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SIGNIFICANCE OF SELECTIVE PREDATION AND DEVELOPMENT OF PREY PROTECTION MEASURES FOR JUVENILE SALMONIDS IN THE COLUMBIA AND SNAKE RIVER RESERVOIRS

ANNUAL PROGRESS REPORT

February 1993 - February 1994

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Part 1

Predator Avoidance Ability of Juvenile Chinook Salmon Exposed to Gas Supersaturated Water

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Abstract.-Supersaturation of atmospheric gas in waters of the Columbia and Snake rivers has long been recognized as a serious problem affecting the survival of salmonids. Although the issue was considered essentially solved by the mid-1970's, recent changes in river management and endangered species listings have renewed the concern about dissolved gas supersaturation (DGS) effects on salmonids. Much of the recent concern involves potential sublethal or indirect effects of exposure to DGS, particularly increased vulnerability to predation. Consequently, we conducted laboratory experiments to assess the effects of an acute exposure to DGS on the predator avoidance ability of juvenile chinook salmon Oncorhvnchus tshawvtscha. We exposed fish to 120% total dissolved gas (TDG) for 8 h and then subjected them, simultaneously with unexposed control fish, to predation by northern squawfish (Ptvchocheilus oreaonensis). A total of 14 predation tests were conducted, but only six of these met our criterion for analysis (i.e., predators had to eat 30-60% of the total number of prey released). Using data from these six tests, we determined there was no significant difference in the numbers of fish consumed from either group ($P > 0.10$; $N = 77$). Statistical power (to detect a 20% effect size) of the pooled chi-square test was 0.38. Although our results suggest that juvenile salmon receiving acute, sublethal exposures to DGS are not more vulnerable to predation, the small sample size and low statistical power preclude any strong inferences from our data. We will continue to explore the effects of DGS on predator avoidance ability to increase our understanding about this potential source of indirect mortality.

In the mid-1960's, supersaturation of atmospheric gas in waters of the Columbia and Snake Rivers--primarily caused by water spilling over hydroelectric dams--was recognized as a serious problem affecting the survival of salmonids. Exposure of fish to water supersaturated with atmospheric gas causes gas bubble trauma (GBT), a non-infectious, physically induced malady which can produce lesions in blood (emboli) and tissues (emphysemas), physiological dysfunction, and death resulting from blood stasis (Bouck 1980). The supersaturation problem in the Columbia River system stimulated a considerable amount of research directed at various aspects of GBT (see reviews by Fickeisen and Schneider 1976; Weitkamp and Katz 1980) and also led to new spillway designs and modifications that helped alleviate or prevent supersaturation (Smith 1974). Because of this effort, the problem was considered tolerable, or even eliminated, by the mid-1970's (Ebel et al. 1975; Ebel 1979; Weitkamp and Katz 1980). Recently, however, dissolved gas supersaturation (DGS) and its effects on salmonids in the Columbia River system has again become a critical issue. High flows and high DGS levels in 1993, the listing or potential listing of several salmonid stocks under the Endangered Species Act, and the use of increasing amounts of spill for fish passage have all contributed to a renewed concern about the effects of DGS, particularly sublethal or indirect effects.

Most research on gas supersaturation effects in fish has been involved with acute mortality. However, because many waters are chronically supersaturated with levels not high enough to result in acute mortality and the effects of DGS on fish depend on a variety of ancillary factors (e.g., DGS level, exposure time, water depth and temperature, and fish size), mortality information alone may be of little value in assessing the overall impact of DGS on fish. Surprisingly, the potentially serious effects that may occur in fish exposed to sublethal gas concentrations have received relatively little attention. Studies have shown that sublethal exposure of fish to DGS can adversely affect swimming performance (Schiewe 1974; Dawley and Ebel 1975), blood chemistry (Newcomb 1974; Dawley and

Ebel 1975), growth (Dawley and Ebel 1975; Krise 1993), thermal tolerance (Ebel et al. 1971), and lateral line function (Weber and Schiewe 1976).

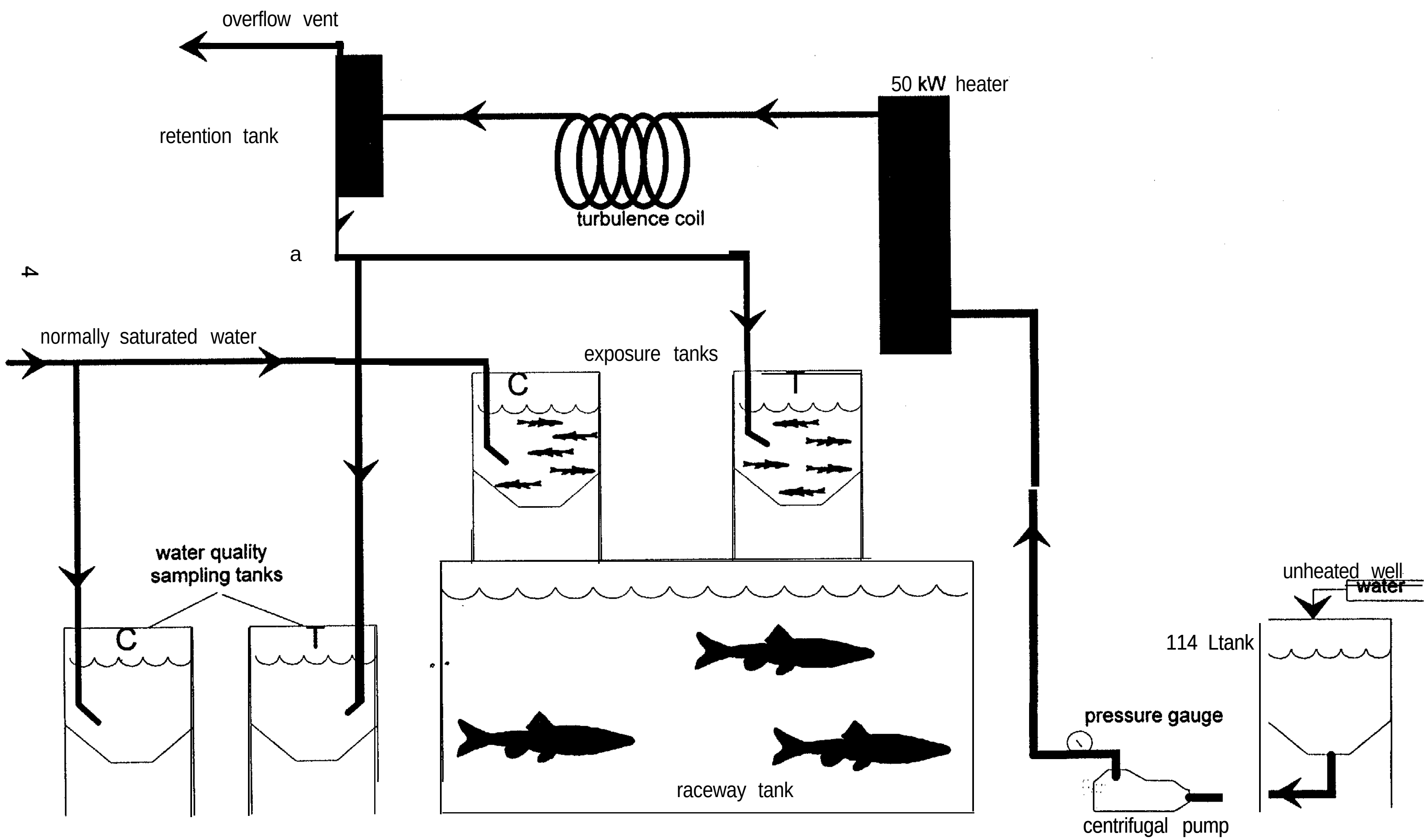
One aspect of fish performance that might be affected by exposure to DGS is the ability to avoid predators. Indeed, several authors have speculated that increased vulnerability to predation is a likely consequence of sublethal exposure to DGS (Newcomb 1974; Schiewe 1974; Dawley and Ebel 1975; Weber and Schiewe 1976; Weitkamp and Katz 1980). Although the ability to avoid predators is an ecologically relevant indicator of environmental stress (see review by Mesa et al. in press) and may be a source of indirect mortality in fish exposed to DGS, we are aware of only one study (White et al. 1991) that has addressed the effects of DGS on predator-prey interactions. This work, unfortunately, was only a small part of a much larger study on the effects of DGS in the Bighorn River and consequently had limited scope, produced equivocal results, and suffered from problems in experimental design (e.g., lack of replication). Clearly, more research is necessary to fully understand the effects of DGS on behavior such as predator avoidance ability.

The purpose of this study was to evaluate the effects of an acute exposure to DGS on the predator avoidance ability of juvenile chinook salmon Oncorhvnchus tshawvtscha. The level of total dissolved gas (TDG) used was 120%, which is 10% higher than state and federal standards for water quality, commonly occurs in the Columbia River system, and is at the upper range of levels that could defensibly be set as new standards.

