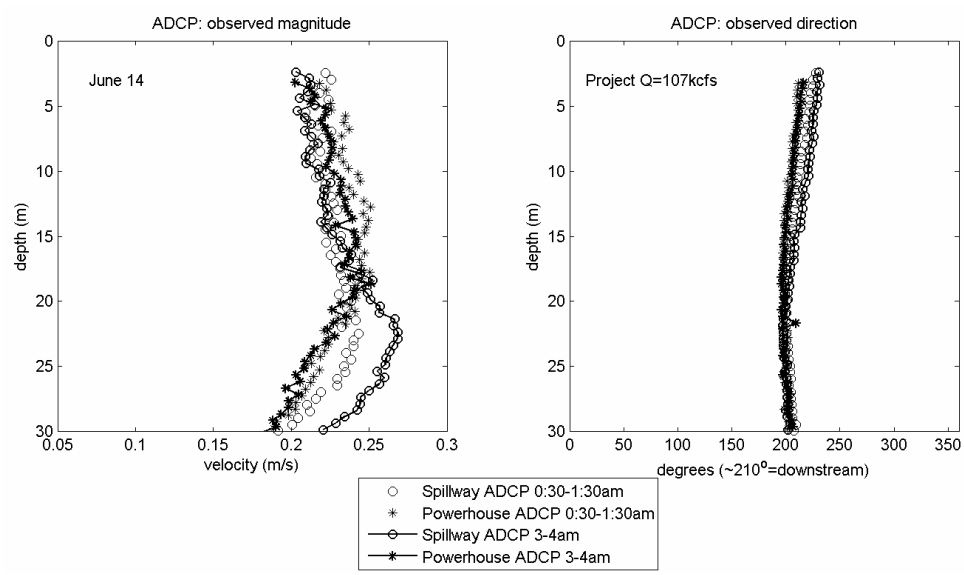

Figure 3.32. Profiles of Water Velocity Magnitude and Direction Collected at the Upstream Edge of the BRZ (LMN 7) on 14 June. The difference in temperature between the 3-m and 30-m loggers was 0.3°C.

30 m and slightly lower water speeds higher in the water column. These changes were small, however, and represent a shift of approximately 0.02 m/s or less than 10% of the depth-averaged velocity magnitude. Therefore, at this distance from the dam (~500 m) and at this project discharge, the water column is insensitive to alterations in project operations.

3.3.4.1.2 8–10 August: Low River Discharge

Water velocity profile data were collected using two ADCPs deployed at the edge of the BRZ between 8 August at 1700 hours and 10 August at 1000 hours. The ADCPs were 230 m apart, as shown in . Project operations at Lower Monumental Dam were steady during the period, and the period-averaged discharge was 27.7 kcfs. Only Turbine Unit 2 was operating, as were spillway bays 2, 6, and 8. During this period, barge traffic forced closure of voluntary spill for three brief periods, all of which were 15 minutes or less. Although ADCP data were collected every 2 minutes, these barge-induced spillway outages were not detectable in the ADCP profiles.

The velocity profiles shown in Figure 3.33 were produced by averaging the ADCP profile data over the entire period. At a depth of 10 m, the spillway-aligned velocity magnitude appears faster than that recorded at the powerhouse-aligned ADCP. However, it should be noted that the magnitude values at this depth are 0.079 (ADCP Powerhouse) and 0.095 (ADCP Spillway) or a difference of 0.016 m/s. Therefore, although a difference is detectable, the difference is small. At this distance from the dam and at this project discharge, there are no significant lateral variations in the velocity flow field.

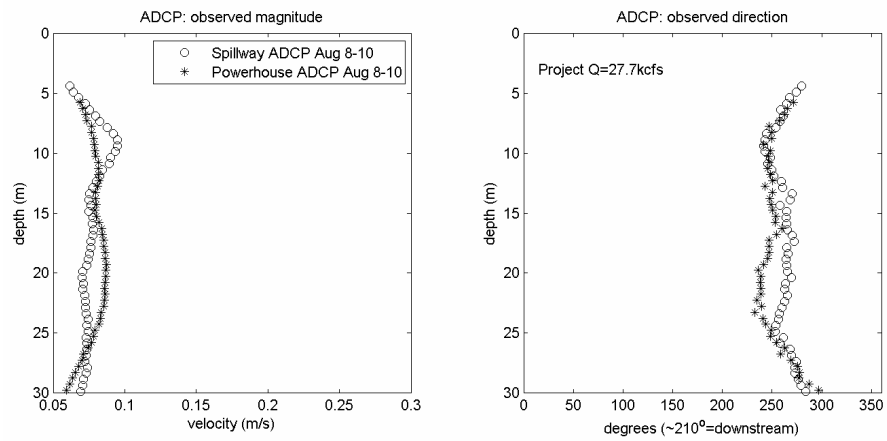

Figure 3.33. Profiles of Water Velocity Magnitude and Direction Collected at the Upstream Edge of the BRZ (LMN 7) between 8 and 10 August. The difference in temperature between the 3-m and 30-m loggers was 1.3°C.

3.3.4.2 Variations in the Velocity Profile as a Function of Dam Operations at the Upstream Edge of the BRZ

A single ADCP was deployed at this site (LMN 7) during the field study. Long-term time series data from this ADCP were used to understand how velocity profiles varied in response to changes in river discharge, dam operations, and vertical temperature gradients. The following series of figures describes the vertical variations in horizontal velocity magnitude and direction. The angular sign convention for these data is as follows: an angular measure of 0° represents water flowing toward the east, and an angular measure of 90° represents water flowing toward true north. As shown in Figure 3.34, an angular measure of 210° represents water flowing toward the powerhouse. The velocity profile figures that follow have been annotated to indicate the angular measure for flow traveling upstream (~30°) and toward the navigation lock guide wall (~250°).

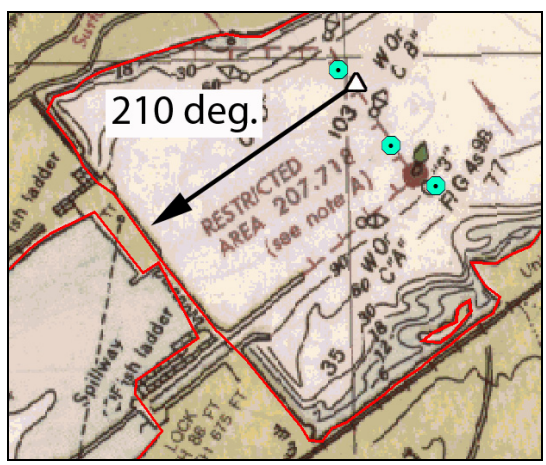

Figure 3.34. Deployment Location of the ADCP (white triangle) and Hydroacoustic Nodes (teal circles) Deployed Along the Upstream Edge of the BRZ. At the ADCP location, an angular measure of 210° represents the direction water would be traveling if flowing directly toward the powerhouse.

Figure 3.35 presents data collected when the project discharge was approximately 100 kcfs. Although a slight trend of increasing velocity magnitude with depth was noted, the variation over the profile was less than 0.03 m/s. The angular direction of the water was uniform throughout the water column and was oriented directly toward the powerhouse.

Figure 3.36 presents data collected when the project discharge was approximately 60 kcfs. The shape of the velocity magnitude profile was strongly slanted, with magnitudes greater than 0.2 m/s at depths greater than 10 m, and magnitudes less than 0.1 m/s at depths below 20 m. At magnitudes less than approximately 0.1 m/s, the coherent directional structure was lost, and the influence of small-scale turbulence induced a wavering in the flow direction. The wavering in the flow direction can be removed by averaging measurements over longer time periods than the 4-hr period used to construct the figure.

Figure 3.37 presents data collected when the project discharge was approximately 45 kcfs. A dramatic shift in the velocity profile was noted over the relatively small range of discharge between 60 and 45 kcfs. At the time both of these measurements were collected, the vertical temperature gradients, computed by subtracting the 3-m temperature from the 30-m temperatures, were approximately the same (1.5°C versus 1.2°C). Coherence in the angular direction was again lost when the velocity magnitude dropped below 0.1 m/s, which occurred in the upper 6 m of the water column. Peak velocity magnitudes were approximately 0.15 m/s and occurred at depths between 11 to 13 m.

Figure 3.38 presents data collected when the project discharge was approximately 30 kcfs. The velocity profile shape in the upper water column was similar to that at 45 kcfs, with peak velocity magnitudes occurring near mid-depth. Peak values slightly eclipsed 0.13 m/s at depths between 13 and 15 m. Unlike the 45 kcfs velocity profile, magnitudes decreased in the lower water column. Coherence in angular direction was noted to decline whenever magnitudes dropped below 0.1 m/s in both the upper (<8 m) and lower (>24 m) portions of the water column.

Unlike the previous figures, which averaged data over periods of 6 hr or less, Figure 3.39 presents data that were averaged over an 18.5-day period. As shown in Appendix C, angular directions in the upper water column varied significantly throughout the averaging period, so the long-term trends shown in Figure 3.39 should not be interpreted as being representative of the instantaneous measurements. The general-trend peak velocity magnitude (0.12 m/s) occurred deep in the water column and at a depth of 21 m. Magnitudes were less than 0.1 m/s at depths above 16 m and deeper than 26 m. Although the average direction of travel at speeds less than 0.1 m/s were not directly upstream, they were oriented closer to upstream than downstream (angular directions between 300° and 350°; pointing toward the upstream south shoreline)

Figure 3.40 presents a 19.5-day average of velocity measurements. Although the peak velocity magnitudes are less than those in Figure 3.39, general trends in both magnitude and direction are similar between the two. As shown in Appendix C, angular directions in the upper water column varied significantly so the long-term trends shown in Figure 3.40 should not be interpreted as being representative of the instantaneous measurements. Consistent with the general decline in river discharge, the peak velocity magnitude was 0.09 m/s. Magnitudes were less than 0.08 m/s at depths above 19.5 m and deeper than 26 m.

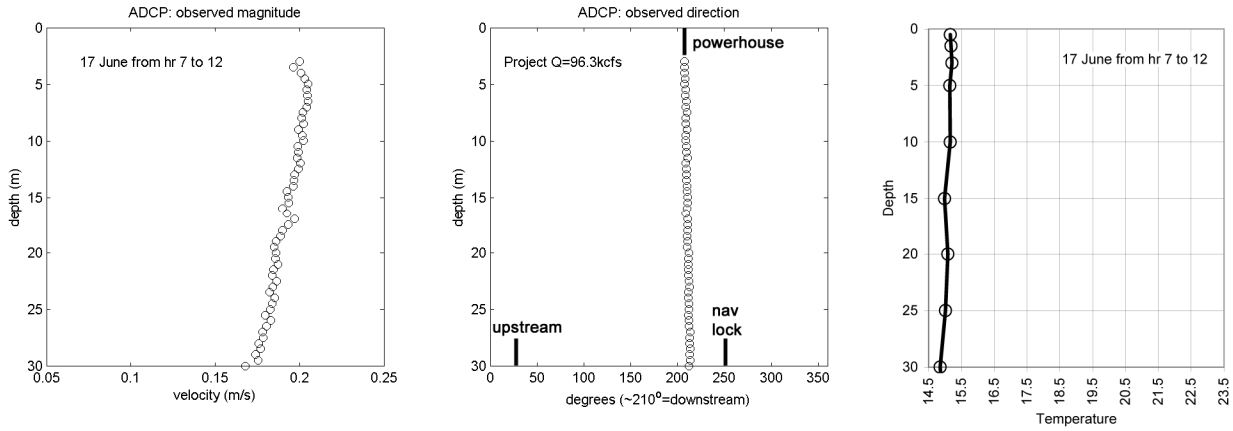

Figure 3.35. Velocity Profile at a Project Discharge of ~100 kcfs. See Figure 3.34 for a description of interpreting velocity direction. Water temperature in degrees centigrade.

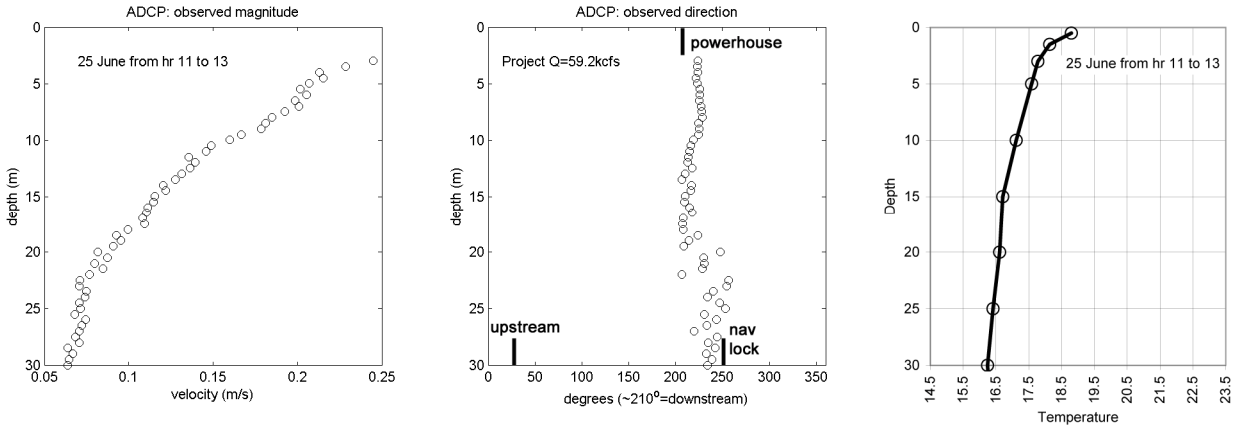

Figure 3.36. Velocity Profile at a Project Discharge of ~60 kcfs. See Figure 3.34 for a description of interpreting velocity direction. Water temperature in degrees centigrade.

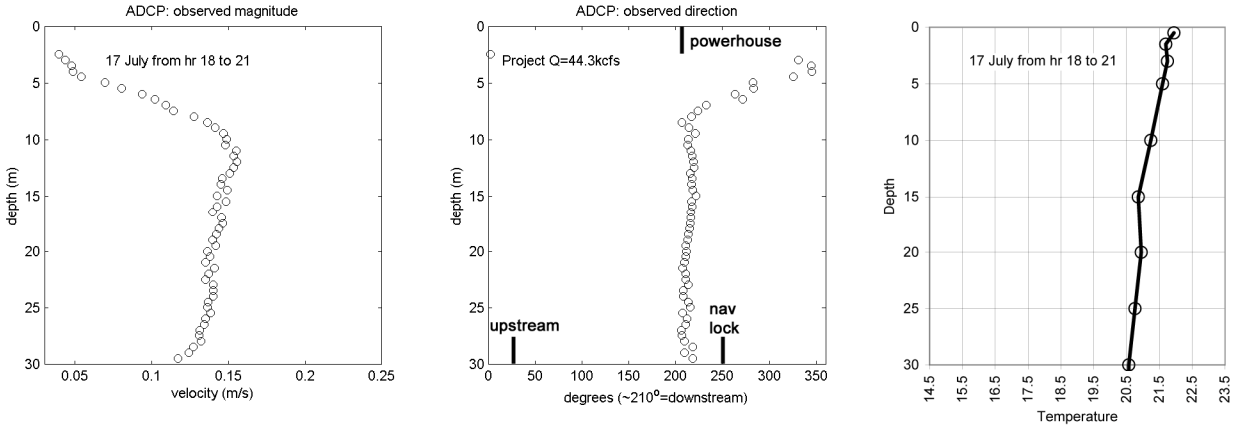

Figure 3.37. Velocity Profile at a Project Discharge of ~45 kcfs. See Figure 3.34 for a description of interpreting velocity direction. Water temperature in degrees centigrade.

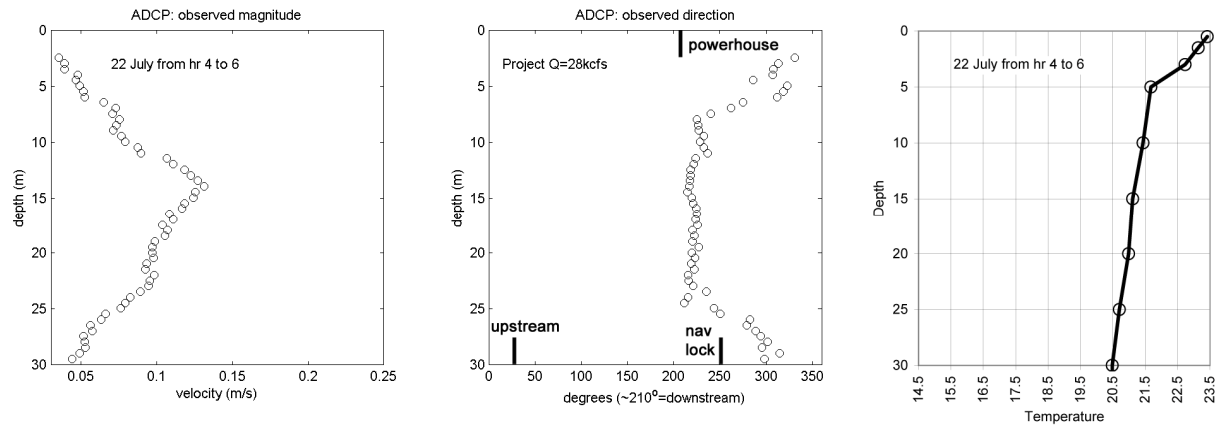

Figure 3.38. Velocity Profile at a Project Discharge of ~30 kcfs. See Figure 3.34 for a description of interpreting velocity direction. Water temperature in degrees centigrade.