Methods

Experimental system.-Supersaturated water was generated by a combination of heating and pumping well water under pressure (Figure 1). Water at 7°C flowed into a 114 L, circular fiberglass tank where it was then pumped under 40 psi into a single-pass 50 kW heater. Water was heated to 15°C before flowing into a 23-m-long coil of 1.3-cm-diameter garden hose to allow some time under

FIGURE 1 .-Schematic diagram of the system used to expose juvenile chinook salmon to gas supersaturated water and for conducting predation tests. C = control, T = treatment.



pressure and to minimize turbulence before water entered a 94 L PVC retention tank. The retention tank vented excess bubbles and maintained a constant head pressure as supersaturated water flowed by gravity (3.8 L/min) into two 114 L tanks. One tank was located above the predation raceway (discussed below) and was used to expose prey to DGS; the other tank was on the ground and was used for monitoring water quality during predation tests. Two other tanks, designated as controls, were set up in a similar manner except for receiving normally saturated water that had passed through a packed column.

Predation tests were conducted in an 11,326 L fiberglass raceway 7.6 m long, 1.2 m wide, and 1.2 m deep. Water temperatures were maintained at 16-17°C, and overhead lighting simulated the ambient photoperiod. Prey were released into the raceway by removing stand pipes and opening knife gates on the tanks above the raceway. For a complete description of this tank, see Mesa (1994).

Test fish.-Age-O spring chinook salmon (average length ± SE = 106 ± 0.77 mm; N = 89) from the Little White Salmon National Fish Hatchery, Cook, Washington, were used for all experiments. The fish were reared in six 228 L, flow-through circular tanks receiving well water heated to 13-14°C. Excess gas was dissipated by passing the water through packed columns before it entered the tanks. Fish were fed ad libitum once daily with commercial feed and held under natural photoperiod. Several weeks prior to predation tests, fish in half the tanks were marked by removing their adipose fin.

We used 9 northern squawfish Ptvchocheilus oregonensis (average length ± SE = 416 ± 11.14 mm;), collected from the Columbia River by electrofishing, as predators. They were held in the raceway and fed a maintenance diet of juvenile chinook salmon. Predation tests did not commence until predators were consistently feeding.

Predation tests.-Tests were conducted from 27 September to 23 November, 1993. On the morning of each test, the gas supersaturation system was turned on and sufficient time allowed to generate a TDG level of 120.0%, ± 1.0% (delta P ± SE = 175.3 ± 4.86) in treatment tanks. After the TDG level had stabilized (about 1 h), 15 juvenile chinook salmon were placed into the treatment and control tanks above the raceway. The tanks had only 57 L of water and therefore allowed little, if any, depth compensation. Fish remained in the tanks for 8 h before they were released into the raceway. The 8 h exposure period at 120% TDG was based on some preliminary work we did evaluating fish for signs of GBT and determining the time necessary to kill 50% of the fish (i.e., the LT_{50}). At 2 h intervals during the exposure, we used a TDG meter (Common Sensing, Inc., Clark Fork, ID) to record water quality variables in the treatment and control tanks located next to the raceway. We monitored barometric pressure, water temperature, total dissolved gas (P_{tot}), partial pressures of oxygen (pO_2) and nitrogen (pN_2), barometric pressure minus P_{tot} (delta P), percent saturation, and percent oxygen.

Predators were deprived of food for 48 h before prey were introduced. After the 8 h exposure period, prey were released into the raceway and predation allowed to continue until 30-60% of the prey were consumed or until 3 h passed, whichever occurred first. The 3 h period was necessary to minimize recovery from GBT. Because northern squawfish feed better in low-light conditions, predation tests were initiated during a simulated evening crepuscular period (Mesa 1994). At the end of each test, all surviving prey were netted from the raceway and identified as treatment or control fish.

Data were analyzed in a manner identical to that of Mesa (1994). We first subjected all data to a heterogeneity chi-square analysis to determine if the individual tests were homogenous (Sokal and Rohlf 1981). Chi-square goodness-of-fit tests were then used on pooled data to determine if predation was random (i.e., 50:50) on treated versus control fish. Because the chi-square test has low statistical power (i.e., low probability of correctly rejecting the null hypothesis) for the small sample sizes in this study, I set alpha at 0.10 to reduce the probability of the more serious type II error (Fairbairn and Roff

1980; Peterman 1990). Tests where either less than 30% or more than 60% of the prey were eaten were excluded from the analysis.

Results

The gas supersaturation system was successful in producing consistent water quality variables that differed significantly from those in water used for control fish (t-tests, $P < 0.05$; Table 1). Although we did not sample our fish prior to release, preliminary experiments provided insight into the symptoms of GBT likely to exist in our treatment fish at the time of release. For example, based on an estimated percentage of the lateral line occluded with gas bubbles, we found that after 8 h at 120% TDG most fish had moderate to severe cases of lateral line occlusion (Figure 2). When we examined control fish during preliminary tests, we rarely found bubbles in the lateral line. Therefore, we feel confident that two groups of fish with distinct differences in physiological condition were released to predators.

We conducted a total of 14 predation tests (Table 2), but only six of these met the 30-60% criterion. Most of the tests required the full 3 h for completion. In the six tests used for analysis, there was no significant heterogeneity and 56% of the prey consumed were treatment fish. There was no significant difference, however, in the total numbers of treatment and control fish eaten (Table 3). Statistical power (to detect a 20% effect size) of the pooled chi-square test was 0.38.

TABLE 1.-Mean (and SE) values of selected water quality variables in control and treatment tanks during the six predation tests-used for analysis. Values are averages of several readings taken during the 8 h exposure period. For each variable, N = 21.

Variable	Control	Treatment
Barometric pressure (mm Hg)	743.8 (0.74)	744.1 (0.82)
Temperature (°C)	14.3 (0.87)	14.6 (0.07)
Total dissolved gas pressure (mm Hg)	766.8 (1.29)	917.8 (4.89)
Partial pressure of oxygen (mm Hg)	138.3 (1.52)	165 (1.27)
Partial pressure of nitrogen (mm Hg)	632.2 (0.97)	756.7 (4.27)
Delta P (mm Hg)	23.7 (1.09)	175.3 (4.86)
Percent saturation	103.1 (0.15)	123.4 (0.67)

FIGURE 2.-Relative severity of gas bubbles in the lateral line of juvenile chinook salmon exposed to 120% TDG for 8 h during preliminary tests. Numbers are based on an arbitrary scale of the estimated percentage of the lateral line occluded with bubbles where **0-25%** = low, 26-75% = moderate, and **>** 75% = severe.

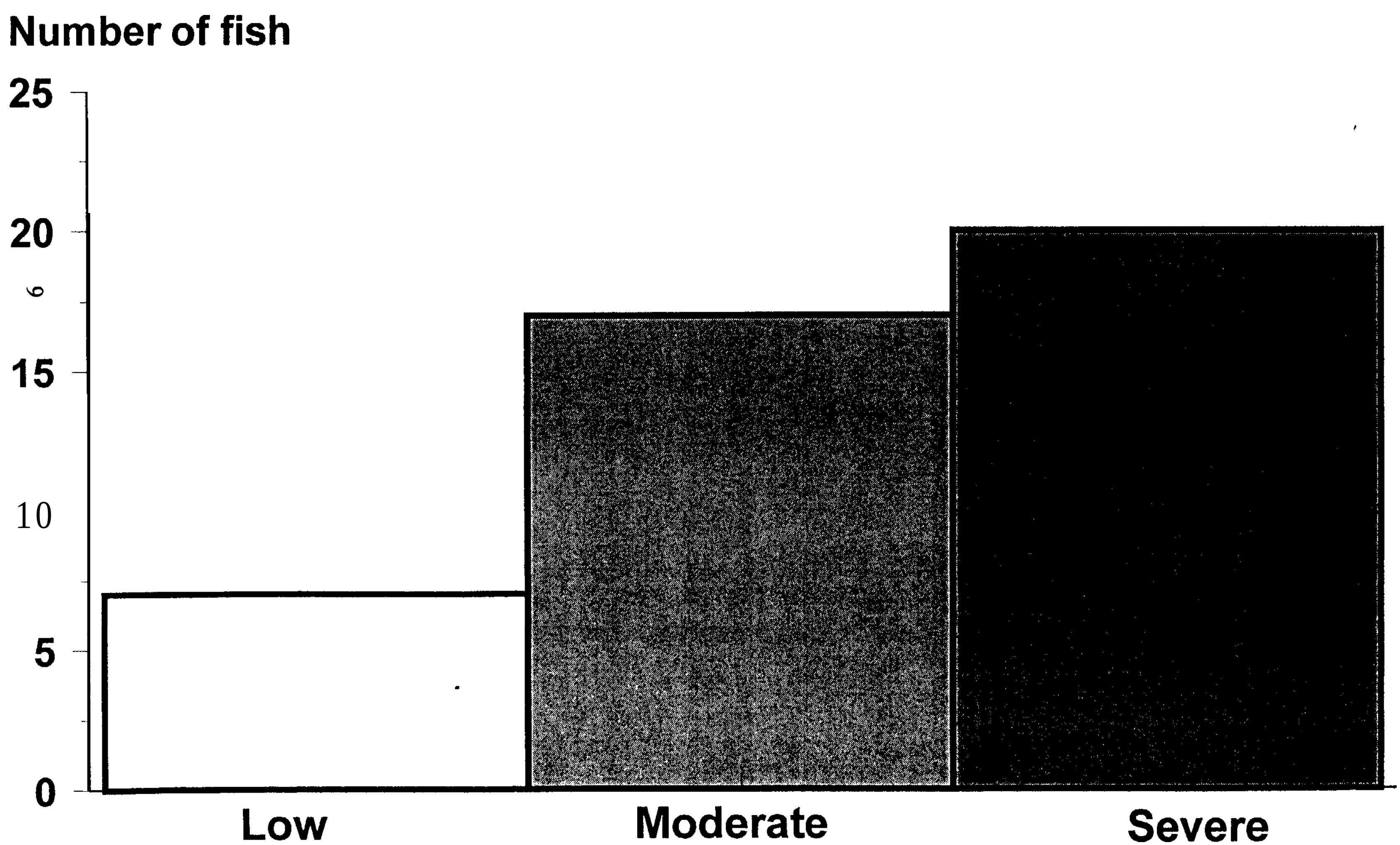


TABLE 2.-Predation on juvenile chinook salmon subjected to 120% TDG for 8 h and exposed to northern squawfish for up to 3 h.

Date	Number eaten		Percent
	DGS exposed	Control	eaten
9/27	11	4	50
9/28	4	8	40
9/30	3	3	20
10/4	3	1	13
10/6	2	0	7
10/8	2	0	7
10/25	2	1	10
10/27	0	2	7
11/2	6	1	23
11/5	5	2	23
11/10	5	5	33
11/16	7	5	40
11/18	10	8	60
11/23	7	4	37

TABLE 3.-Predation on juvenile chinook salmon subjected to 120% TDG for 8 h and exposed to predation by northern squawfish for up to 3 h. Only tests where 30-60% percent of the prey released were eaten are included in the analysis. Asterisks denote predation rates that differ significantly ($P < 0.10$) from random (50:50, DGS exposed:control).

Replicate or statistic	Number eaten: DGS exposed	Number eaten: Control	Statistics: df	Statistics: x^2
1	11	4	1	3.267'
2	4	8	1	1.333
3	5	5	1	0.000
4	7	5	1	0.333
5	10	8	1	0.222
6	7	4	1	0.818
Total	44	34	6	5.974
Pooled			1	1.282
Heterogeneity			5	4.692

Discussion

Prey in substandard condition are often eaten in higher than expected proportions (Temple 1987; Mesa et al. Oin mess) due to either increased prey vulnerability or active predator selection. r experiments, however, indicate that exposure to 120% TDG for 8 h did not increase the vulnerability of juvenile chinook salmon to predation by northern squawfish. Our results represent a first attempt to explore an ecologically significant sublethal effect of DGS and may not be applicable to other exposure scenarios (e.g., low-level chronic or intermittent exposures). For reasons mentioned in the introduction, our choice of exposure level is relevant to fish in the Columbia River system and may be considered a worst-case scenario since fish were unable to use depth for compensation. Unfortunately, because of small sample sizes and low statistical power (discussed below), we feel it would be premature to use our results to help guide management of the Columbia River system.

Statistical power analysis is an extremely important yet vastly underused tool by fishery scientists for formally testing null hypotheses (for an excellent review, see Peter-man 1990). Statistical power is defined as $1-\beta$, where β is the probability of making a Type II error (not rejecting a null hypothesis [H_o] when it should have been). As discussed by Peterman (1990), a common problem occurs when an analysis fails to reject H_o and conclusions are drawn or decisions made as if H_o were true, even though a false H_o could have been missed because of small sample sizes or large sampling variability. This is exactly the situation a mis-interpretation of our data could create. In our case, we failed to reject the null hypothesis of no effect of TDG on the vulnerability of juvenile chinook salmon to predation, but conducted an experiment that had low power due to the small sample size. Although chi-square is an appropriate testing procedure for this type of data it requires larger sample sizes (e.g., $\geq$ 200 to detect a 20% effect size) to bring statistical power within an acceptable range (e.g., around 0.8; Fairbaim and Roff 1980; Elrod and Frank 1990). We feel that, in the case of TDG effects, the cost of making a Type II error is too large and we urge readers to use caution when interpreting our

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water adaptability. In 1994, we will continue to conduct predation experiments to increase statistical integrity and explore other DGS-related research questions. Collectively, this should help increase our understanding about an issue that is central to the management of Columbia River salmonids.

References

Bouck, G.R. 1980. Etiology of gas bubble disease. Transactions of the American Fisheries Society 109:703-707.

Dawley, E.M., and W.J. Ebel. 1975. Effects of various concentrations of dissolved atmospheric gas on juvenile chinook salmon and steelhead trout. Fishery Bulletin 73:787-796.

Ebel, W. J. 1979. Effects of atmospheric gas supersaturation on survival of fish and evaluation of proposed solutions. In United States Army Corps of Engineers. Fifth progress report on fisheries engineering research program 1973-1978. Portland District, Fish and Wildlife Section, Portland, Oregon, USA.

Ebel, W. J., H. L. Raymond, G. E. Monan, W. E. Farr, and G. K. Tanonaka. 1975. Effect of atmospheric gas supersaturation caused by dams on salmon and steelhead trout of the Snake and Columbia rivers. National Marine Fisheries Service, Northwest Fisheries Center, Seattle, Washington, USA.

Ebel, W.J., E.M. Dawley, and B.H. Monk. 1971. Thermal tolerance of juvenile pacific salmon and steelhead trout in relation to supersaturation of nitrogen gas. Fishery Bulletin 69:833-843.

Elrod, J.H., and A. Frank. 1990. Sample size requirements and analysis of tag recoveries for paired releases of lake trout. North American Journal of Fisheries Management 10: 196-201.

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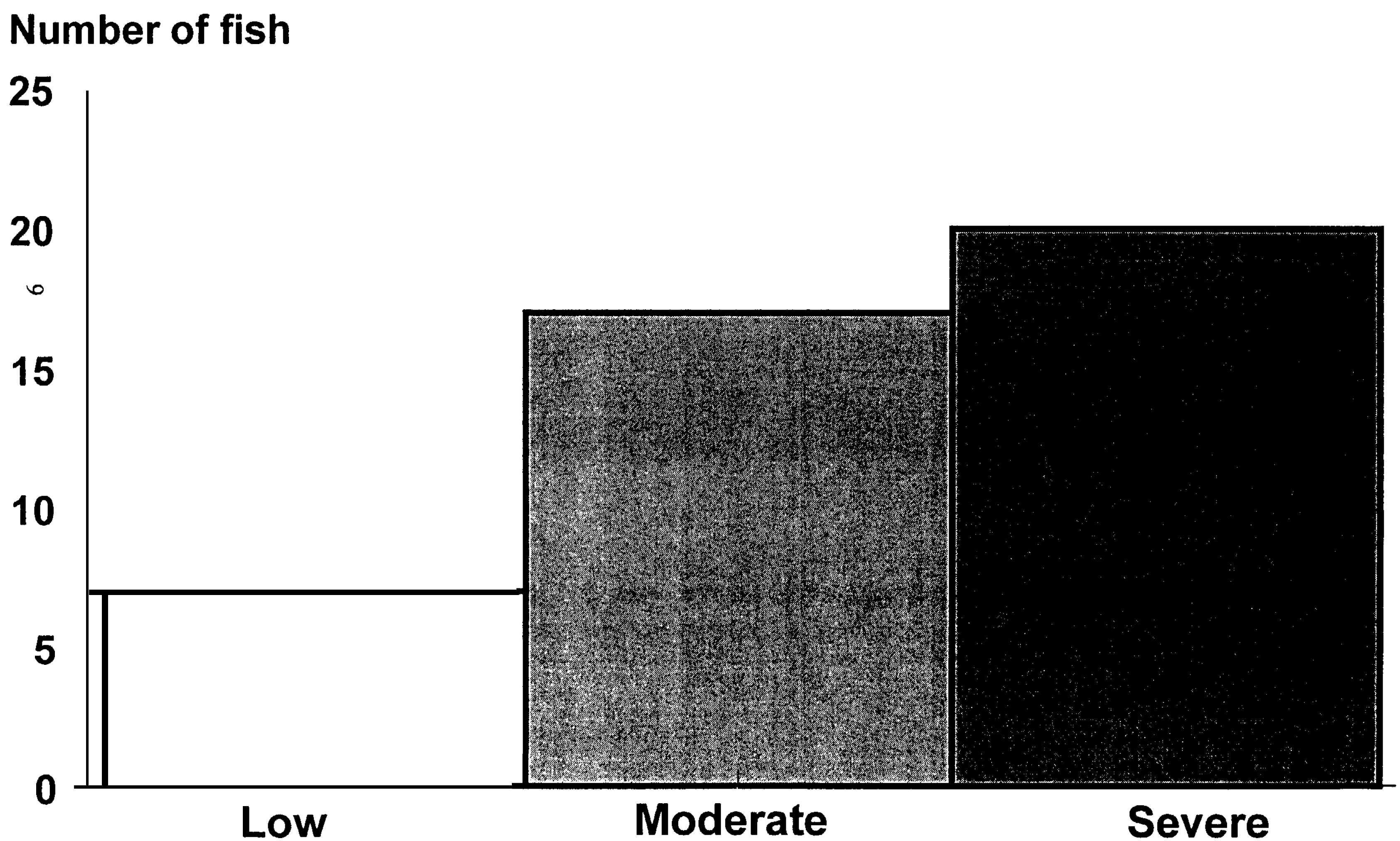

Partridge, B. L. & Pitcher, T. J. (1980). The sensory basis of fish schools: relative roles of lateral line and vision. Journal of Comuarative Physiology A 135, 315-325.