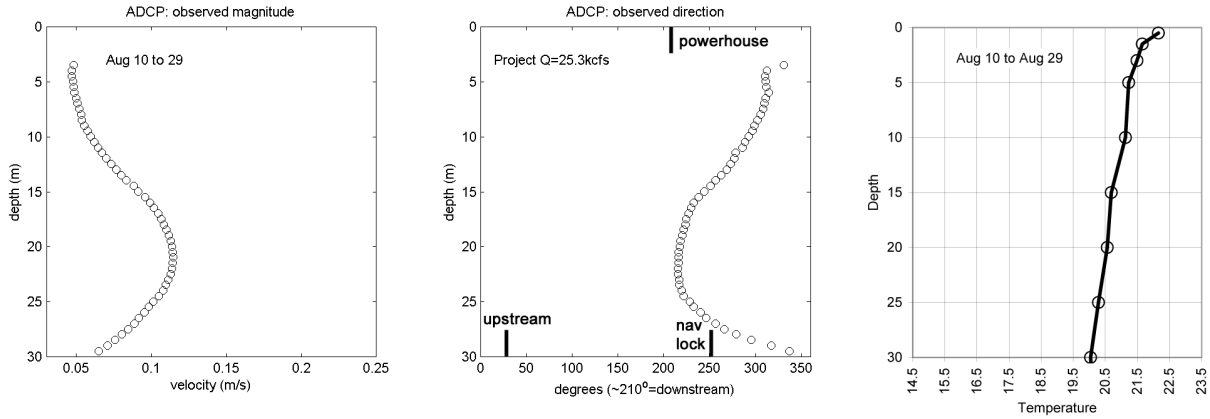

Figure 3.39. Long-Term Average Velocity Profile Spanning Several Weeks in August. See Figure 3.34 for a description of interpreting velocity direction. Water temperature in degrees centigrade.

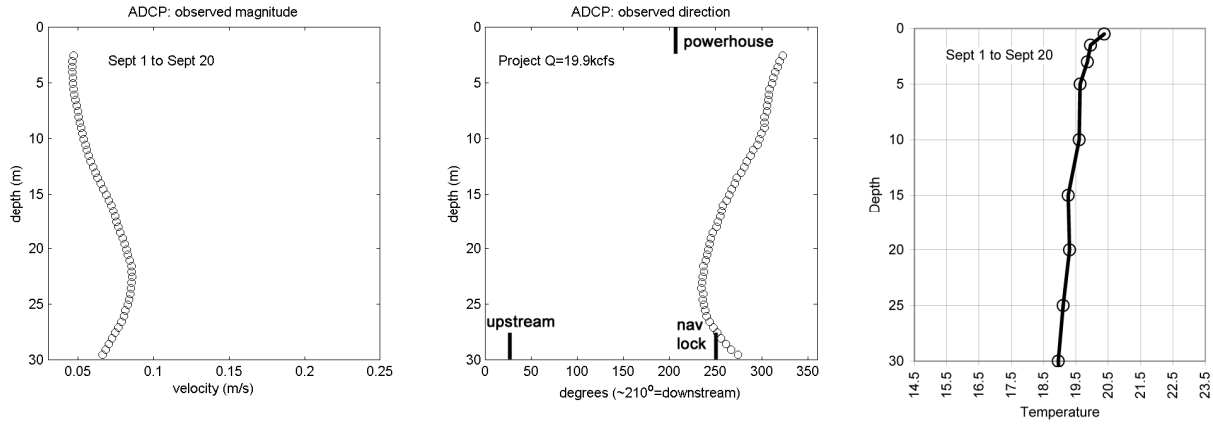

Figure 3.40. Long-Term Average Velocity Profile Spanning Several Weeks in September and After the Cessation of Spillway Releases. See Figure 3.34 for a description of interpreting velocity direction. Water temperature in degrees centigrade.

3.4 Numerical Model Results

3.4.1 Water Velocity

ADCPs were deployed in Lower Monumental Reservoir at LMN 3, LMN 5, and LMN 7. These observed water velocities and directions were compared to numerical model results at the same time/location. The primary water velocity calibration parameter in the model was bottom friction (Manning's n), and a sensitivity analysis of this parameter was performed. Figure 3.41 and Figure 3.42 compare observed versus simulated results for the period between 14 and 28 June at LMN 7.

The laterally averaged model categorizes the water as flowing either upstream or downstream (i.e., 210º for downstream or 30º for upstream at the forebay BRZ). The ADCP, however, measures flow direction in every direction. The model generally predicted the water speeds well. However, when the velocity magnitudes were lower than approximately 0.1 m/s, small-scale turbulent fluctuations become proportionally more significant. These small-scale fluctuations in velocity magnitude and direction were not well captured by the numerical model (see Section 3.4.3).

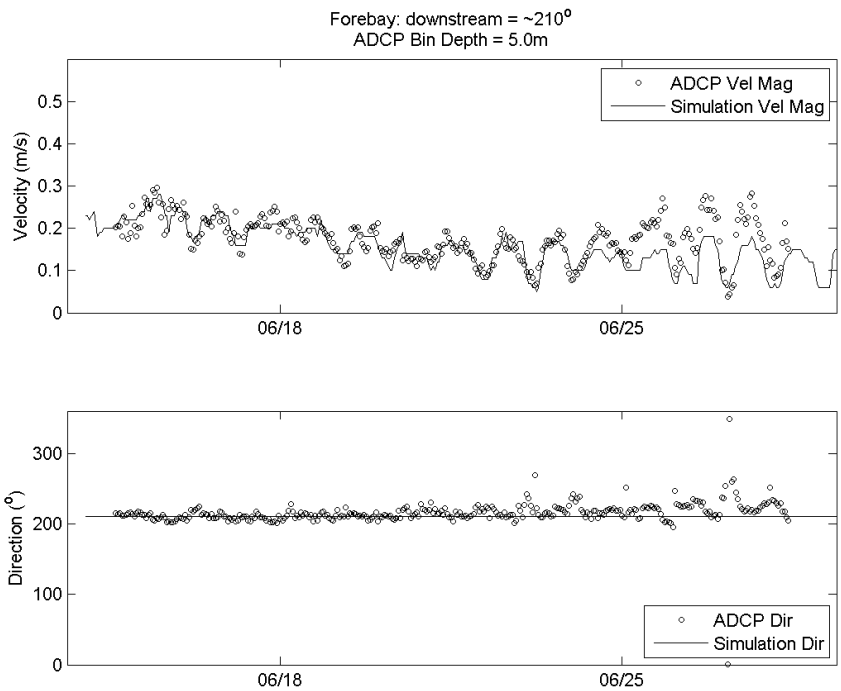

Figure 3.41. Sample Comparison of Observed and Simulated Velocities at LMN 7 (Forebay BRZ) at a Depth of 5.0 m

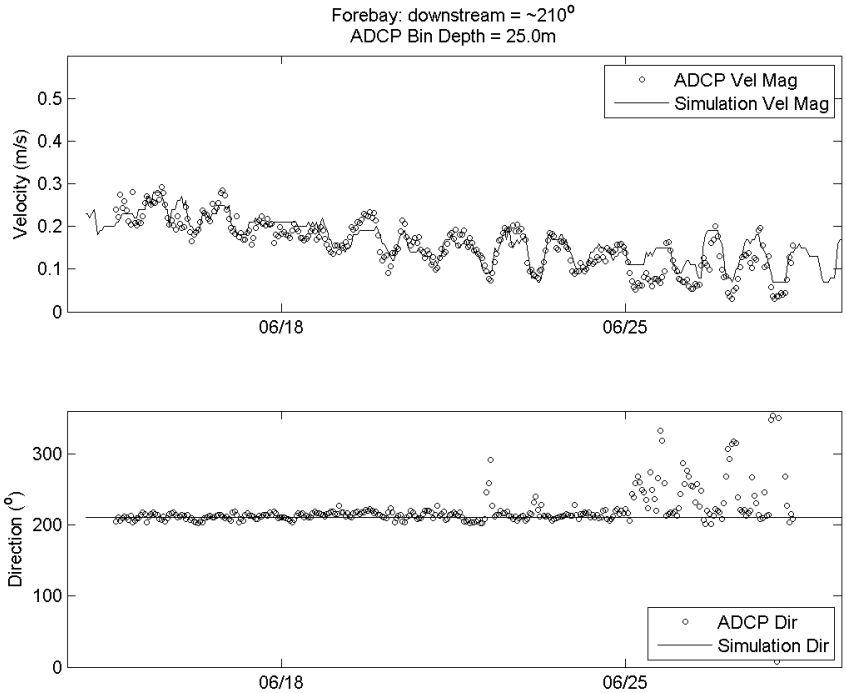

Figure 3.42. Sample Comparison of Observed and Simulated Velocities at LMN 7 (forebay BRZ) at a Depth of 29.5 m

3.4.2 Water Temperature

A temperature calibration was performed by comparing observed temperatures at LMN 2, LMN 3, LMN 5, LMN DST and LMN 7 against simulation results. Figure 3.43 compares simulated versus observed data at both the LMN 7 (upstream of the forebay BRZ). These graphics illustrate the ability of the model to effectively capture the wide range of conditions that occurred in the reservoir.

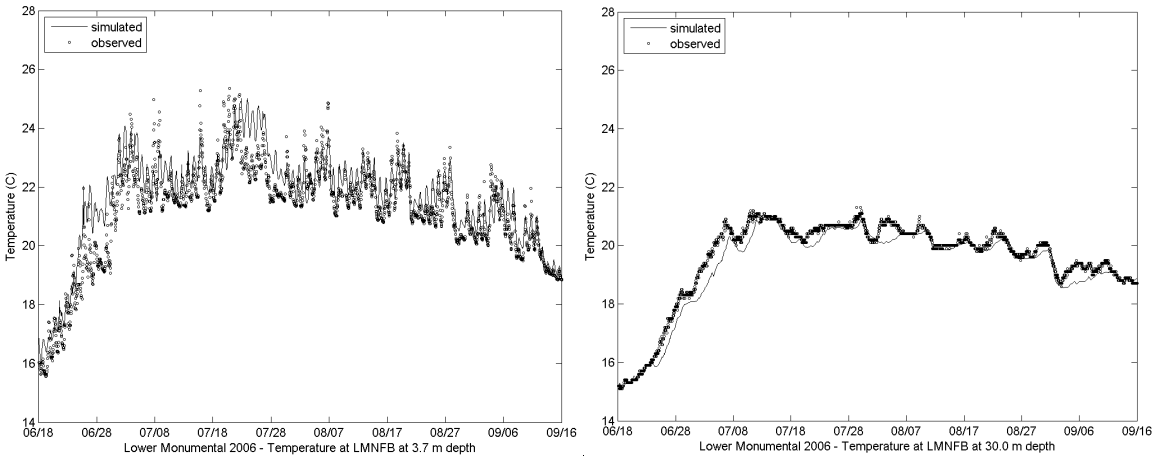

Figure 3.43. Sample Comparison of Observed and Simulated Data at Mid-Reservoir near the Surface (left) and Near-Bottom (right) at LMN 7

3.4.3 3-D Zones Not Captured by the 2-D Numerical Model

Most of the hydraulic and water temperature conditions observed in Lower Monumental Reservoir can be approximated sufficiently using a 2-D laterally averaged model. However, this section of the report is provided to identify zones that were noted during the field program to be 3-D (i.e., having vertical, lateral, and longitudinal variations) and hence extend beyond the assumptions inherent in the 2-D numerical model. These zones occur wherever significant lateral variations were present and were observed in primarily two area categories: 1) the river reach beginning at Lower Monumental Dam and extending upstream for approximately 5 km and 2) most near-shore areas. Included in the near-shore category are river reaches near the confluences of the Palouse and Tucannon rivers. This category also includes near-shore areas at and downstream of river bends. Under stratified conditions, isotherms were noted to tilt laterally (as expected) as the flow passed through all river bends. Interpretation of 2-D model results in these areas (near-shore and at river bends is compromised because the model will compute only the cross-sectional average current pattern, and this pattern may not fully convey to the model operator the complex hydraulic variations that exist in these areas.

Figure 3.44 compares model results versus ADCP data at the edge of the forebay BRZ and in the upper water column. The model captured the diurnal rise and fall of velocity magnitude during mid July, as well as the steady-magnitude period in early August when project operations were no longer varying throughout the day. What the model did not capture well were subtle changes in angular direction. Because the model is laterally averaged, water can flow either upstream or downstream, and the solution for this entire period was downstream (angular direction of 210°). If the ADCP data were time-averaged and the results were binned into a binary logistic (i.e., going either upstream or downstream), the resultant direction would match the model result. Therefore, although 2-D model is correctly simulating the problem as posed, the laterally averaged assumptions inherent in the numerical model can skew interpretation of angular direction results.

Figure 3.45 displays an ADCP transect across the river and within 5 km of the dam. This reach of the river consists of two channels—the larger and deeper main channel to the south and a shallower, although significant, secondary channel. Between these two channels is a long underwater bar with water depths less than 15 m. The hydraulic conditions observed in the secondary channel were often significantly different from those in the main channel, as shown in Figure 3.44. Water in the top 6 m of the water column is traveling upstream (blue color), while beneath this layer in the main channel the water is flowing coherently downstream (red color). In the secondary channel, the water is almost stagnant, and the angular direction of the flow is not well structured. Because assumptions inherent in the numerical model force it to average laterally across the river, the numerical solution will not represent the field conditions in this hydraulically complex area.

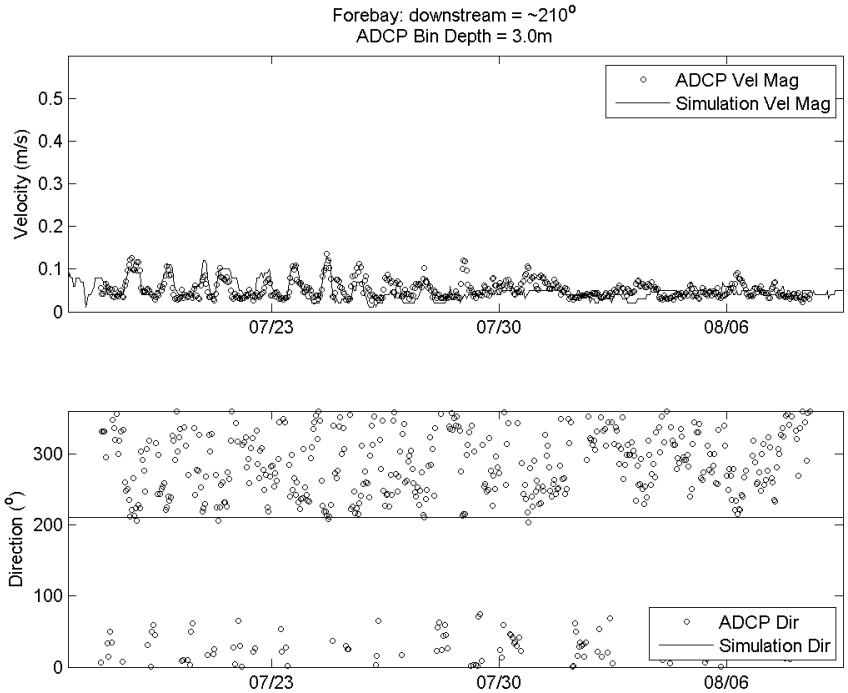

Figure 3.44. 2-D Numerical Model Results and 3-D ADCP Data at LMN 7 During the End of July and Early August

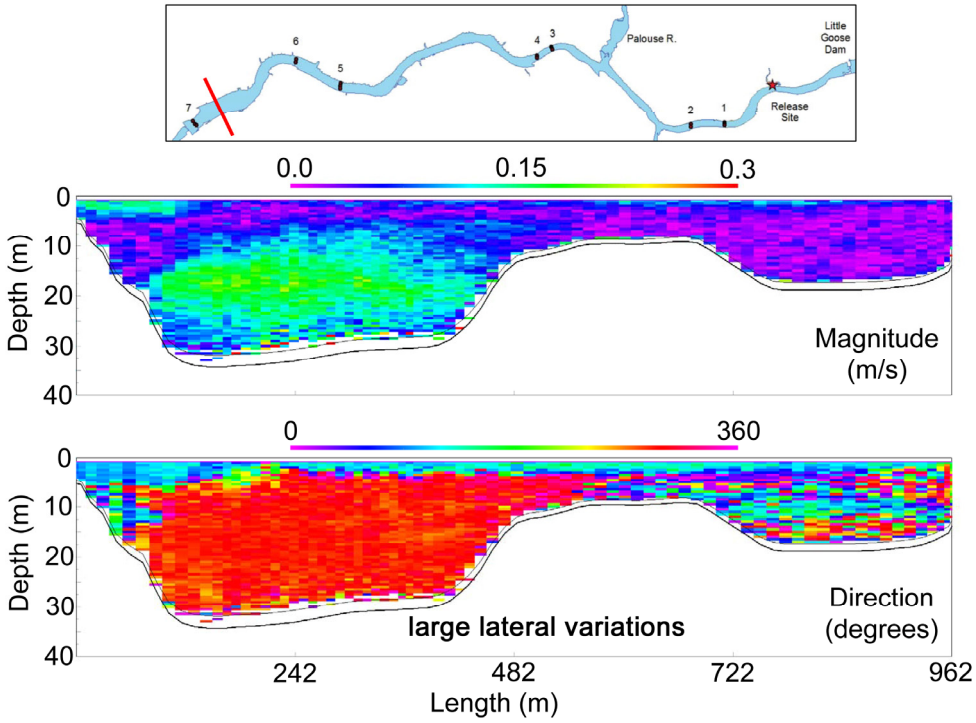

Figure 3.45. ADCP Transect at near the DST Temperature Monitoring Site (Figure 2.9) on 10 August. River discharge at the time of the measurement was 33.3 kcfs. Transect orientation: figure left equals river left (i.e., viewed as if looking downstream).