Peterman, R. M. 1990. Statistical power analysis can improve fisheries research and management. Canadian Journal of Fisheries and Aquatic Sciences 47:2-15.

Schiewe, M. H. 1974. Influence of dissolved atmospheric gas on swimming performance of juvenile chinook salmon. Transactions of the American Fisheries Society 103:717-721.

Smith, H. A., Jr. 1974. Spillway redesign abates gas supersaturation in Columbia River. Civil Engineering (New York) 144:70-73.

Sokal, R. R., and F. J. Rohlf. 1980. Biometry. Freeman, New York.

Temple, S. A. (1987). Do predators always capture substandard individuals disproportionately from prey populations? Ecology 68, 669-674.

Weber, D. D., and M. H. Schiewe. 1976. Morphology and function of the lateral line of juvenile steelhead trout in relation to gas-bubble disease. Journal of Fish Biology 9:217-233.

Weitkamp, D. E., and M. Katz. 1980. A review of dissolved gas supersaturation literature. Transactions of the American Fisheries Society 109:659-702.

White, R. G., G. Phillips, G. Liknes, J. Brammer, W. Connor, L. Fidler, T. Williams, and W. P. Dwyer. 199 1. Effects of supersaturation of dissolved gases on the fishery of the Bighorn river downstream of the Yellowtail afterbay dam. Completion Report for the Bureau of Reclamation, Missouri Basin, Region 6.

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Various studies in the lower Columbia and Snake rivers indicate that predators, especially northern squawfish (*Ptychocheilus oregonensis*), congregate in tailrace areas below hydroelectric dams where juvenile salmonids are often injured, stressed or disoriented due to dam passage making them more vulnerable to predation (Matthews et al. 1986; Maule et al. 1988; Mesa 1994). Juvenile bypass systems (JBS) are intended to reduce turbine mortality of juvenile salmonids passing through hydroelectric dams, however recent studies at Bonneville Dam indicate that juvenile salmonids passing through the JBS have a lower survival rate compared to other passage routes, including turbine passage (Ledgerwood et al. 1992; Dawley et al. 1994). It is possible that JBS intended to reduce mortality associated with dam passage may actually increase predation related mortality at JBS outfall sites and negate some of their benefits. Information regarding the movement patterns of predators and prey, especially overlaps in distribution, would be useful in locating, modifying, and operating JBS at Columbia and Snake river dams.

In 1984-85, the U.S. Fish and Wildlife Service and the Oregon Department of Fish and Wildlife conducted a radio telemetry study of northern squawfish in McNary Dam tailrace to describe their distribution during different flow regimes (Faler et al. 1988). They reported the distribution of northern squawfish was influenced by river discharge and current velocity (i.e. fish were not found in velocities greater than 70 cm/s) and that fish congregated in the area of the JBS outfall at McNary Dam when water velocities were reduced. As a result they suggested that predation may be reduced in certain areas if high water velocities (> 100 cm/s) were maintained near JBS outfall areas. These findings were supported by Mesa and Olson (1993) who reported that northern squawfish quickly fatigued at water velocities greater than 100 cm/s. They also recommended that future bypass outfalls be located in areas of high water velocity and distant from eddies, submerged cover, and littoral areas.

In 1992 we initiated a radio telemetry study at The Dalles Dam, Columbia River to examine how the movement patterns and distribution of northern squawfish change with respect to

Fairbairn, D.J., and D.A. Roff. 1980. Testing genetic models of isozyme variability without breeding data: can we depend on the χ^2? Canadian Journal of Fisheries and Aquatic Sciences 37:1149-l 159.

Fickeisen, D. H., and M. J. Schneider, editors. 1976. Gas bubble disease. CONF-741033, Technical Information Center, Energy Research and Development Administration, Oak Ridge, Tennessee, USA.

Gadomski, D. M., Mesa, M. G. & Olson, T. M. (1994). Vulnerability to predation and physiological stress responses of experimentally descaled chinook salmon, Oncorhvnchus tshawytscha. Environmental Biology of Fishes 39, 191-199.

Krause, J. (1993). The effect of 'Schreckstoff' on the shoaling behaviour of the minnow: a test of Hamilton's selfish herd theory. Animal Behaviour 45, 10 19- 1024.

Krise, W.F. 1993. Effects of one-year exposures to gas supersaturation on lake trout. The Progressive Fish-Culturist 55: 169-176.

Mesa, M. G. 1994. Effects of multiple acute stressors on the predator avoidance ability and physiology of juvenile chinook salmon. Transactions of the American Fisheries Society 123:786-793.

Mesa, M. G., T. P. Poe, D. M. Gadomski, and J. H. Petersen. In press. Are all prey created equal? A review and synthesis of differential predation on prey in substandard condition. Journal of Fish Biology 45 (supplement A).

Newcomb, T. W. 1974. Changes in blood chemistry of juvenile steelhead trout, Salmo pairdneri, following exposure to nitrogen supersaturation. Journal of the Fisheries Research Board of Canada 31:1953-1957.

Olla, B. L. & Davis, M. W. (1989). The role of learning and stress in predator avoidance of hatchery-reared coho salmon (Oncorhvnchus kisutch) juveniles. Aquaculture 76, 209-214.

Part2

Movements and distribution of radio-tagged northern squawfish near The Dalles and John Day dams

Annual Report of Research

1993

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In 1984-85, the U.S. Fish and Wildlife Service and the Oregon Department of Fish and Wildlife conducted a radio telemetry study of northern squawfish in McNary Dam tailrace to describe their distribution during different flow regimes (Faler et al. 1988). They reported the distribution of northern squawfish was influenced by river discharge and current velocity (i.e. fish were not found in velocities greater than 70 cm/s) and that fish congregated in the area of the JBS outfall at McNary Dam when water velocities were reduced. As a result they suggested that predation may be reduced in certain areas if high water velocities (> 100 cm/s) were maintained near JBS outfall areas. These findings were supported by Mesa and Olson (1993) who reported that northern squawfish quickly fatigued at water velocities greater than 100 cm/s. They also recommended that future bypass outfalls be located in areas of high water velocity and distant from eddies, submerged cover, and littoral areas.

In 1992 we initiated a radio telemetry study at The Dalles Dam, Columbia River to examine how the movement patterns and distribution of northern squawfish change with respect to

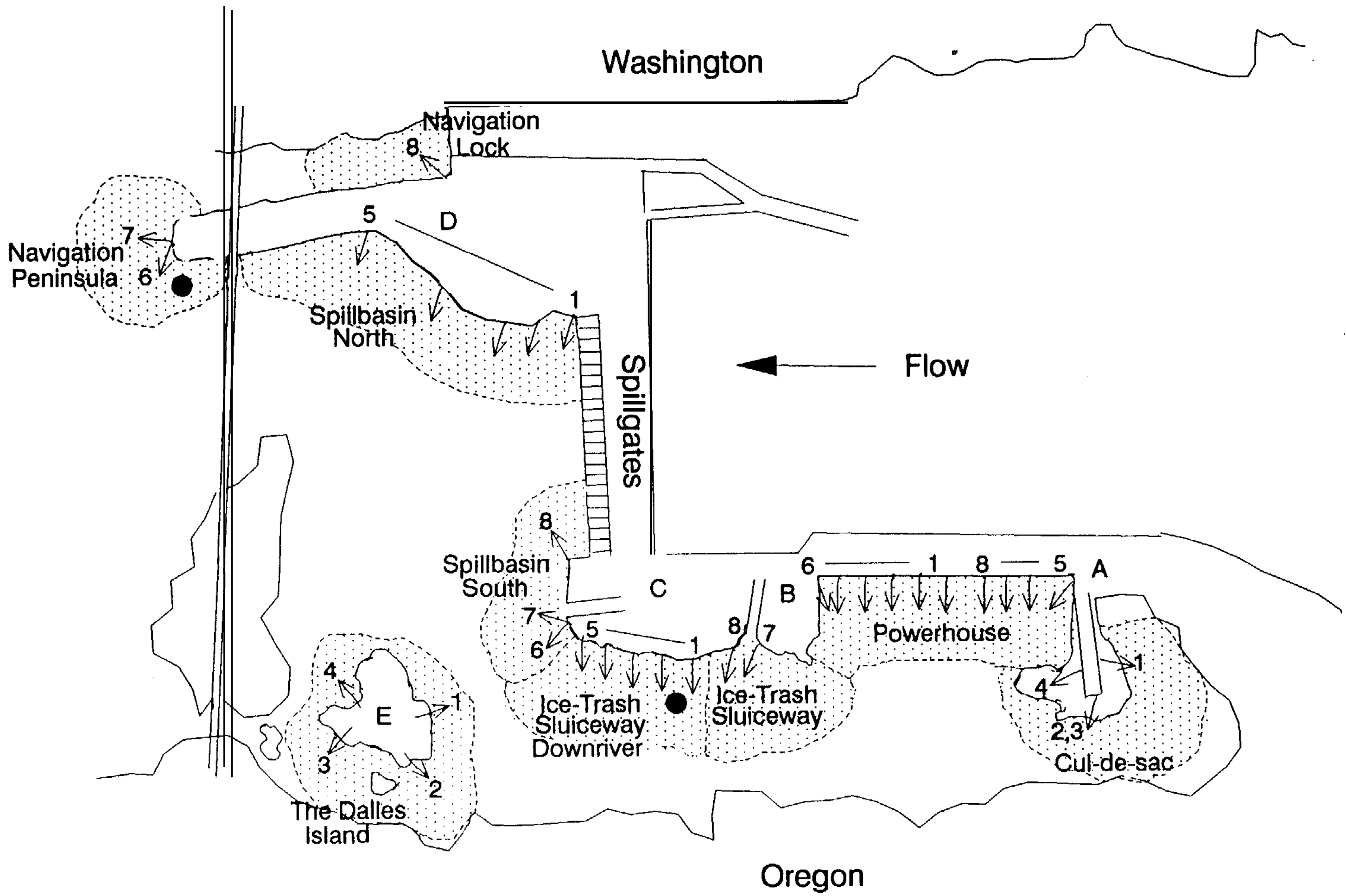

Figure 1. Location and orientation of fixed stations comprised of datalogging receivers (A-E) and their associated Yagi antennas (arrows labeled 1-8) at The Dalles Dam tailrace, Columbia River, 1993. Major habitats are labeled and areas of intended coverage are shaded. Potential locations for the proposed juvenile bypass outfall are indicated by circles.

were digitally-encoded allowing multiple transmitters per frequency and measured 14 x 43 mm and weighed 4.3 g in water.

Sixty-four northern squawfish were radio-tagged and released at TDA, whereas 71 fish were tagged and released at JDA. Fifty-six fish were released within the tailrace at TDA, including 45 in areas adjacent to the dam and 19 outside the BRZ. Six of the fish used at JDA were released at the mouth of the Deschutes River, 28 fish were released in the vicinity of John Day Island, 33 fish were released within the BRZ, and 4 fish were released in the downstream entrance to the JDA navigation lock. Radio-tagged northern squawfish ranged in size from 359 to 550 mm forklength (mean length = 452 ± 6mm; mean ± 1 SE) at TDA, whereas fish tagged at JDA ranged in size from 340 to 5 15 mm forklength (mean length = 414 ± 6mm; mean ±1 SE).

Five fixed-receiver stations were established at TDA to monitor northern squawfish movements in the vicinity of the two proposed JBS outfall sites (below the ice-trash sluiceway outfall and the main river channel south of the navigational lock peninsula) as well as other areas of interest in the boat restricted zone (Figure 1). A fixed-receiver station consisted of a Lotek' SRX-400 scanning receiver, an antenna switch box (that allowed the receiver to monitor up to 8 antennas), an array of 4 and B-element yagi antennas, and a 12v battery. Antenna coverage at TDA remained similar to 1992 in the areas of the ice-trash sluiceway and the cul-de-sac, however several changes were made for 1993 including: additional coverage in the areas along the powerhouse and the island located within the BRZ, and a reduction in coverage in the area of the spill basin to allow for more discretion among antennas in this area.

Seven fixed-receiver stations were established in the tailrace area of JDA (Figure 2). Three receiver stations with a combination of yagi and underwater coaxial cable antennas were located near the JBS outfall to monitor northern squawfish movements in this area. Yagi antennas were used to

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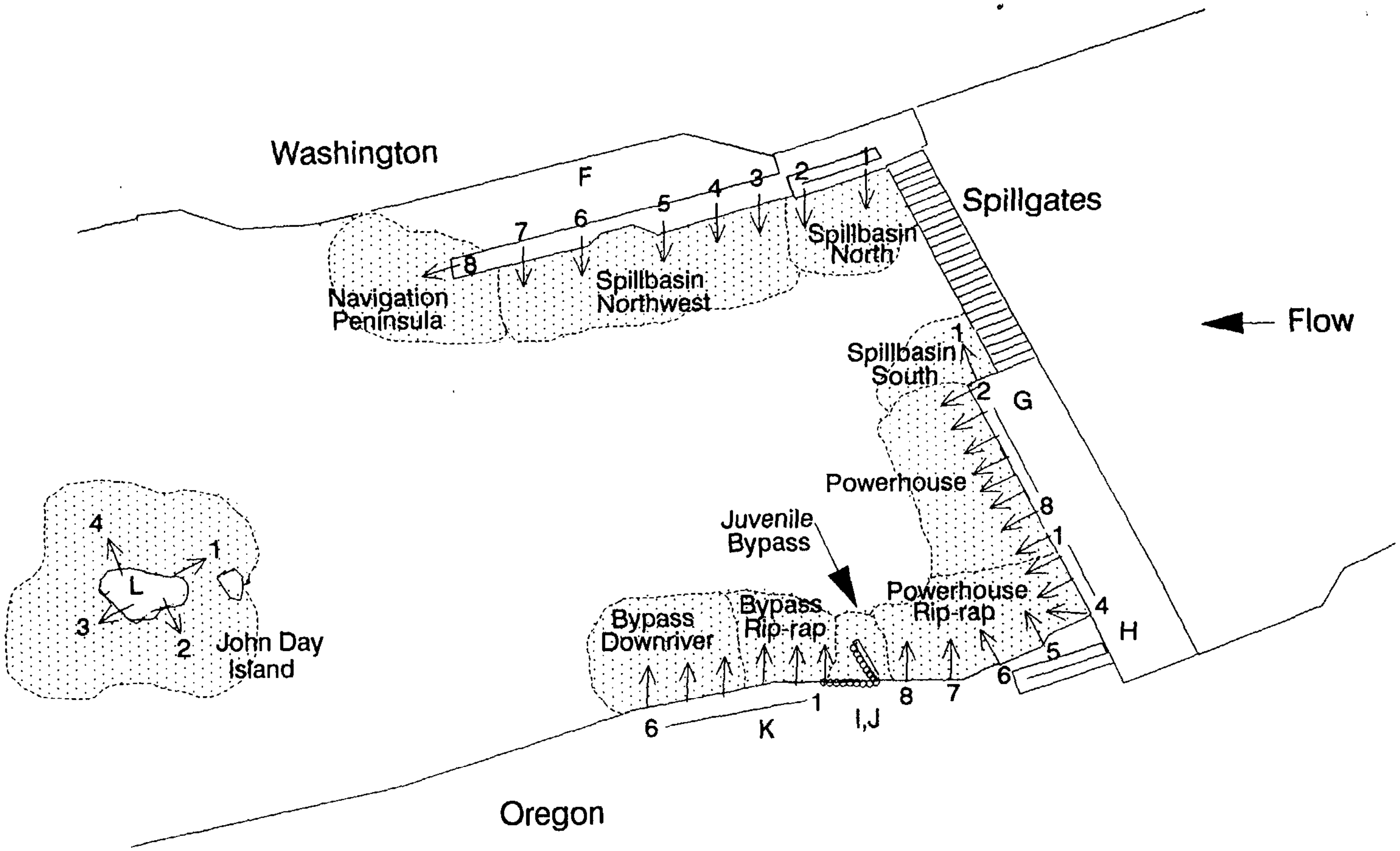

Figure 2. Location and orientation of fixed stations comprised of datalogging receivers (F-K) and their associated Yagi antennas (arrows labeled 1-8) at John Day Dam tailrace, Columbia River, 1993. Major habitats are labeled and areas of intended coverage are shaded.

migrating salmonids on squawfish behavior. No smolt counts were made at TDA, but due to the close proximity of the 2 dams it was assumed that the composition and pattern of the downstream salmonid migration would be similar at both IDA and TDA.

Seasonal use of areas adjacent to TDA and IDA by individual northern squawfish was determined as the percentage of observations in each area over all days in a month. General areas at both dams were established for purposes of analyses by grouping areas of coverage believed to have similar habitat characteristics (Figures 1 and 2). Differences in use among months were determined using multivariate analysis of variance (MANOVA) on the percentage of observations in each area (Tabachnick and Fidell 1983). Percentage data were normalized using an angular transformation (Zar 1984) and the F approximation of Wilk's Criterion (Tabachnick and Fidell 1983) was used to reject or accept the null hypothesis. Northern squawfish having less than 30 observations for a month were considered to provide an inaccurate estimate of individual habitat use and were excluded from the analyses; data were also excluded for days that downtime occurred to avoid introducing bias into use estimates due to missing data.