Figure 3.46 displays an ADCP transect collected upstream of LMN 5 and downstream of the plunge line (i.e., in the zone where the underflow had already developed). The vertical temperature gradient at mid-channel was 1.5°C. As water passed through the river bend, the isotherms tilted laterally, with the denser hypolimnetic water being pushed outward from the channel centerline and rising upward along the outside of the bend. The epilimnetic water collected on the inside of the bend and had an angular direction corresponding to traveling upstream (blue). These lateral variations will not be captured by the 2-D laterally-averaged model. Although these assumptions do not influence the ability of the model to simulate thalweg conditions, near-shore processes are obviously not captured.

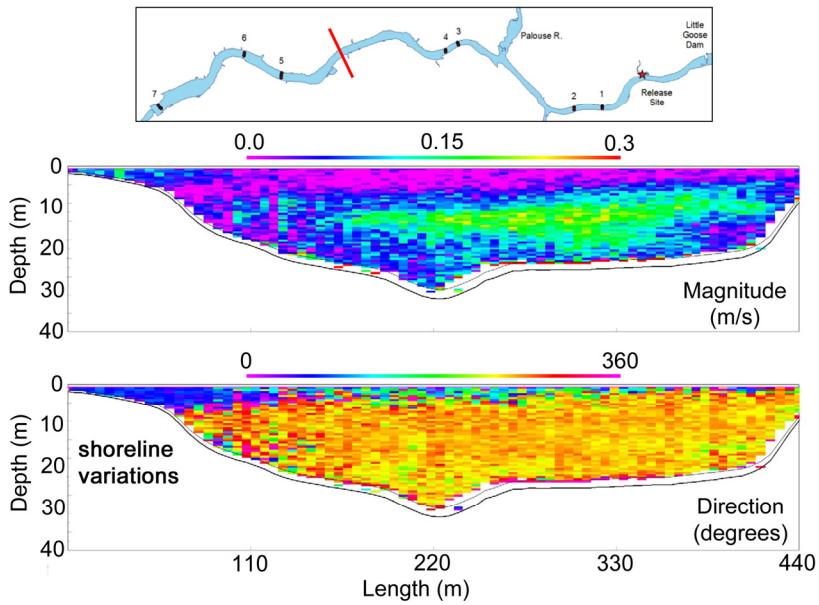

Figure 3.46. ADCP Transect Between Sites LMN 4 and LMN 5 on 16 August. River discharge at the time of the measurement was 27.0 kcfs. Transect orientation: figure left equals river left (i.e., viewed as if looking downstream).

3.4.4 Goodness-of-Fit Metrics

Several statistics were computed to evaluate model performance. These statistics are used to compare hydraulic (i.e., forebay water surface elevation) and water temperature goodness-of-fit between observed data and simulated results. These statistics are defined as follows:

$$bias = \frac{1}{n}\sum_{n}^{1}\left(y_i - y_{obs}\right)^2 \tag{3.1}$$

$$MAE = \frac{1}{n}\sum_{n}^{1}\left|y_i - y_{obs}\right| \tag{3.2}$$

$$RMS = \sqrt{\frac{1}{n}\sum_{n}^{1}\left(y_i - y_{obs}\right)^2} \tag{3.3}$$

where *MAE* is mean absolute error, *RMS* is root mean square error, y_i are computed model values (either forebay elevation or water temperature), and y_{obs} are observed values.

3.4.4.1 Velocity

The model captured most of the water surface variations, and all goodness-of-fit values are reasonably small. Bias between observed and predicted water velocities in the top and bottom model layers was small (Table 3.11), and the highest mean absolute error was 0.08 m/s.

Table 3.11. Comparison of Model-Simulated Velocities to Observed Velocities for Each Site of Lower Monumental Reservoir

Site		Bias (m/s)	MAE (m/s)	RMS (m/s)
LMN 3/4	Top	0.008	0.08	0.09
15 June to 8 August	Bottom	0.004	0.05	0.06
LMN 5	Top	0.002	0.03	0.04
31 August to 20 September	Bottom	0.005	0.05	0.07
BRZ	Top	0.001	0.02	0.03
14 June to 18 September	Bottom	0.001	0.03	0.04

3.4.4.2 Temperature

Model-generated temperature data were compared with observed data. For each depth where a temperature logger was available, model temperature output was compared to observations. Goodness-of-fit statistics were generated for bias, MAE, and RMS. The model evaluation period consisted of times both with and without stratification, and model results were compared to observed data for as long a period as possible.

Simulation results produced a maximum bias result of 0.30ºC at LMN 7 (upstream of the forebay BRZ). MAE and RMS errors are slightly larger, however, all values were less than 0.6°C (see Table 3.12).

Table 3.12. Comparison of Model-Simulated Temperatures to Observed Temperatures for Each Lower Monumental Reservoir Site for the Period 20 June to 20 September

Site	Bias (ºC)	MAE (ºC)	RMS (ºC)
LMN 2	0.06	0.18	0.25
LMN 3/4	0.10	0.23	0.32
LMN 5	0.16	0.30	0.40
LMN DST	0.16	0.29	0.40
LMN 7	0.30	0.42	0.56

3.5 Linking Fish Passage and Hydraulic Condition Results

Observed water temperature profiles and river discharge were used to predict the presence and persistence of thermal stratification at each site. This was done by calculating the Froude number and classifying each hour as either above or below the Fr cutoff (Table 3.10). This created an hourly binary index that could be summed over a 24-hr period to calculate the proportion of hours when the Froude number was above the Fr cutoff, which is how we define the Fr index. This value was linked to the study fish and provided the hydraulic conditions at the farthest downstream location each fish was known to be in the reservoir, whether or not it migrated below Lower Monumental Dam. The data were aggregated by release group and by time and location of last detection, then fit to a logistic regression model using

maximum likelihood methods. SAS software (version 9.1; SAS Institute, Cary, NC) was used for these analyses. For a more complete discussion of logistic regression theory and applications, see Hosmer and Lemeshow (1994).

Figure 3.47 shows an aligned time series of the Fr index at the five hydraulic sites with the 10 fish release groups shown in the upper panel as numbered vertical green lines. Dates are shown along the bottom axis, while Julian date is shown along the top axis. The bottom panel shows a bar graph of daily counts of study fish detected below the dam (migrating fish). Spikes of study fish passages appear at intervals following releases and correspond approximately with downward spikes in the Fr index, indicating a breakdown in thermal stratification in the vicinity of a hydraulic site. Figure 3.46 shows the progression from no thermal stratification at the start of the season to stable and persistent stratification in the lower half of the reservoir later in the season.

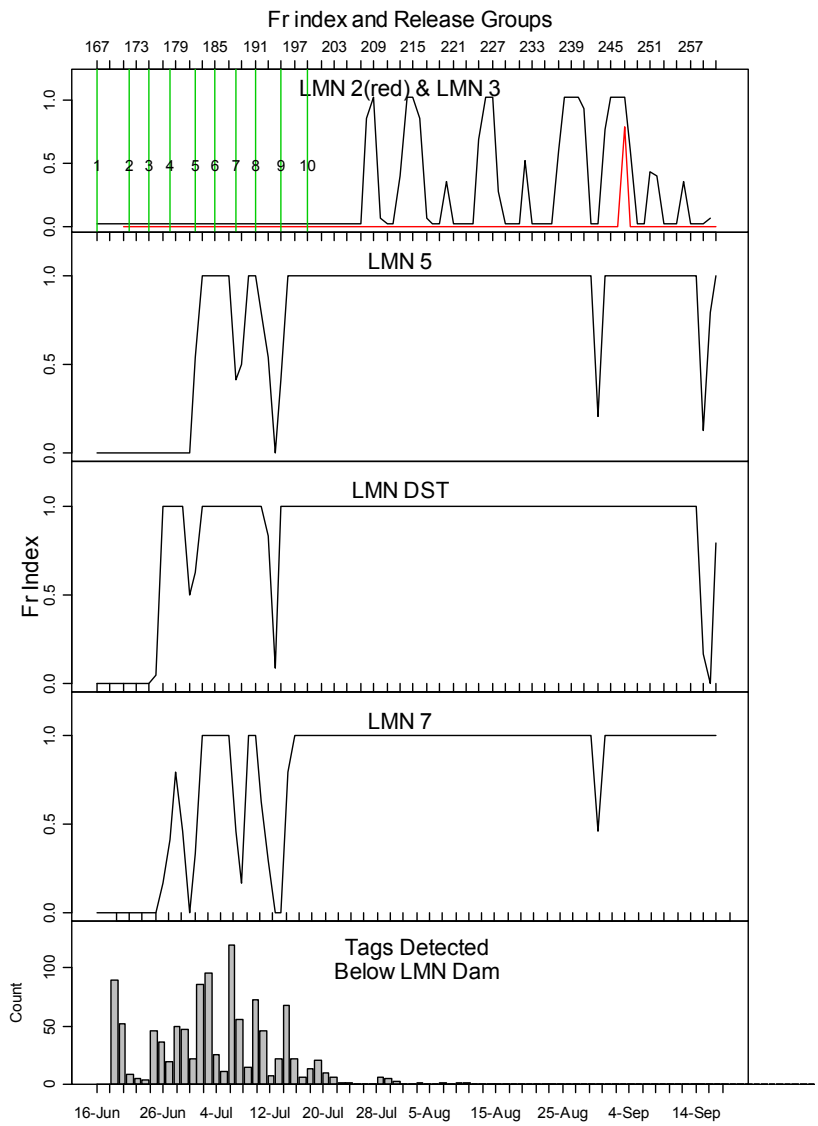

Figure 3.47. Time Series of Froude Index and Release Groups at the Five Water Temperature Sites and a Bottom Panel of Daily Counts of Study Fish Detected Downstream of Lower Monumental Dam

Table 3.13 and Table 3.14 show results for the fixed effects of fork length and Fr index in the model, where fish with release groups (sample groups) were treated as random effects. A positive coefficient estimate for Fr index with significant *P*-values in Table 3.13 supports a positive association between the underflow condition and the cessation of subyearling fall Chinook salmon migration. The statistically significant ANOVA results in Table 3.14 also provide good evidence to suggest that a positive association persists, even when biological effects are accounted for first.

Table 3.13. Mixed Effects Model: Fixed Effects Parameter Estimates

Effect	Estimate	StdErr	DF	tValue	Probt
Intercept	4.723	0.781	1772	6.05	<0.0001
Length	−0.051	0.007	1772	−7.22	<0.0001
Frindex	0.874	0.121	1772	7.25	<0.0001

Table 3.14. Mixed Effects Model: Fixed Effects Analysis of Deviance Table

Effect	NumDF	DenDF	FValue	ProbF
Length	1	1772	43.6	<0.0001
Frindex	1	1772	52.55	<0.0001

4.0 Discussion

The joint probability of survival and passage of subyearling Chinook salmon through Lower Monumental Reservoir decreased markedly between 1 and 11 July. This decrease coincided with changes in physical/environmental and biological factors, including 1) increasing depth-averaged water temperatures, 2) releases from Dworshak Reservoir that decreased Little Goose tailrace temperatures below equilibrium temperature, inducing underflow (stratified) hydraulic conditions, 3) decreasing river discharge, and 4) decreasing length of the fish that were tagged.

Estimated joint probability of survival and passage of subyearling Chinook salmon passing through the reservoir (from point of release to Lower Monumental Dam tailrace) was high (0.84 to 0.96) for fish released between 16 June and 1 July, decreased for fish released between 4 and 11 July (0.46 to 0.78), and was low for fish released between 14 and 19 July (0.09 to 0.19). The transition period between relatively high and low estimated joint probability of survival and passage coincided with large changes in the physical environment within Lower Monumental Reservoir.

Migration rate of subyearling Chinook salmon is influenced by water velocity/discharge (Connor et al. 2003). At the onset of the study, we were aware of variations in water velocity along the centerline of the reservoir (Figure 4.1). Of particular note was a sharp decrease near Lyons Ferry, at the confluence of the Palouse and Snake rivers. However, the percentage of fish that ceased migrating in this region was low during the study, as can be seen in values for last detections of fish in the upper portion of Figure 4.1. Almost no study fish were last detected in the tributaries. The first location in the reservoir where large numbers of study fish ceased migration was between sites LMN 4 and LMN 5, which is near the midpoint of the reservoir.

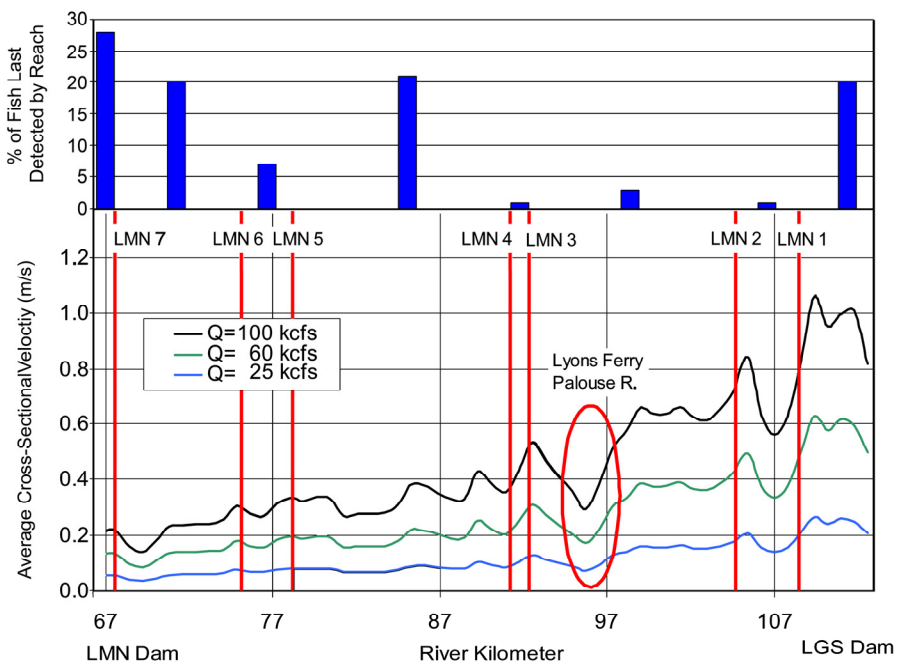

Figure 4.1. Percentage of Last Detections for Study Fish and Cross-Sectional Average Water Velocity Magnitudes at Three Discharge Levels

A logistic regression model (univariate analysis) showed a significant correlation between the cessation of fish migration and the onset of stratification with underflow hydraulic conditions. The direction of this correlation suggests that fish exposed to longer periods of stratification with underflow conditions exhibited an increasing likelihood to cease downstream migration. However, when a 10-level factor variable for release group was entered into the model (multivariate analysis), the direction of the correlation remained the same but the hydraulic index variable was no longer significant at the $\alpha = 0.05$ level. In other words, the effect of stratification with underflow hydraulic conditions suggests a strong correlation, but this relationship was confounded with fish release date.

The change in the mean length of the subyearling Chinook salmon we tagged may indicate a change in the source of the fish during the study, with an increase in the proportion of the fish having been released in the Clearwater River. Pulses of PIT-tagged subyearling Chinook salmon that were released at the Big Canyon acclimation facility and the Nez Perce Tribal Hatchery on the Clearwater River (Figure 4.2), as well as the decrease in mean fork length (Figure 4.3; 114 mm to 108 mm) that occurred during the first ten days of July, may indicate that the fish we tagged during the latter half of the study had a higher chance of being released into the Clearwater River than into the Snake River. Note that we did not implant microacoustic transmitters into previously PIT-tagged fish; we are presenting the PIT tag detections at Little Goose Dam as an indicator of the various groups of subyearlings that were available for tagging over the course of our study.

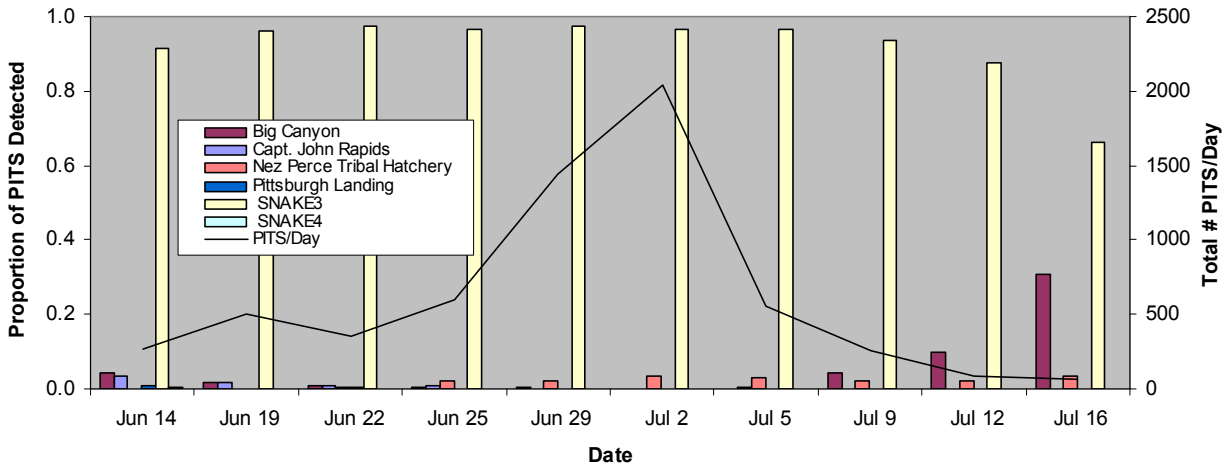

Figure 4.2. Daily Proportion of PIT-Tagged Subyearling Chinook Salmon at Little Goose Dam from Various Release Locations on Days When Fish Were Collected for the Acoustic Tagging Project. The total number of PIT tags detected per day also is shown.