Diel movements of northern squawfish to and from the dams were analyzed by calculating the mean number of fish recorded at TDA and IDA during l-h intervals over a 24-h period. Differences among l-h intervals were determined using Kruskal-Wallis one-way analyses of variance. Diel use of specific areas was determined as the percent of locations in each area for six 4-h intervals over all days in a month. Insufficient numbers of observations for some 4-h intervals precluded analyses based on the use of areas by individual northern squawfish; hence, data were pooled over all individuals. A Chi-square (χ^2) contingency table analysis was used to examine if the distributions of northern squawfish observations among areas were the same for all time intervals.

Use of selected tailrace areas by northern squawfish under different ice-trash sluiceway operating conditions was determined as the percent of observations in each area when the sluiceway migrating salmonids on squawfish behavior. No smolt counts were made at TDA, but due to the close proximity of the 2 dams it was assumed that the composition and pattern of the downstream salmonid migration would be similar at both JDA and TDA.

Seasonal use of areas adjacent to TDA and JDA by individual northern squawfish was determined as the percentage of observations in each area over all days in a month. General areas at both dams were established for purposes of analyses by grouping areas of coverage believed to have similar habitat characteristics (Figures 1 and 2). Differences in use among months were determined using multivariate analysis of variance (MANOVA) on the percentage of observations in each area (Tabachnick and Fidell 1983). Percentage data were normalized using an angular transformation (Zar 1984) and the F approximation of Wilk's Criterion (Tabachnick and Fidell 1983) was used to reject or accept the null hypothesis. Northern squawfish having less than 30 observations for a month were considered to provide an inaccurate estimate of individual habitat use and were excluded from the analyses; data were also excluded for days that downtime occurred to avoid introducing bias into use estimates due to missing data.

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Use of selected tailrace areas by northern squawfish under different ice-trash sluiceway operating conditions was determined as the percent of observations in each area when the sluiceway discharge of 287 KCFS occurred on 17 May. At both TDA and JDA, minimum and maximum daily discharges often differed substantially (Appendix Figure 2); maximum spill discharges occurred at night, whereas maximum turbine discharges occurred during mid-day (Appendix Figure 3).

Surface and mean column water velocities were determined near the JBS at John Day Dam under low flow conditions in November (<80 KCFS). Water velocities ranged from approximately 1 to 4 ft/s (surface: 1 .1-3.9 ft/s; mean column: 1.2-3.4 ft/s). Velocities were lowest immediately downriver of the bypass flume in an eddy near the oregon shore, while velocities farther offshore and immediately downriver of the point of bypass outfall generally exceeded 3 ft/s.

The downstream migration of juvenile salmonids was comprised of two temporally distinct parts as reflected by fish counts at John Day Dam. The number of early migrants composed largely of steelhead *Oncorhynchus mykiss*, yearling chinook *0. tshawytscha*, coho 0. *kisutch*, and sockeye 0. *nerka* salmon peaked in mid May and declined by early June. Subyearling chinook were predominant in the second portion of the downstream migration that reached maximum abundance in late-June and early-July and continued through August (Appendix Figure 4).

Seasonal Movements at TDA

Fifty-five (86%) of the northern squawfish tagged and released below TDA and 1 fish released above the dam at the mouth of the Deschutes River were recorded by fixed stations for a total of 26,121 observations at TDA tailrace between 12 May and 30 September (Appendix Table 1). Fish were logged for an average of 466 ± 61 observations (mean ± 1 SE, N=56); ten fish were observed more than 1,000 times at the dam, while 2 fish had only 3 observations (Appendix Table 2). Fish were contacted a mean of 44 ± 5 days (mean ± 1 SE, N=56), ranging from 1 to 133 days. Individual northern squawfish were not present at the dam during all months; during May through September a total of 27, 43, 32, 29, and 26 individual fish were logged at the dam (Appendix Table 2). Only 24%

of the fish recorded that left the dam returned to be logged in later months. Eight radio-tagged northern squawfish were caught by anglers and reported by the Washington Department of Fisheries (WDF) sport bounty program or by Columbia River Inter-Tribal Fisheries Commission (CRITFC) personnel.

The daily number of northern squawfish recorded near TDA corresponded with changes in both dam operations and the out-migration of juvenile salmonids. Initially, few of the tagged fish released in the boat restricted zone (BRZ) and none of the fish released outside of the restricted zone were recorded near the dam when spill and turbine discharges were high (Figure 3). However, with increasing numbers of smolts and temporary reductions in spill and turbine discharges, the number of northern squawfish recorded increased rapidly.

The number of northern squawfish decreased as the counts of early out-migrating salmonids passing the dam declined in late May, but rose again when mean spill discharges were reduced to less than 15 KCFS. Few fish radio-tagged and released outside the boat restricted zone were recorded by fixed stations at the dam until 12 June following the rapid decline in mean spill discharge; but once present, changes in their abundance followed a pattern similar to fish released within the boat restricted zone (Figure 3). The daily number of northern squawfish at the dam peaked (N=29) on 21 June just prior to the arrival of large numbers of subyearling chinook salmon.

The number of northern squawfish located near the dam decreased after the June peak despite relatively large numbers of subyearling chinook in the river and continued to decline to a low of 12 fish on 24 July. The number of tagged fish at the dam rose once again in August to 2 1, fluctuating up and down with the number of subyearling chinook in the river, and declined to a summer low of 9 fish as the salmonid out-migration neared an end in early September. Another increase in the numbers of squawfish was observed beginning on 7 September, coinciding with high numbers of out-migrating

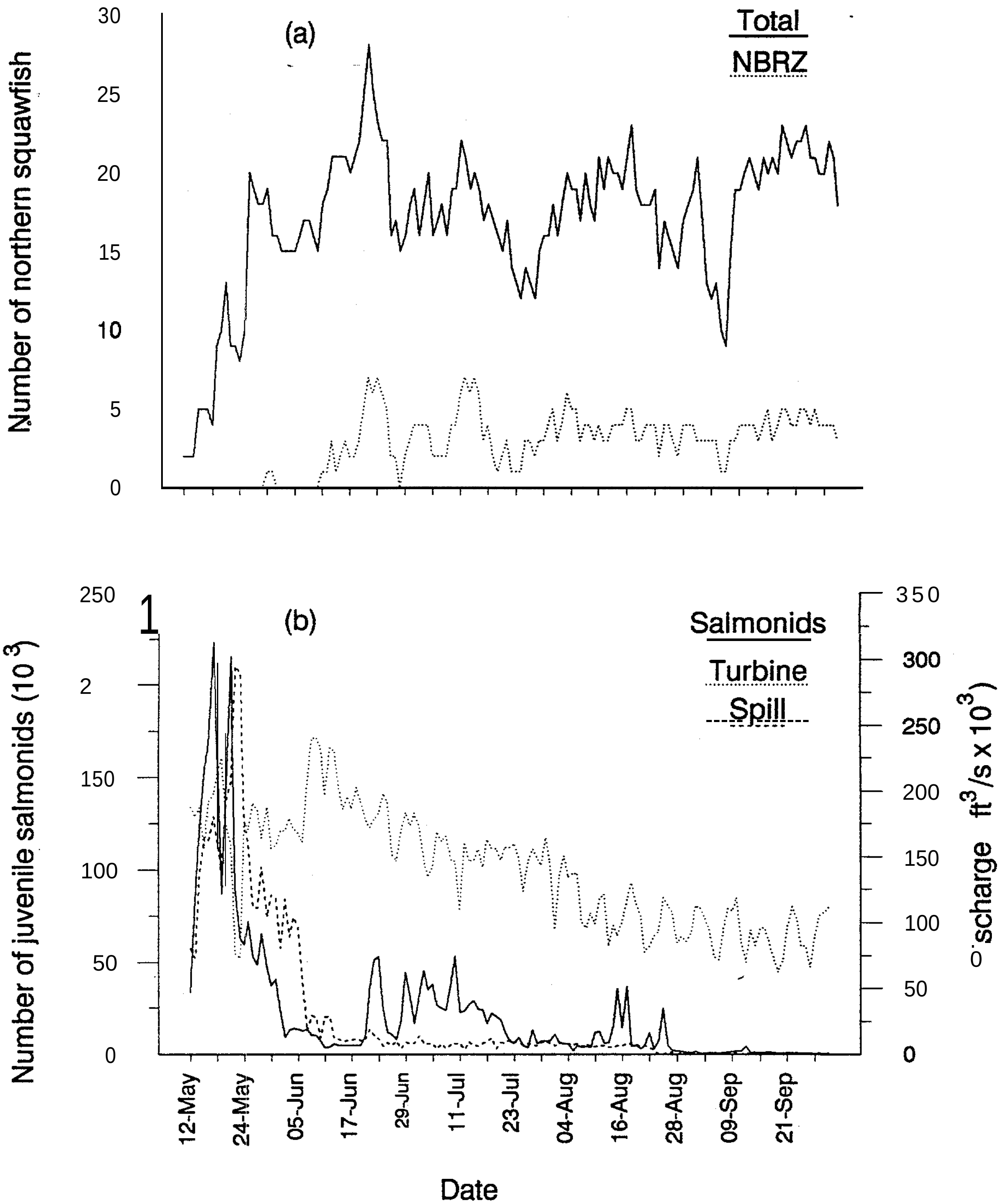


Figure 3. Total number of northern squawfish released downriver of The Dalles Dam and number of fish released only outside the boat restricted zone (NBRZ) recorded by fixed stations at The Dalles Dam (a), compared to juvenile salmonid index counts (John Day Dam) and turbine and spill discharges (b), 12 May - 30 September 1993.

juvenile American shad *Alosa sapidissima* that peaked during the second week of the month (Rick Martinson, National Marine Fisheries Service, Personal Communication).

Seasonal Use of TDA Tailrace Areas

Use of areas near the dam by northern squawfish differed significantly among months (Figure 4; MANOVA, $F_{[24,346]} = 7.33$, $P < 0.001$, angular transformation). Few northern squawfish were recorded at the tip of the navigation lock peninsula or in the navigation lock. The cul-de-sac, ice-trash sluiceway, and downriver ice-trash sluiceway were the most heavily used areas by northern squawfish, accounting for a mean of 39, 28, and 16% of the observations logged, when spill and turbine discharges were the highest May. At the cul-de-sac most locations (56%) for northern squawfish were recorded directly south of the powerhouse by antenna A4 (Figure 1) at the interface of the powerhouse discharge and the protected waters of the cul-de-sac. Approximately 97% of all observations at the sluiceway were logged immediately upstream on the east side of the structure at antenna B7, a slack water area where northern squawfish had easy access to discharges from the sluiceway and powerhouse.

In contrast, during June when minimum and mean turbine discharges rose and spill consisted primarily of a much reduced nighttime discharge and a daytime attraction flow, the sluiceway had a mean percent use of 42%; whereas all other areas had means less than 16%. Sixty percent of all observations at the ice-trash sluiceway were logged upstream and 40% of the observations were logged immediately downstream of the sluiceway structure at antenna B8 (Figure 1).

The primary areas used by northern squawfish shifted again during July, when most subyearling chinook salmon passed the dam. The south spillbasin and powerhouse areas accounted for a mean of 29% and 24% of the individual fish observations, respectively. Prior to this, both areas had received a minor but increasing amount of use by northern squawfish. At the south spillbasin area,

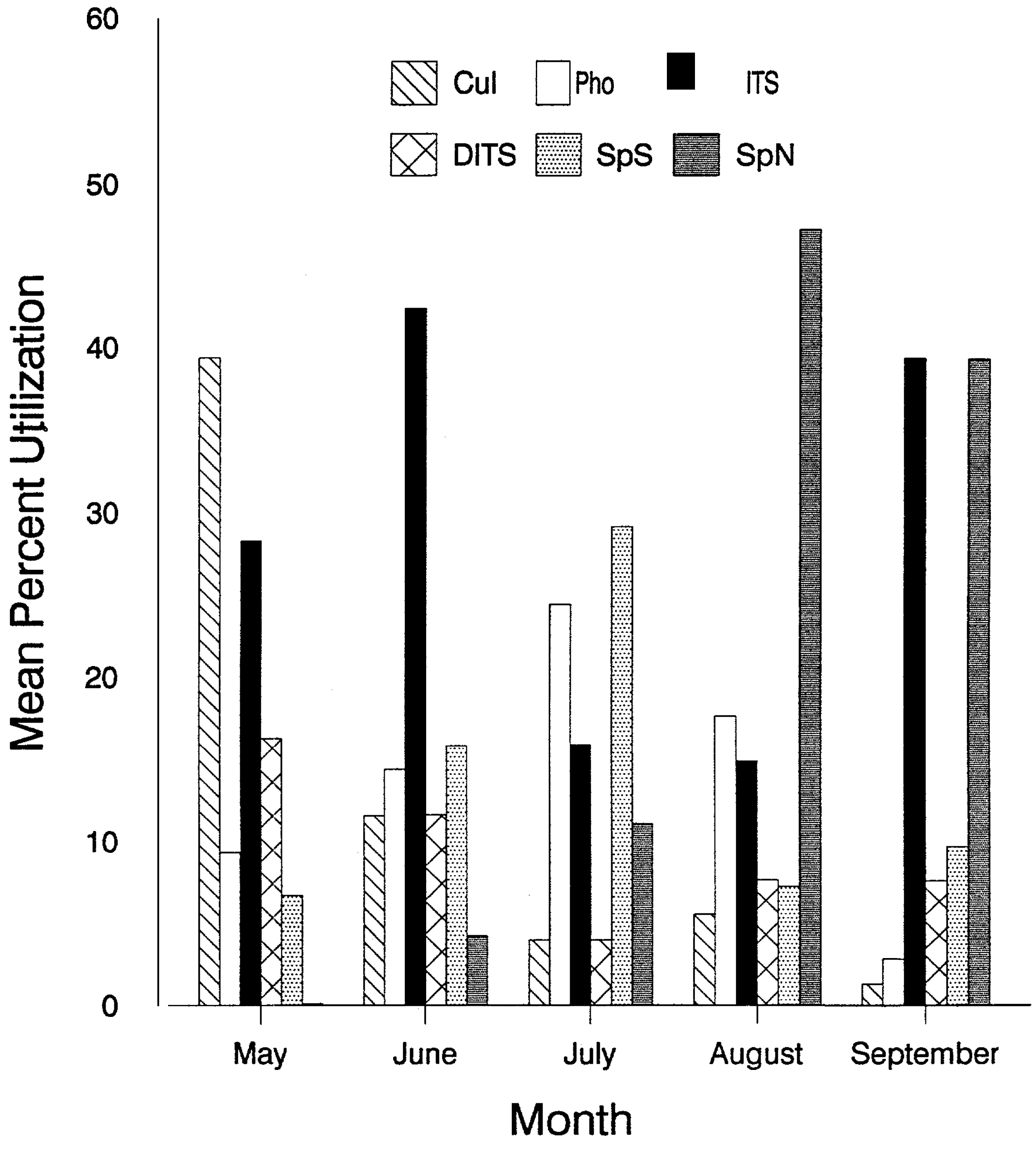


Figure 4. Seasonal variation in relative use of **tailrace** areas by northern squawfish at The **Dalles** Dam, May - September 1993. **Tailrace** areas: **Cul** = Cul-de-sac, Pho = Powerhouse, ITS = Ice-Trash Sluiceway, **DITS** = Downriver Ice-Trash Sluiceway, Sps = Spillbasin South, **SpN** = Spillbasin North. More details on **tailrace** areas are given in Figure 1. Areas consistently having monthly mean percents c 2 are not shown. Only fish having at least 30 observations for a month were included in the analyses. N (number of northern squawfish) = 20 for May; N = 31 for June; N = 22for July; N = **18** for August; N = 21 for September.

77% of the locations were recorded at antenna C8 immediately adjacent to the spillbasin. Antennas B6 and A5, located at the west and east ends of the powerhouse (Figure I), recorded 33% and 24% of all locations at the powerhouse; less than 10% of the observations were recorded by antennas located across the face of the powerhouse.

Northern squawfish used the north end of the spillbasin to a much greater degree as the numbers of smolts declined in early August. The north spillbasin had a mean percent use (i.e. mean percent frequency of total observations at the dam that were logged at the north spillbasin for each individual fish over all days of the month) of 47%, whereas areas southeast of the spillbasin (powerhouse, ice-trash sluiceway, downriver ice-trash sluiceway, and south spillbasin) accounted for no more than a mean of 18% of the total individual fish observations at the dam. Sixty-six percent of the total observations logged by northern squawfish at the north spillbasin were logged at antenna D1 (Figure 1), immediately downstream of the spillway and north fish ladder, and 26% of the observations were recorded at antenna D2.

Use by northern squawfish was divided equally among the north spillbasin and the sluiceway in September following the reduction in spill to only adult attraction flows in late August. Both these areas had a mean percent utilization of 39%. In contrast to the pattern of use at the sluiceway in May and June, however, most northern squawfish (91%) were logged immediately downstream of the sluiceway at antenna B8 rather than immediately upstream at antenna B7.