There were suspected losses of study fish to predation. For example, 20% of the fish that did not emigrate from the reservoir were not detected on the first detection line (LMN 1). Mobile tracking data suggest that many fish may have been preyed upon by piscivorous fishes such as smallmouth bass, channel catfish, and walleye shortly after they were released along the shoreline. Almost all (99%) of the locations of our tagged smallmouth bass were located in areas within 200 m of either shore. The majority (84%) of the Chinook salmon located by mobile tracking were also within 200 m of shore. Some overlap

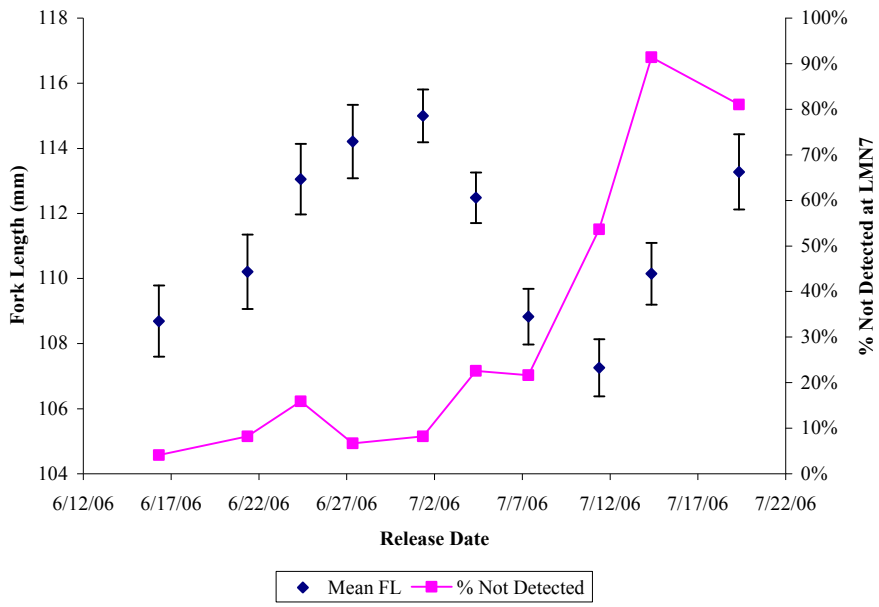

Figure 4.3. Mean (± 1.96*SE) Fork Length of Subyearling Chinook Salmon Tagged with Microacoustic Transmitters at Little Goose Dam and the Percentage of These Fish Not Detected at the Acoustic Array in the Forebay of Lower Monumental Dam (LMN 7)

in smallmouth bass and Chinook salmon locations may indicate predation was a factor for the fish from later releases being less successful at migrating out of the reservoir. This was most evident in the mobile tracking data from the release area. Tabor et al. (1993) also suggested the increased potential for salmonid predation by smallmouth bass in overlapping habitats. Other studies in Lower Granite Reservoir suggest that juvenile Chinook salmon remain offshore in summer and fall (Connor et al. 2003; Curet 1993). Our data showed that Chinook salmon located in the forebay area were somewhat dispersed and in deeper water, which may suggest that potential predation was less a factor in this region of the reservoir than in the release area.

Detections of acoustic tagged subyearling Chinook salmon that stopped near autonomous nodes provided useful information on the possible fates of these fish. Detection histories (presented graphically as bar codes) of subyearling Chinook salmon that did not leave the reservoir showed evidence of movement. The bar codes were a useful way to illustrate that many of the non-migrant fish were moving around for extended periods in the lower half of the reservoir.

Tagged subyearling Chinook salmon that were not detected downstream of the reservoir may have been consumed by piscivorous fishes, including smallmouth bass. For discussion purposes only, we used a minimal amount of data from our study (size information on smallmouth bass and subyearling Chinook salmon we tagged) to speculate about how consumption of the juvenile salmon may have been influenced by water temperatures in the reservoir. Daily consumption rates (prey/predator/day) of smallmouth bass on subyearling Chinook salmon were estimated from 15 June to 1 August. Digestion rate (time to evacuate 90% of prey) of smallmouth bass was first calculated using the equation

$$ET90 = 24.542S^{0.29}e^{0.15T}W^{0.23}$$

where *ET90* = the time in hours for a prey item to be 90% evacuated, *S* = prey weight (g), *T* = temperature (°C), and *W* = predator weight (g) (Rogers and Burley 1991; Fritts and Pearsons 2004). Mean weight of tagged subyearlings was used as an estimate of prey weight (*S*). Daily mean temperatures from the LMN tailrace were used. Mean predator weight was estimated from fork lengths of smallmouth bass tagged during our predator tagging and was assumed constant throughout the duration of our consumption rate calculations. Daily consumption rate was then calculated using digestion rate

$$C = \frac{24}{ET90}$$

and was based on the assumption that smallmouth bass contained one subyearling Chinook salmon in their gut at all times and that as soon as one subyearling was 90% evacuated, another salmon was consumed. Daily consumption rates were compared to prey availability to evaluate predation potential trends. Smolt passage data from the Little Goose Dam juvenile bypass facility were used as an index to subyearling Chinook salmon availability (FPC 2007).

Estimated consumption rates increased from mid June through early July and remained relatively constant from early July through early August (Figure 4.4). The highest consumption rates in early July corresponded to decreasing subyearling Chinook salmon abundance, which declined from about 60,000 individuals on 3 July to about 200 individuals on 1 August. Therefore, if our assumptions are correct, it appears that the metabolic needs of the smallmouth bass increased dramatically at a time when the availability of subyearling Chinook salmon declined after the peak of emigration. The result of this may be an increased per capita impact on subyearling Chinook salmon that remain in the reservoir for extended periods during the summer period.

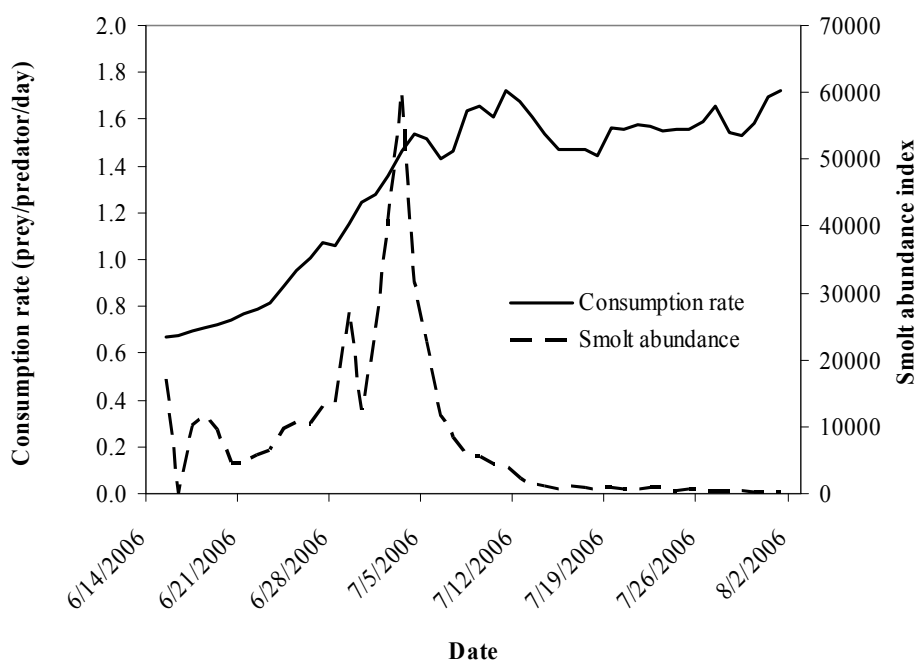

Figure 4.4. Consumption Rate (prey/predator/day) of Smallmouth Bass on Subyearling Chinook Salmon in Relation to Subyearling Abundance Index Data Collected from the Little Goose Juvenile Bypass Facility, 15 June to 1 August

Data obtained from mobile tracking provided little conclusive evidence of the fates of the tagged salmon that ceased migration in Lower Monumental Reservoir. It did, however, corroborate the information on general distribution and timing (with respect to release groups) of cessation of migration. Mobile-tracked fish that left the release area were detected mostly within 6 km of Lower Monumental Dam. Migration rates (kilometers per day) of these fish were commensurate with rates for fish that continued their migration past Lower Monumental Dam. Migration rates tend to increase as fish travel farther downstream (Smith et al. 2003; Connor et al. 2003). However, radio-tagged subyearling Chinook salmon took an average of about one day to pass Little Goose Dam after initially encountering the dam (Venditti et al. 2000). Therefore, encountering a dam may delay migration and increase their susceptibility to predation or temperature stress (Connor et al. 2003; Smith et al. 2003; Curet 1993).

5.0 Conclusions and Recommendations

5.1 Conclusions

Detections on acoustic receivers at several locations in Lower Monumental Reservoir indicated that 44% (N = 852) of tagged subyearling Chinook salmon (N = 1949) did not pass downstream of the dam. The number of fish within each release group that ceased migrating within the reservoir varied over the study, with fewer fish emigrating from the reservoir over time. The majority of the fish that did not leave the reservoir were last detected in the lower half of the reservoir. This finding suggests that juvenile fall Chinook salmon that failed to emigrate from Lower Monumental Reservoir during the study period were not evenly distributed throughout the reservoir.

The lower half of the reservoir stratified in early July. Upstream-directed water motions in the top 6 m of the water column frequently occurred in the stratified half of the reservoir, and a plunge line developed near the midpoint of the reservoir. Thus, circulation patterns in the lower half of the reservoir changed as a result of the stratification that persisted between July and September.

Hydraulic conditions were examined during the time and location at which each fish was detected in the reservoir. Our results show a statistically significant correlation exists between the time and location at which downstream migration ceased and the presence of thermal stratification with underflow hydraulic conditions. However, numerous other physical and biological conditions also changed throughout the study period and potentially confounded this relationship.

Fish that ceased to migrate within the reservoir did not restart movement during our study period (i.e., prior to 25 September). The last tagged fish detected leaving the reservoir did so on 3 August (released 18 July). The last PIT tag detection of any study fish was on 25 July at Lower Monumental Dam and 4 August at McNary Dam (detectors were active until 30 September and 28 November, respectively). Voluntary spill at Lower Monumental Dam ceased on 1 September. We found no evidence to suggest that juvenile fall Chinook salmon restarted downstream migration as a result of declining water temperatures, variable river discharge, and/or cessation of spill at Lower Monumental Dam.

5.2 Recommendations

Based on the results of this project in 2006, we recommend several studies be considered for increasing the understanding of interactions between migrating juvenile fall Chinook salmon and environmental factors that develop in Lower Monumental Reservoir during the summer months. These include the following:

- With the intent of increasing understanding of the fate of subyearling Chinook salmon that fail to emigrate from Lower Monumental Reservoir, increase the number of acoustic receivers placed in the lower half of the reservoir and Lower Monumental Dam forebay.

- Assess how other biological factors (e.g., abundance of ichthyoplankton, fish source, smolt quality, predator fish distribution) could influence ‘motivation’ to migrate and/or ultimate fate of subyearling Chinook salmon passing through lower Snake River reservoirs. Document how these

biological factors change over time when juvenile fall Chinook salmon are present in the reservoirs. Determine if a relationship exists between these biological factors and cessation of downstream migration.

- Hydraulic conditions (e.g., water velocity and water temperature) in the reservoir and atmospheric parameters (e.g., wind speed and direction, air temperature) that affect hydraulic conditions should be documented in conjunction with emigration and fate measurements of subyearling Chinook salmon.

6.0 References

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Appendix A

Lower Monumental Project Operations

Appendix A – Lower Monumental Project Operations

Data presented in this appendix are from the U.S. Army Corps of Engineers, Walla Walla District. Blue lines in each of the figures are instantaneous measurements automatically collected every 5 minutes. The broader black lines are 24-hr moving average time series computed using the 5-minute data sets.

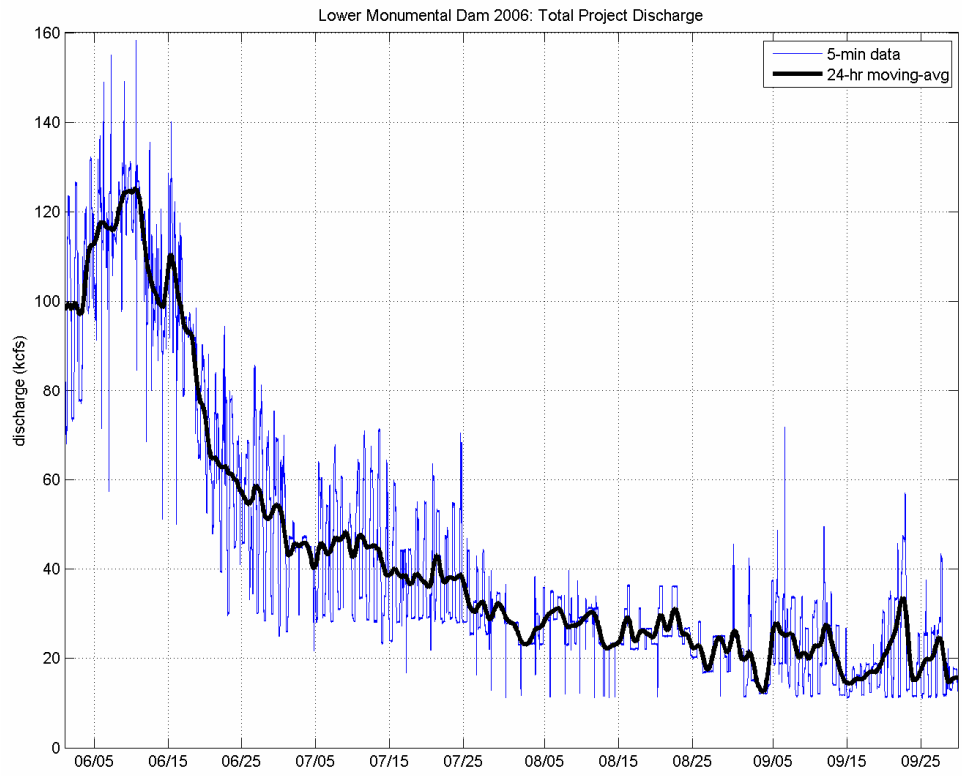

Figure A.1. Time Series of Total Project Discharge Passed Through Lower Monumental Dam During the Study Season

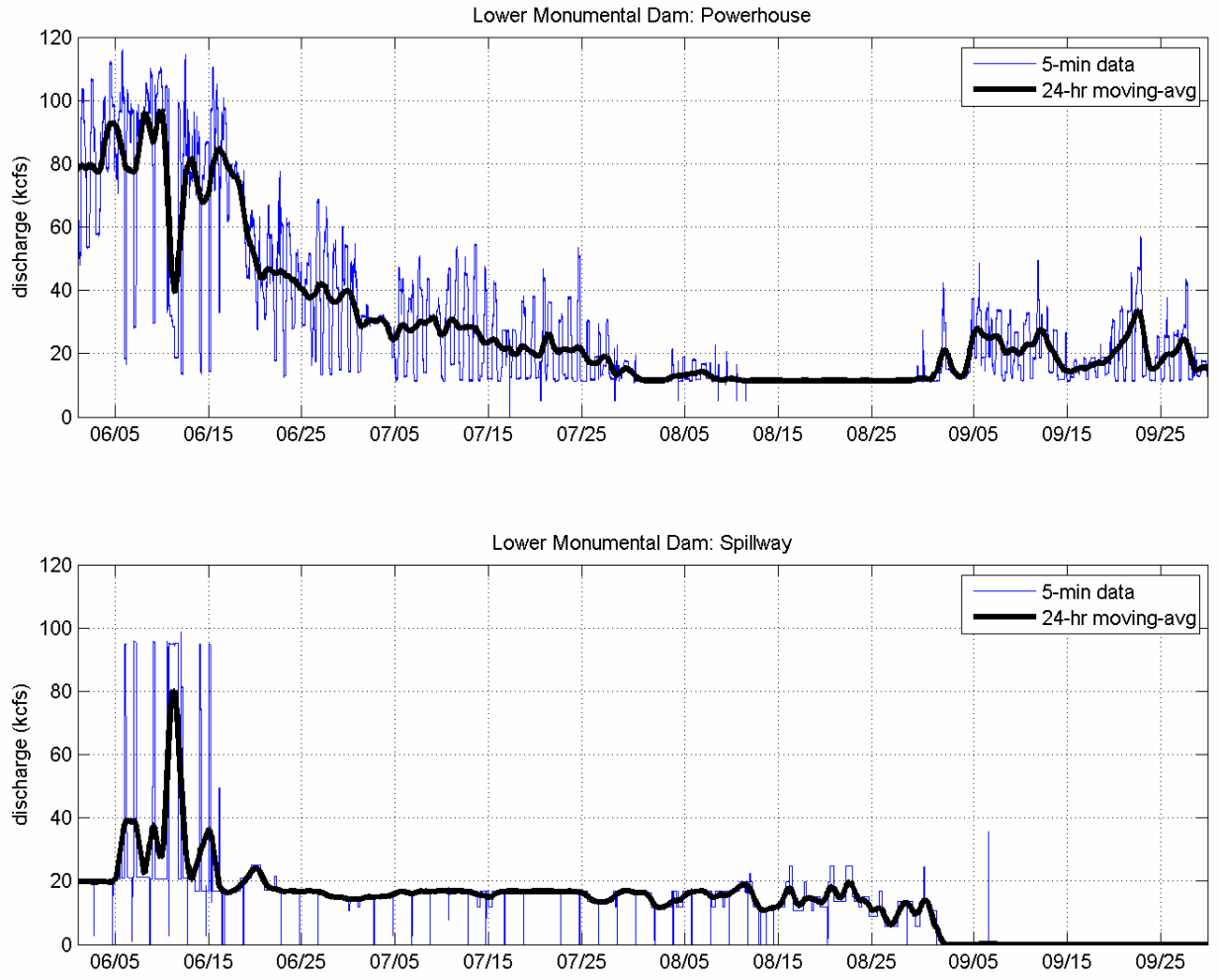

Figure A.2. Time Series of Powerhouse (Upper Panel) and Spillway (Lower Panel) Discharge Passed Through Lower Monumental Dam During the Study Season

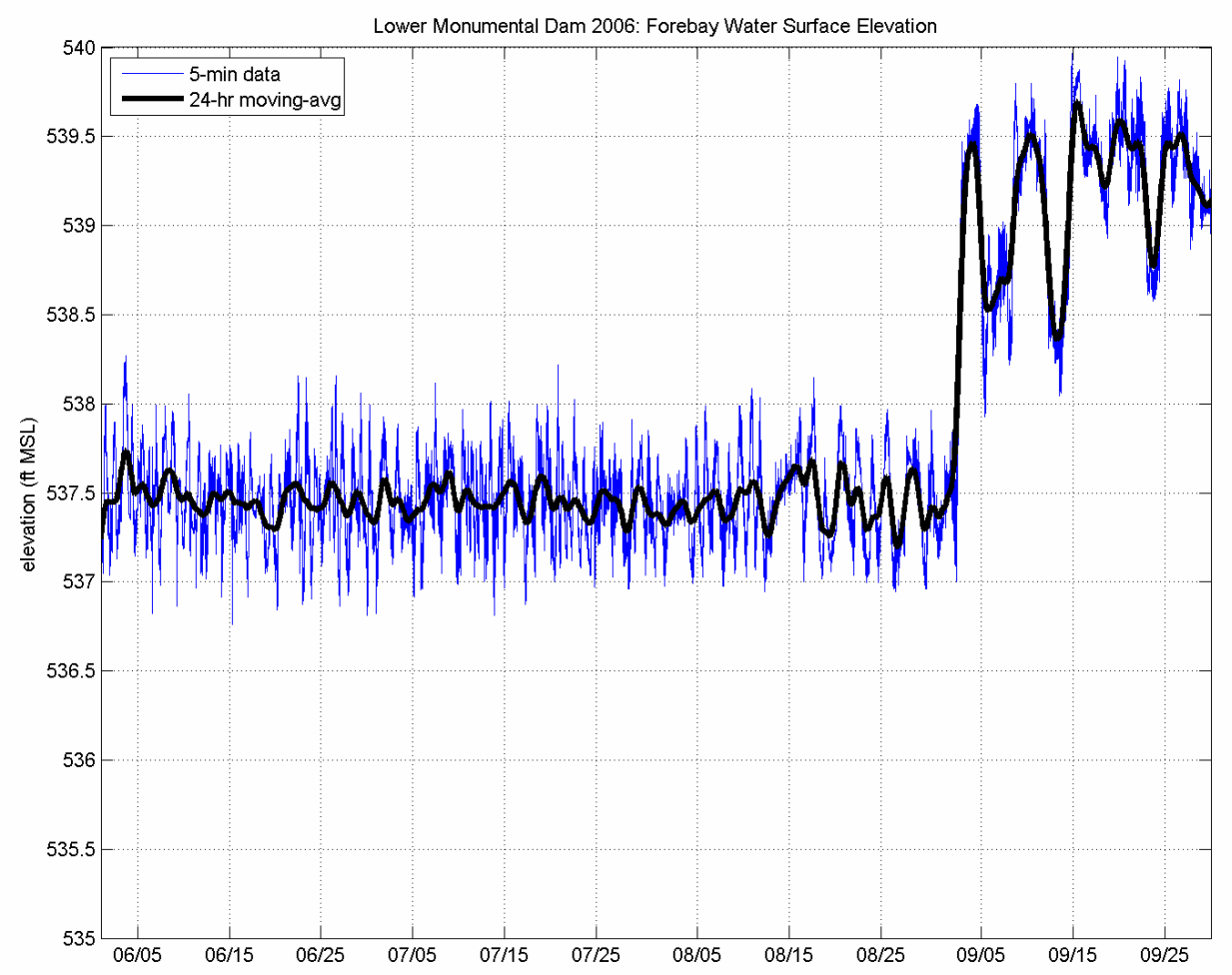

Figure A.3. Time Series of Lower Monumental Reservoir Water Surface Elevation During the Study Season

Appendix B

Observed Temperatures in Lower Monumental Reservoir

Appendix B – Observed Temperatures in Lower Monumental Reservoir

Water temperature data collected by Pacific Northwest National Laboratory are summarized in this appendix. The coordinates for each site are displayed in Table B.1. The coordinate system for these data is WGS84.

Table B.1. Coordinates of Temperature Strings in Lower Monumental Reservoir

Site	Latitude	Longitude
LMN 2	46.55433850	-118.1583806
LMN TUC	46.55676139	-118.1768007
LMN PAL	46.59670482	-118.2108203
LMN 3	46.59833450	-118.2608976
LMN 5	46.58686197	-118.4282277
LMN DST	46.57644809	-118.4970852

Figures B.1 through B.7 depict the observed temperatures over the study period for each site. Logger depths shown in the legend of each figure are in meters beneath the water surface.

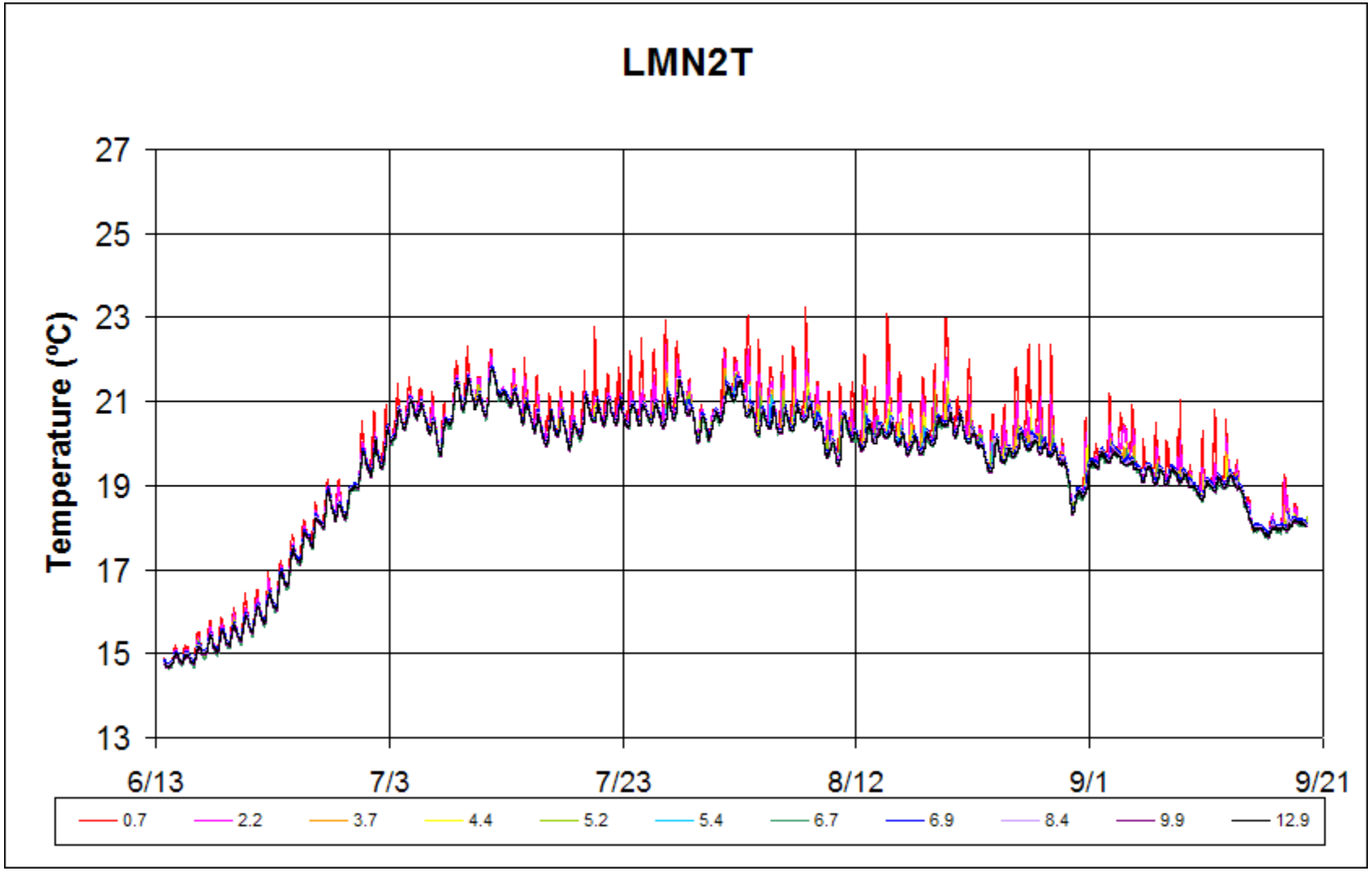

Figure B.1. Temperatures at Site LMN 2 at Different Depths (m) of the Water Column

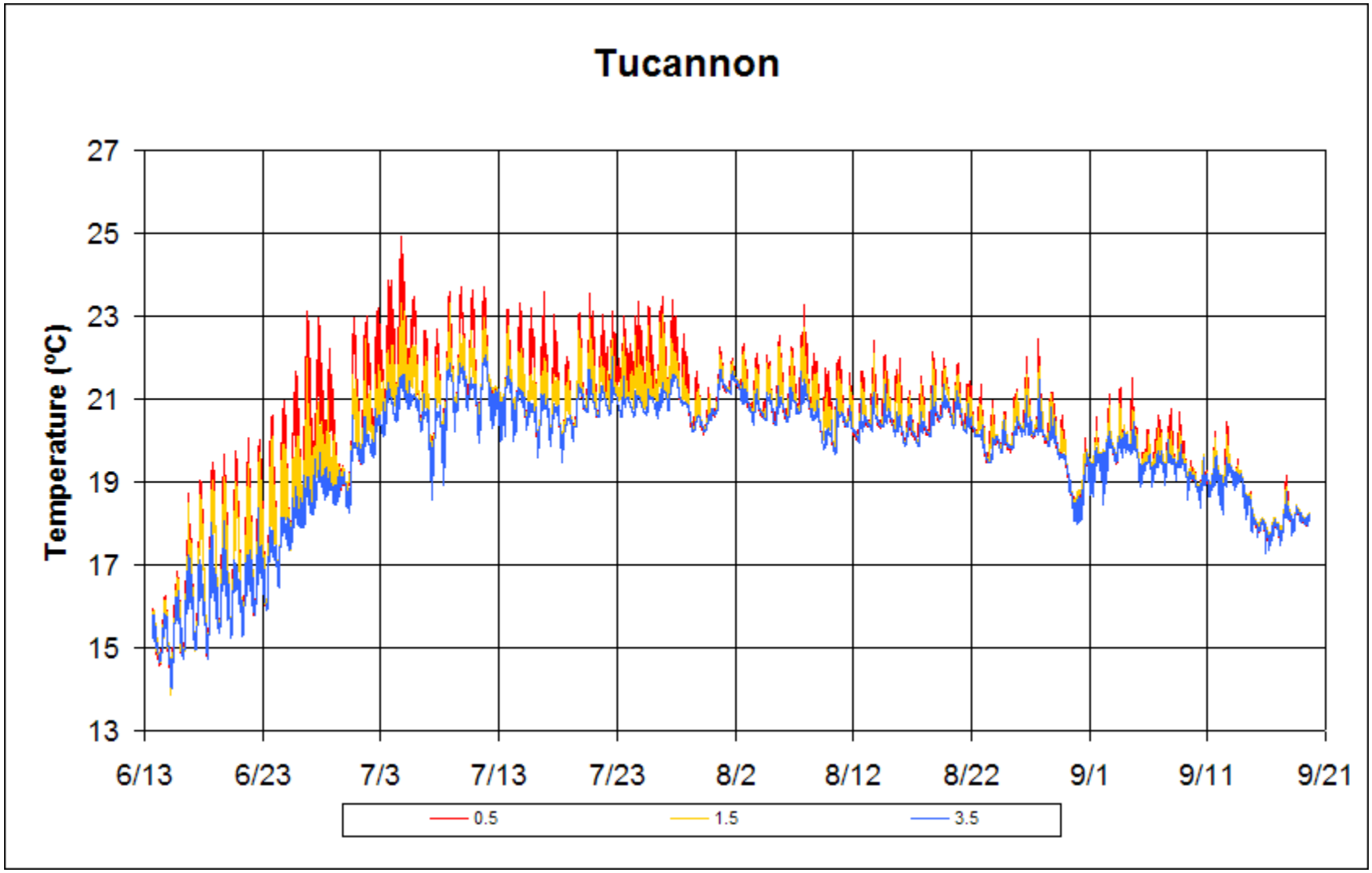

Figure B.2. Temperatures at Mouth of the Tucannon River at Different Depths (m) of the Water Column

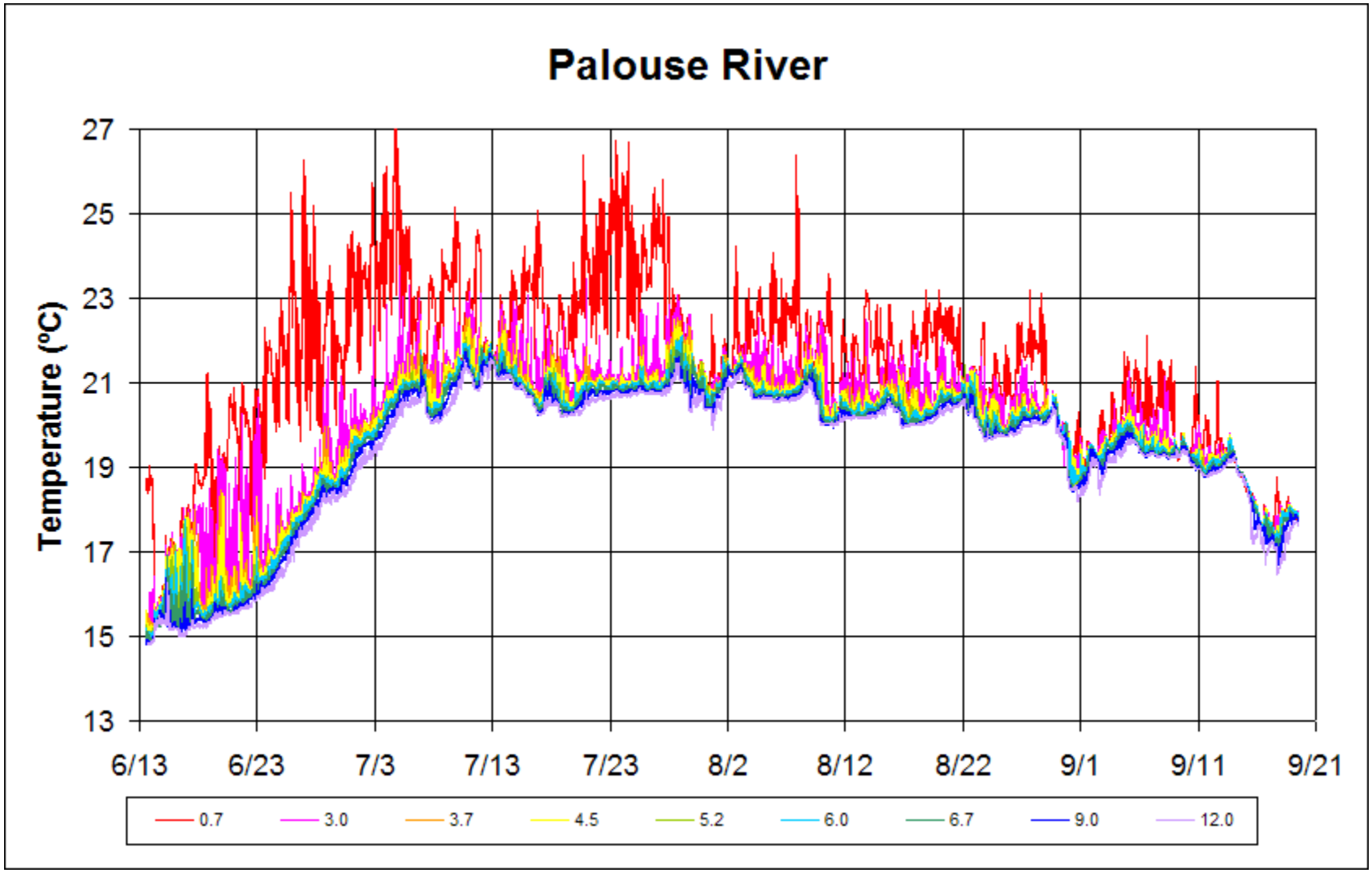

Figure B.3. Temperatures at Mouth of the Palouse River at Different Depths (m) of the Water Column

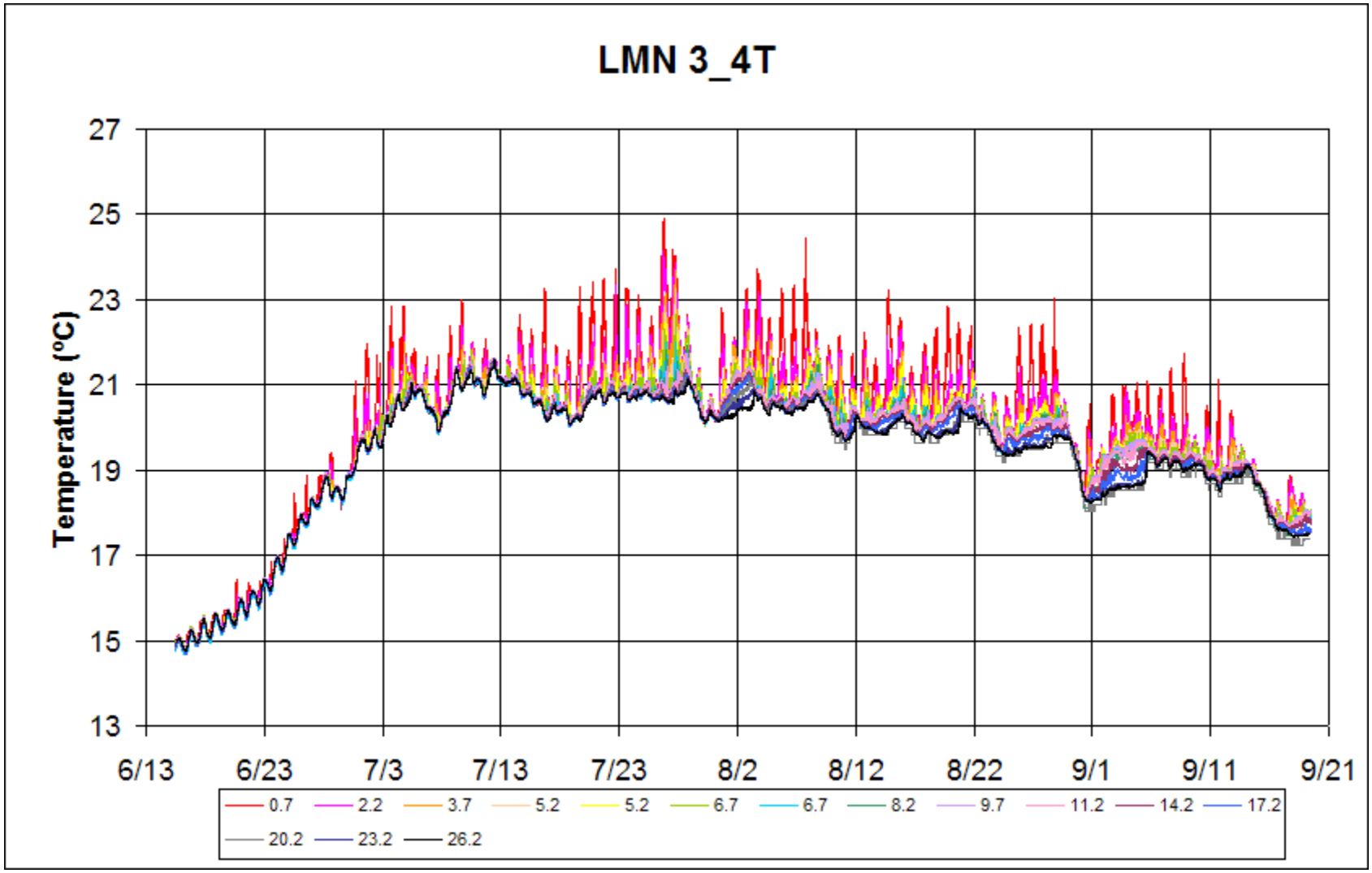

Figure B.4. Temperatures at Site LMN 3/4 at Different Depths (m) of the Water Column

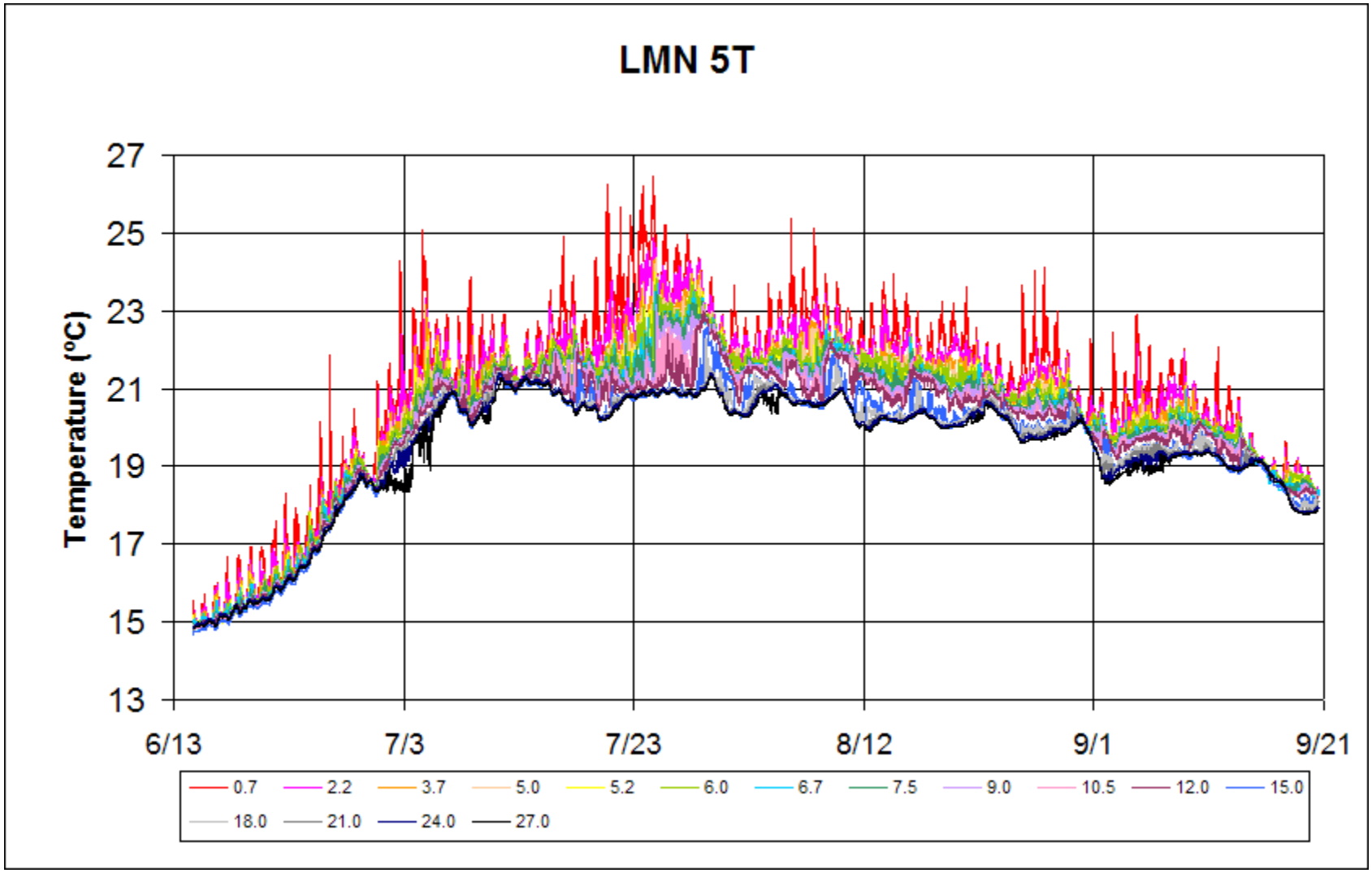

Figure B.5. Temperatures at Site LMN 5 at Different Depths (m) of the Water Column

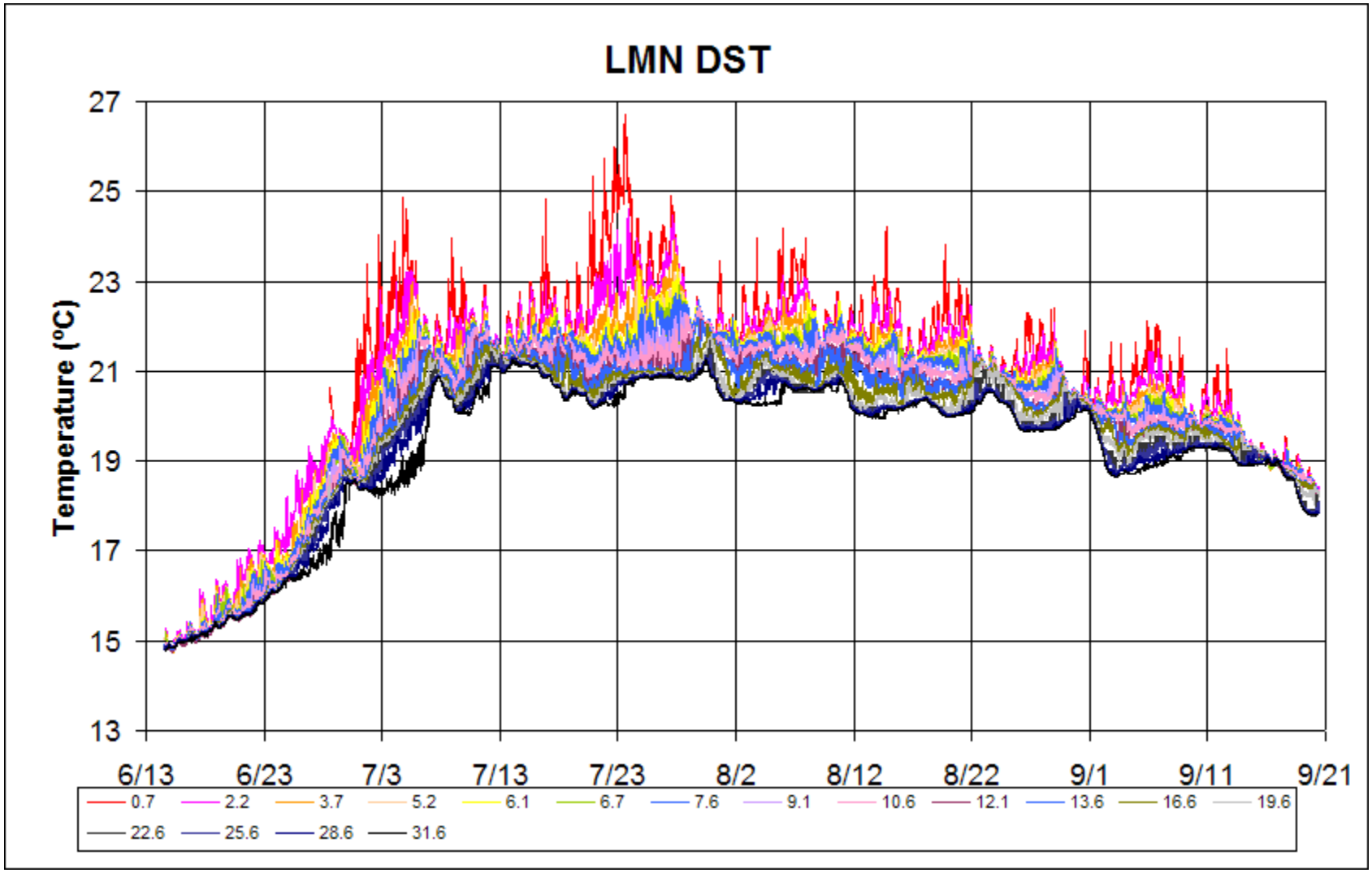

Figure B.6. Temperatures at Site LMN DST at Different Depths (m) of the Water Column

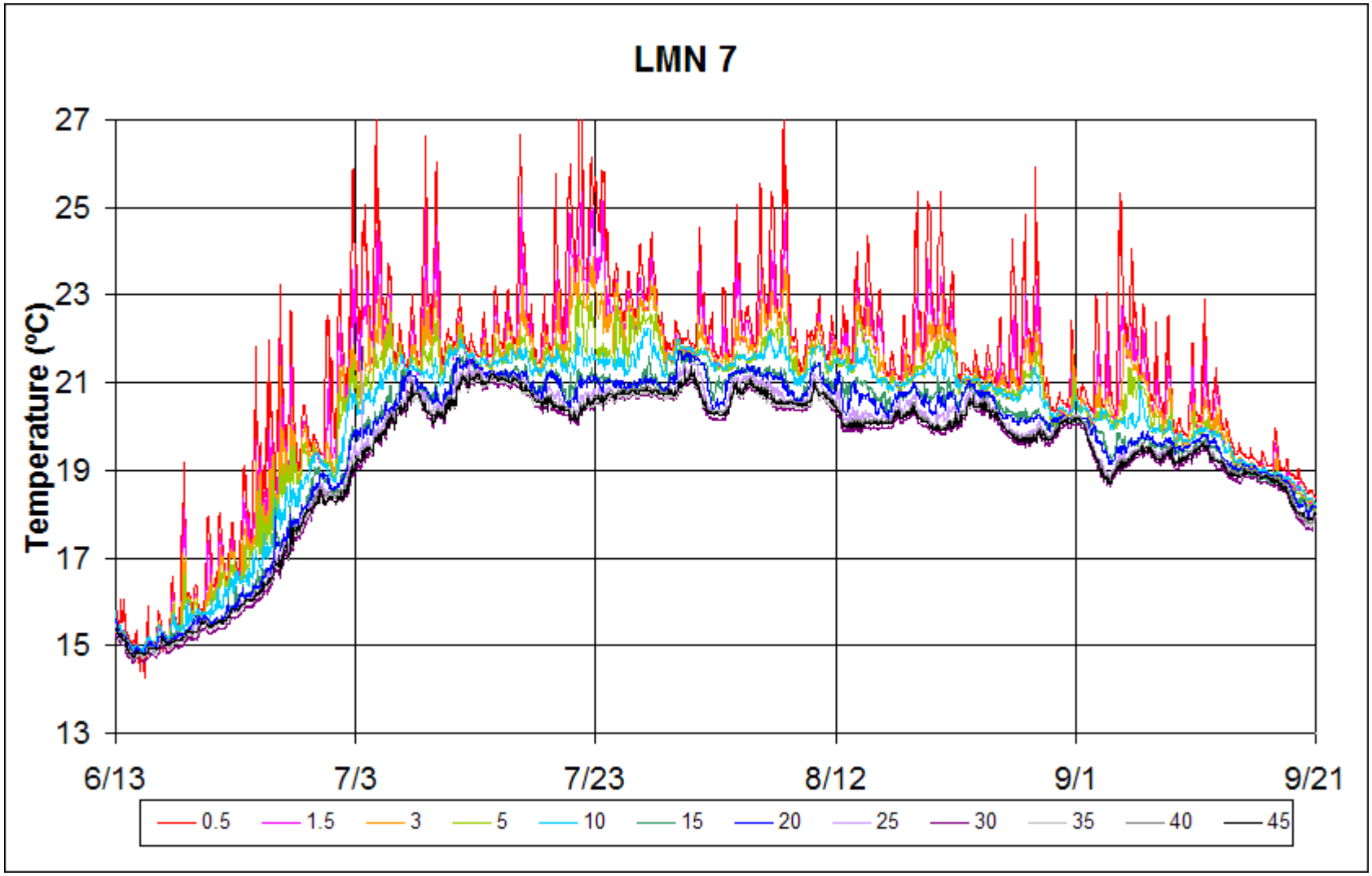

Figure B.7. Temperatures at Site LMN 7 at Different Depths (m) of the Water Column

Appendix C

Variations in Densimetric Froude Number and Water Angular Direction

Appendix C – Variations in Densimetric Froude Number and Water Angular Direction

This appendix presents time series variations in densimetric Froude number (Fr) values, ADCP water direction measurements in the upper and lower portions of the water column, and histograms of angular differences between the upper and lower water column directions. These figures were created to put Fr values in context with physical phenomena occurring in Lower Monumental Reservoir.

A cutoff Fr value (see Table 3.10) was determined empirically using these data. Whenever the Fr value was greater than or equal to the cutoff, the entire water column was moving uniformly downstream. Because there is always some variation in velocity direction, especially at low speeds, angular differences of 60° or less were considered as moving in the same direction. It should be noted that whenever the Fr value is less than the cutoff, water direction in the epilimnion is uncertain. It is only when the Fr value is equal to or above the cutoff that the direction the epilimnetic water is traveling is known. Defined in this way, a low Fr value is a necessary condition for epilimnetic water to be moving upstream. However, a low Fr value by itself is not sufficient to know which direction the epilimnetic water is traveling.

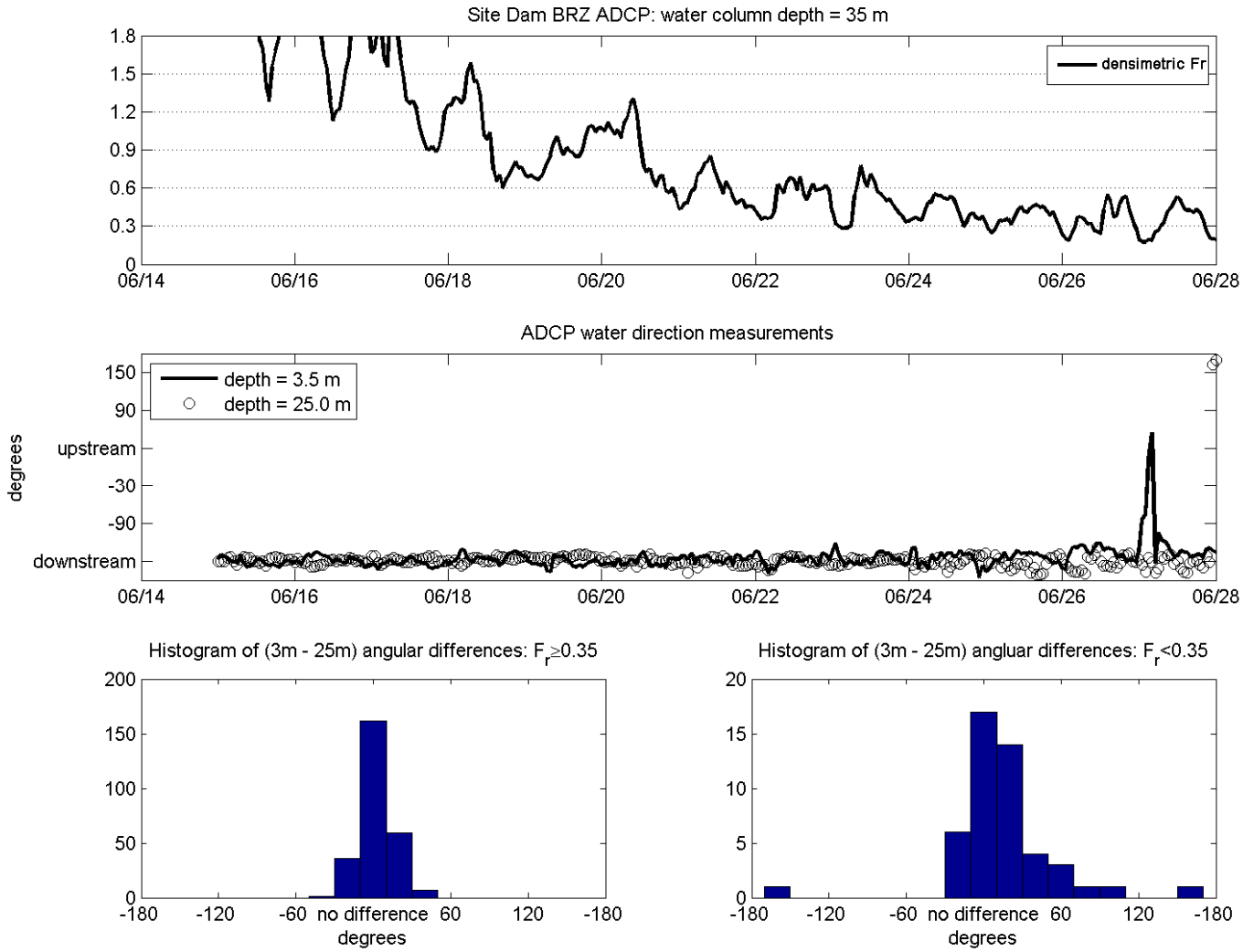

Figure C.1. Site LMN 7 Conditions for Mid to Late June

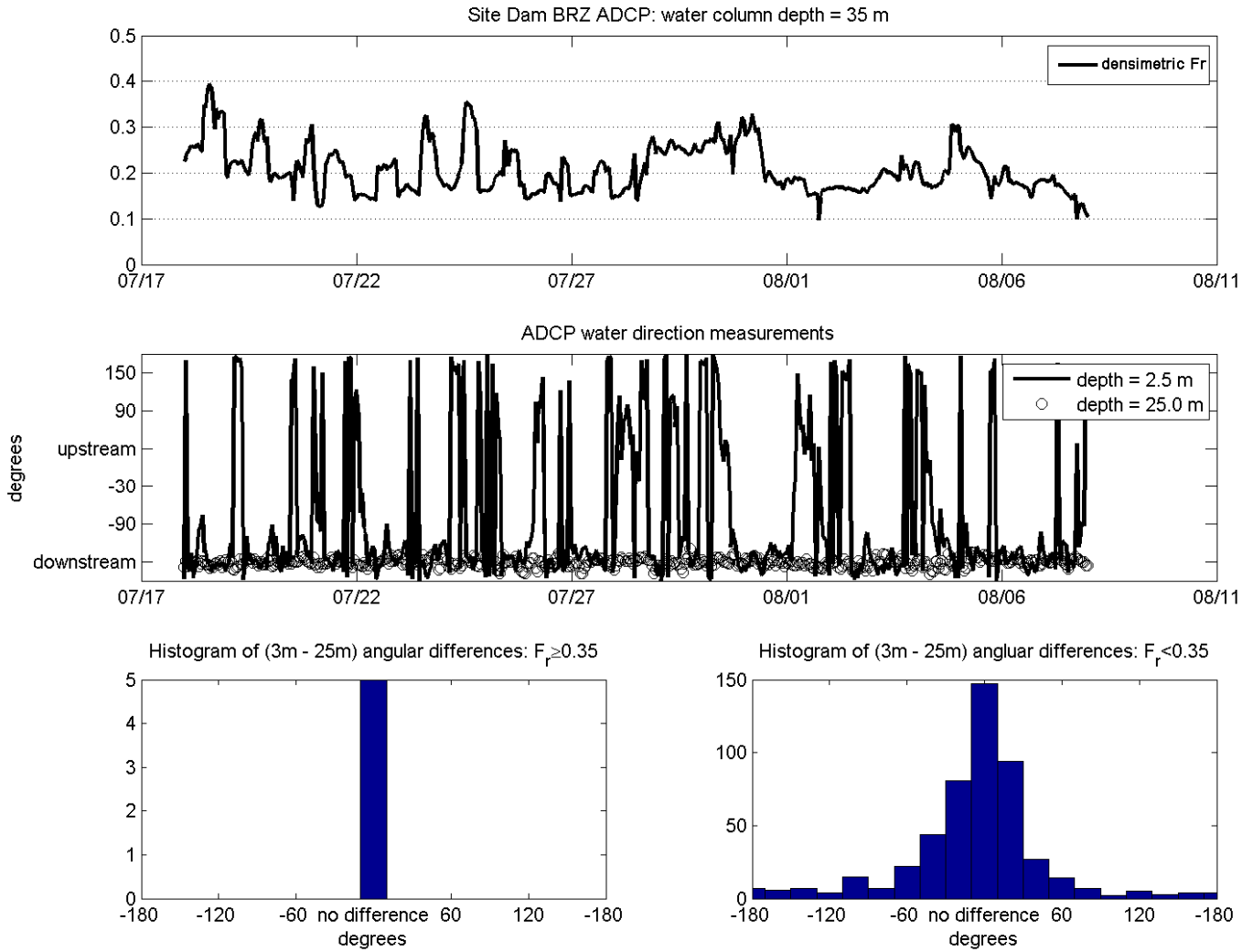

Figure C.2. Site LMN 7 Conditions from Mid July to Early August

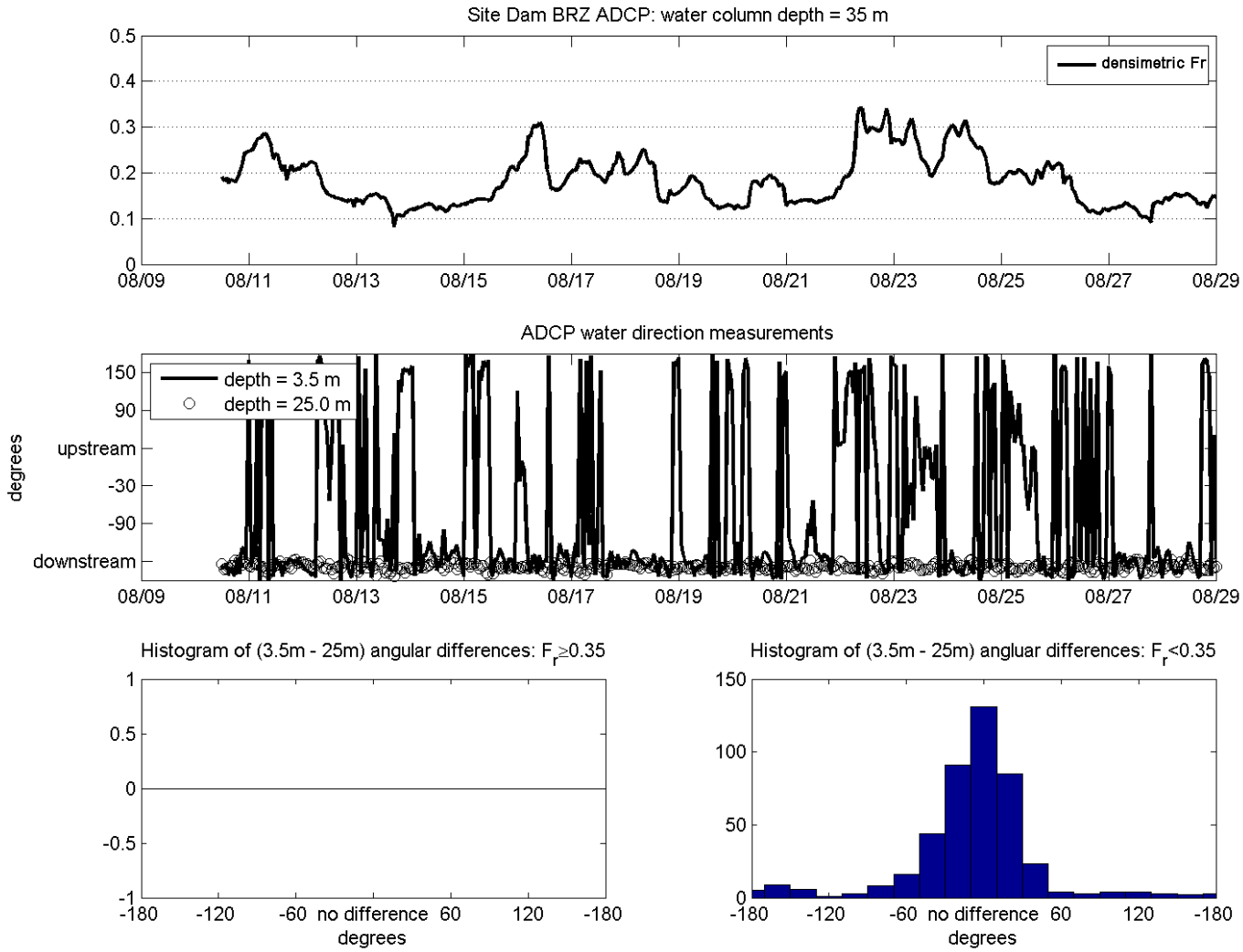

Figure C.3. Site LMN 7 Conditions for August

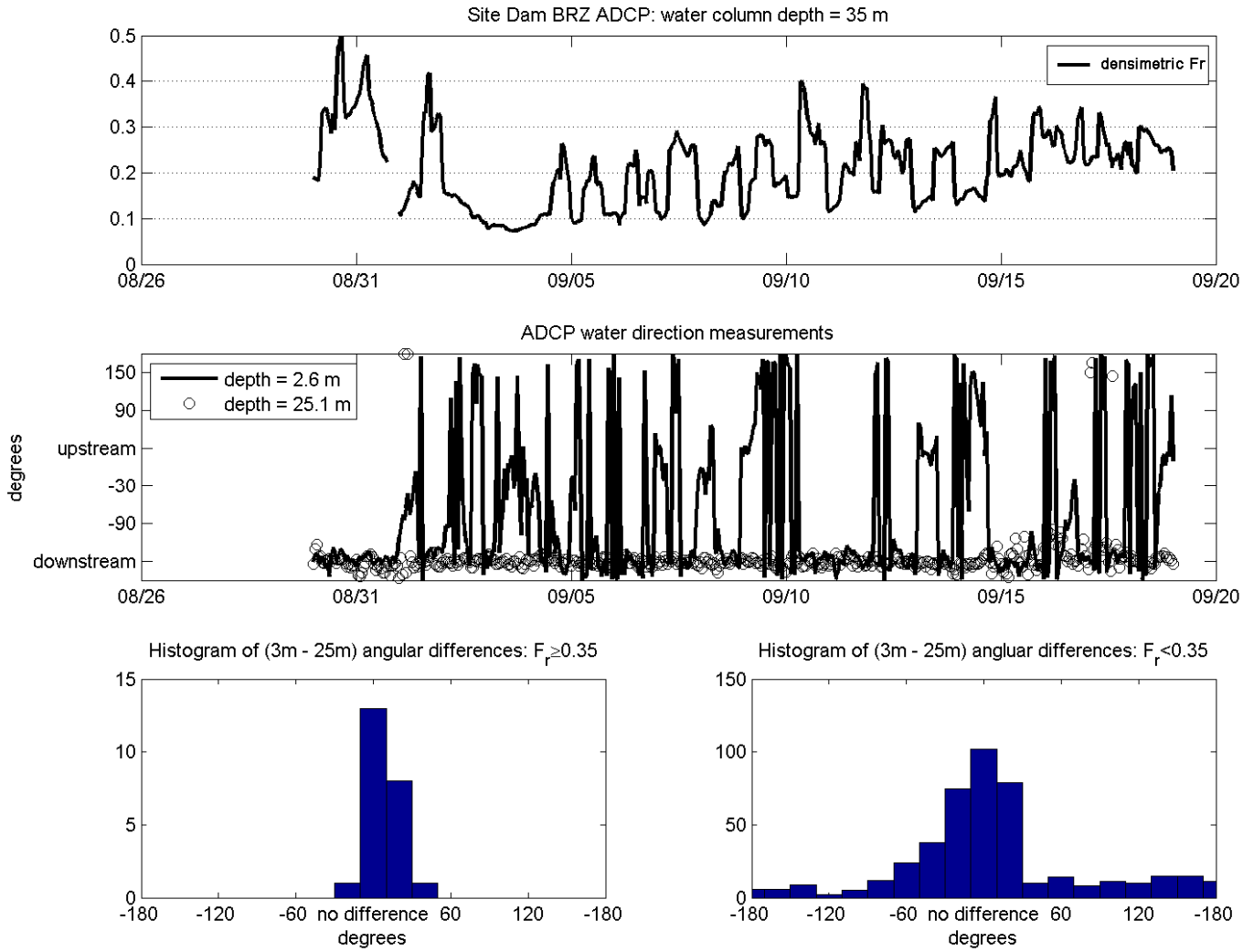

Figure C.4. Site LMN 7 Conditions for September

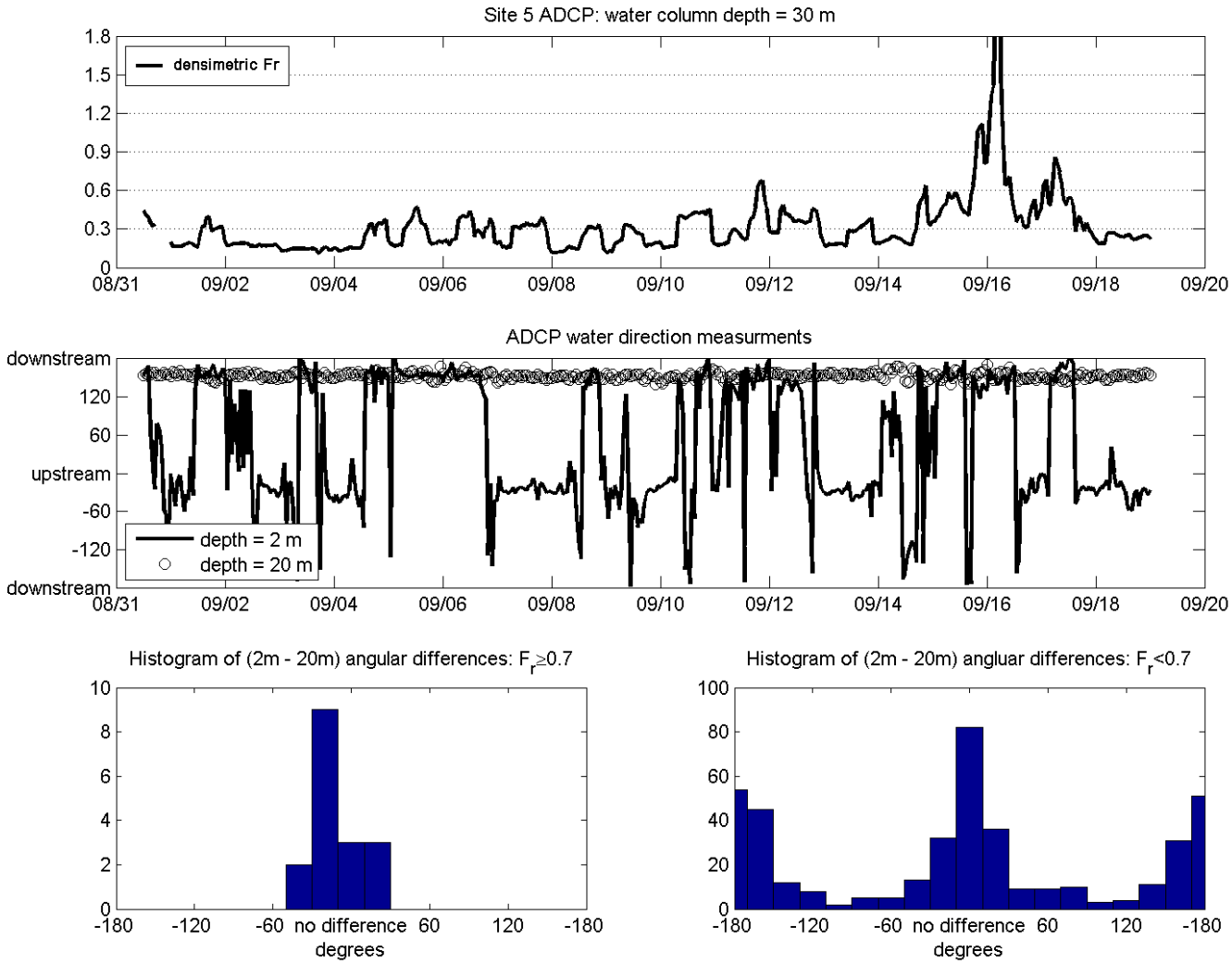

Figure C.5. Site LMN 5 Conditions for September

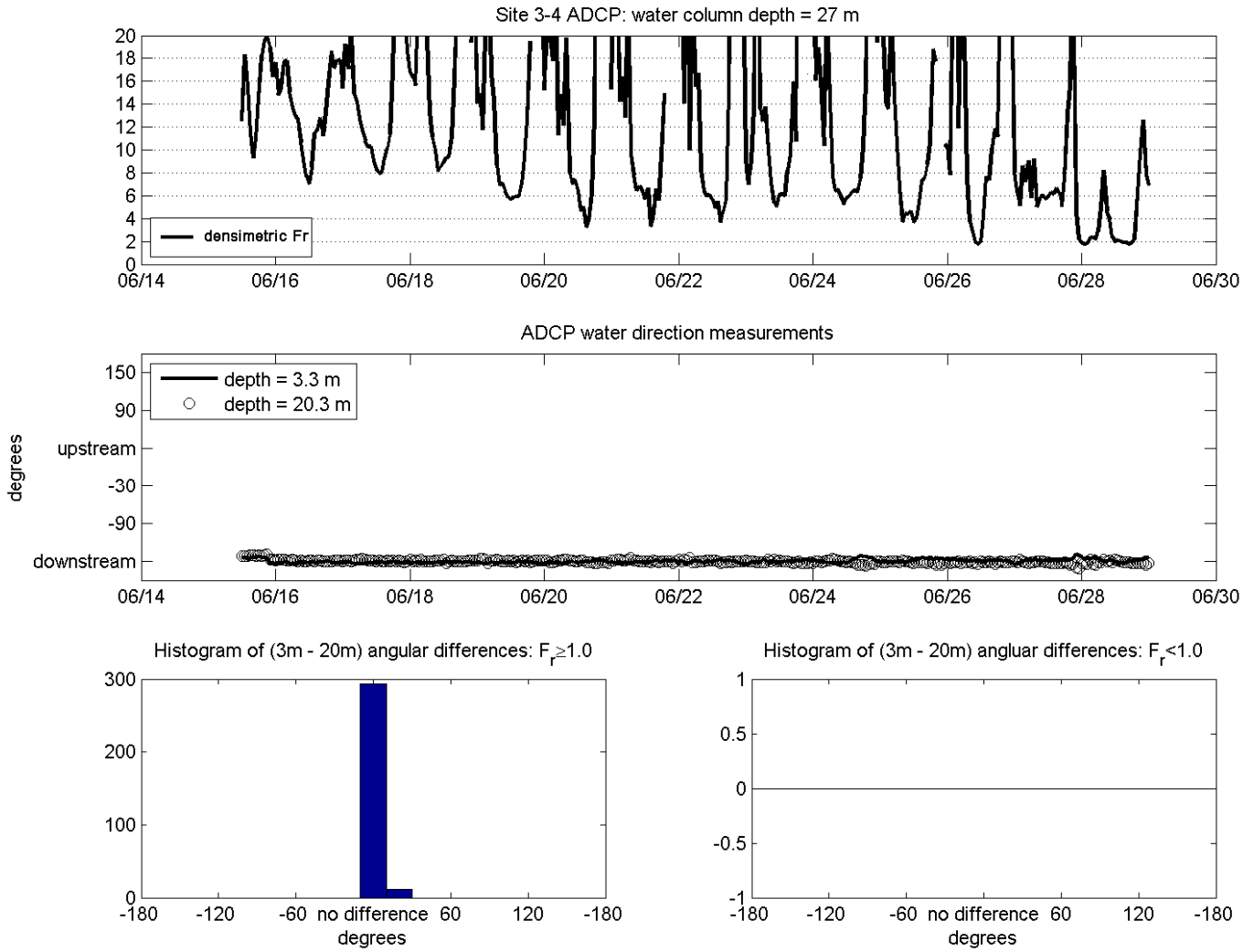

Figure C.6. Site LMN 3 Conditions from Mid to Late June

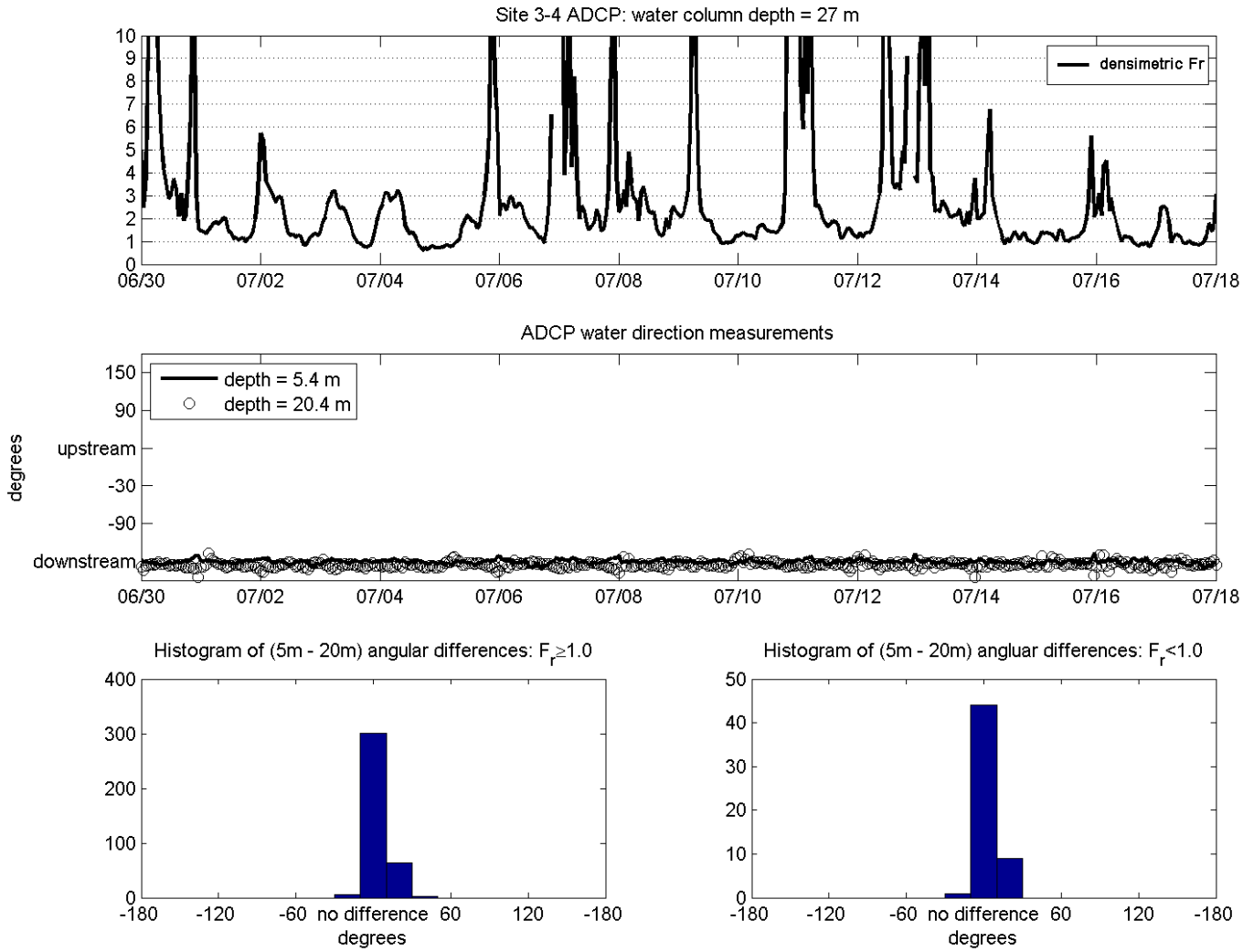

Figure C.7. Site LMN 3 Conditions from Early to Mid July

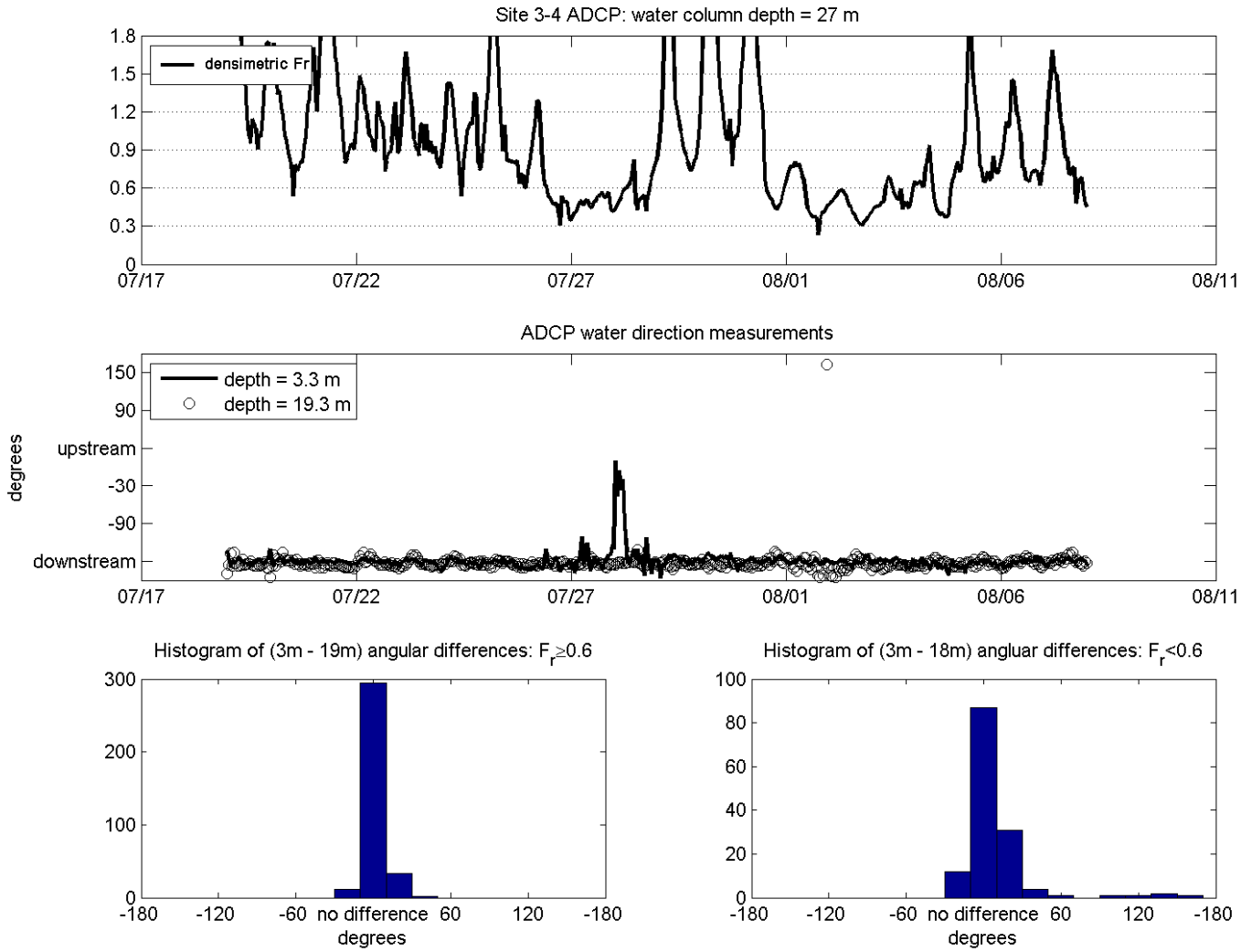

Figure C.8. Site LMN 3 Conditions from Mid July to Early August

Appendix D

Acceptance Testing (Nodes)

Appendix D – Acceptance Testing (Nodes)

Autonomous receiving nodes, which included on-board power (30-day battery life) and data storage (1 GB Compact Flash [CF]), were deployed to detect and record the presence of fish bearing microacoustic transmitters. Each receiver underwent a rigorous acceptance testing protocol performed by an independent contractor prior to being delivered from the manufacturer and deployed in the field. First, a gross examination was completed to ensure all parts were present and properly labeled. These parts included the upper and lower housings, bridle, battery retaining device, board sets, CF card mount switch, stereo plug, hydrophone, and temperature and pressure sensors. Then the nodes were activated, and basic function was evaluated. Function evaluation included checking whether the pressure and temperature sensors and the clock were properly calibrated and that the node was able to properly receive, decode, and store acoustic signals to the CF card. Finally, node performance was measured and the housings were tested for leaks. This was done in a large tank lined with anechoic material, using a signal generator and attenuator to simulate range. Each node was placed in the tank at a known distance from the signal transducer element. An attenuation curve was created by calculating the percentage of transmissions that were correctly detected and decoded at each of six signal levels (−20, −30, −40, −45, −50, −55 dB). Acceptance criteria required detection efficiency of 80% or higher at each level down to −45 dB (see Figure D.1). Nodes that failed any part of the test were returned to the manufacturer for repair or replacement and were retested prior to acceptance.

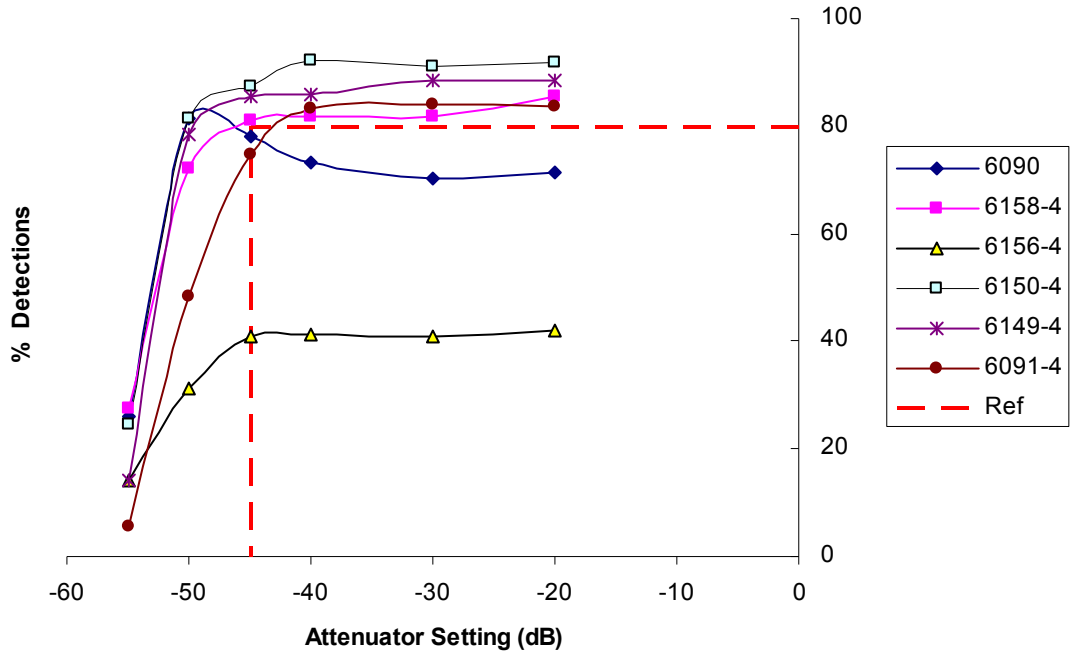

Figure D.1. An Example of Autonomous Receiver (Node) Acceptance Test Data. Percentage of detections decoded is plotted versus signal strength (dB). Acceptance criteria are defined by the red lines (nodes that produced detection lines that stay above and to the left of the red lines were accepted). In this example, nodes 6156-4, 6090, and 6091-4 were not accepted, while the other three were accepted.