Diel Use of TDA Tailrace Areas

The number of northern squawfish recorded during each hour at the dam within a 24-h period remained constant some months, but fluctuated considerably in others (Figure 5). In May, August, and September the number of northern squawfish tracked by fixed stations did not differ among l-h intervals within a 24-h period (Figure 5; all Kruskal-Wallis one-way ANOVAS, $P > 0.12$). In

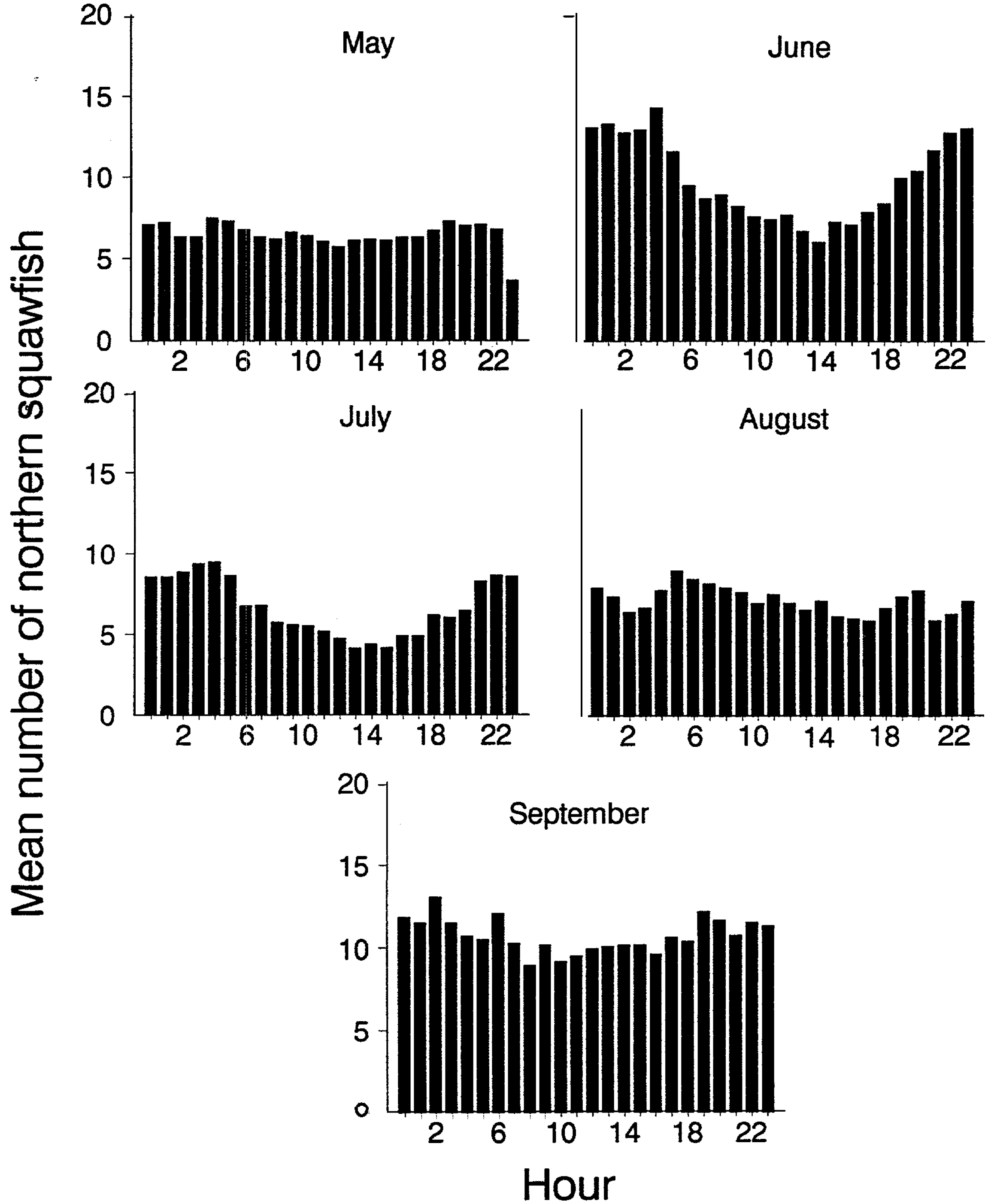


Figure 5. Diel variation in the mean number of radio-tagged northern squawfish at The Dalles Dam, May - September 1993. Days on which fixed station receivers failed were not included in the analyses. N (number of days) = 15 for May; N = 17 for June; N = 18 for July; N = 7 for August; N = 9 for September.

contrast, the time of day had a significant influence on the number of northern squawfish logged at the dam during June and July (Figure 5; both Kruskal-Wallis one-way ANOVAS, $P < 0.001$). During both months the mean number of fish at the dam during the late-evening and early-morning hours (2100-0600) were almost twice that of the mid-afternoon hours (1400-1600).

The distribution of northern squawfish observations among dam areas differed significantly for 4-h time intervals during May through September (all Chi-squares, time period x dam area, $P < 0.001$). However, these differences were more pronounced during some months than others (Figure 6). Changes in the distribution of northern squawfish at TDA among time periods were primarily a result of diel movements at the powerhouse (Figure 6) which accounted for 40 to 67% of the total Chi-square values during May, June, July, and August. Although the relative use of the powerhouse area varied from month to month, patterns of use over a 24-h period were consistent. This was most apparent during July and August when subyearling chinook were abundant and northern squawfish utilized the powerhouse area the most; the percentage of observations recorded at the powerhouse from 2000-0400 (30 to 51%) were considerably higher than the percentage of observations logged from 1200-1600 (1 to 17%). In contrast to the nighttime peaks in relative use at the powerhouse, other areas downstream of the powerhouse tended to be utilized most by northern squawfish during the daytime. The distribution of northern squawfish showed peaks in the percent of total observations recorded at the sluiceway from 0400-2000; lows in the percentage of observations occurred from 2000-0400 (Figure 6). It was also true in September when no more than 10% of the observations were logged at the ice-trash sluiceway from 2000-0400, but 68% of the observations were logged from 1200-1600.

The south and north spillbasin areas had similar distributions of northern squawfish observations over a 24-h period with the exception of May and June when northern squawfish were rarely recorded at the north spillbasin (Figure 6). In July and August the percentage of observations

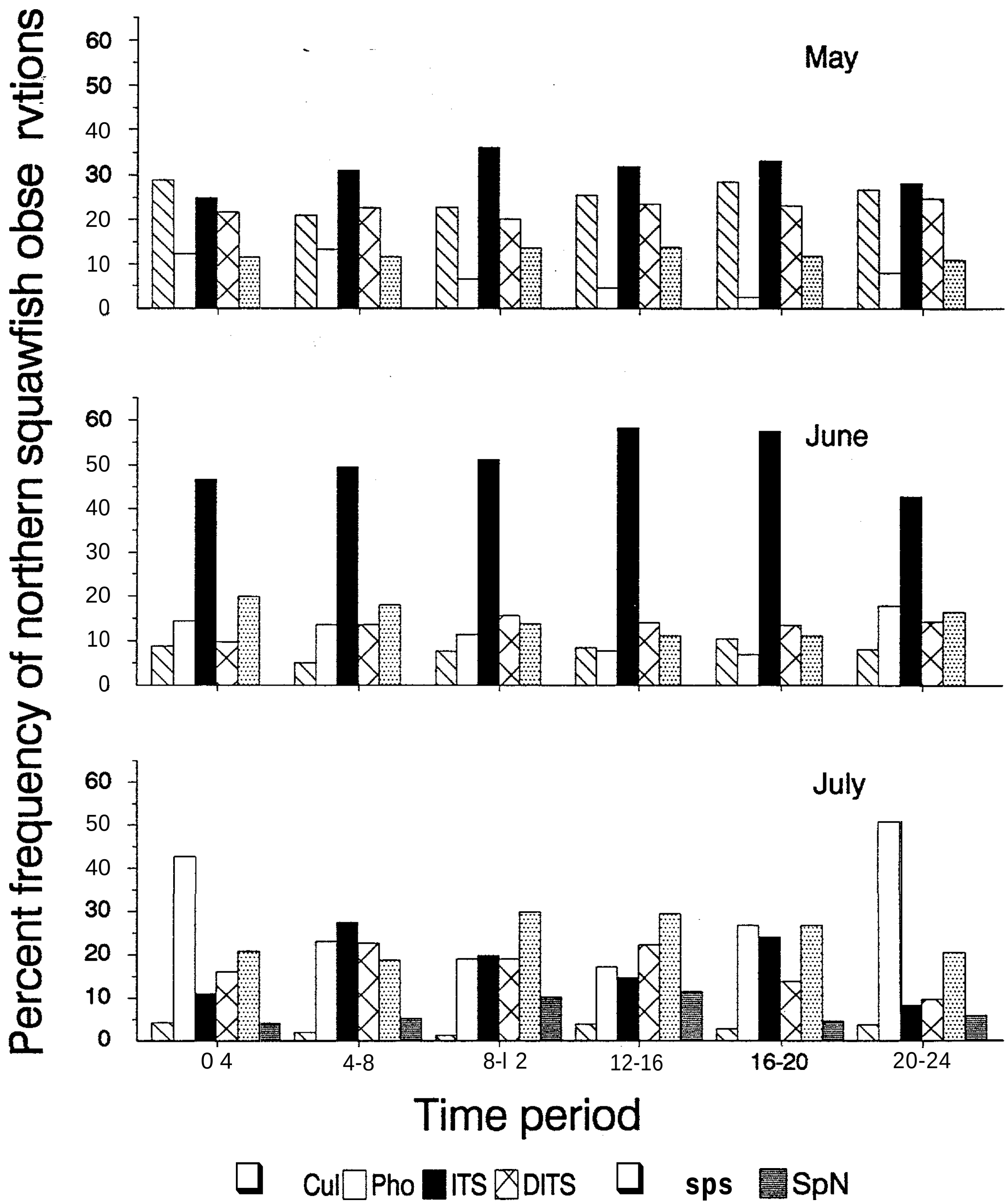


Figure 6. Diel variation in relative use (percent frequency of total number of observations) of tailrace areas by northern squawfish at The Dalles Dam, May - September 1993. Tailrace areas: Cul = Culde-sac, Pho = Powerhouse, ITS = Ice-Trash Sluiceway, Sps = Spillbasin South, SpN = Spillbasin North. More details on tailrace areas are given in Figure 1.

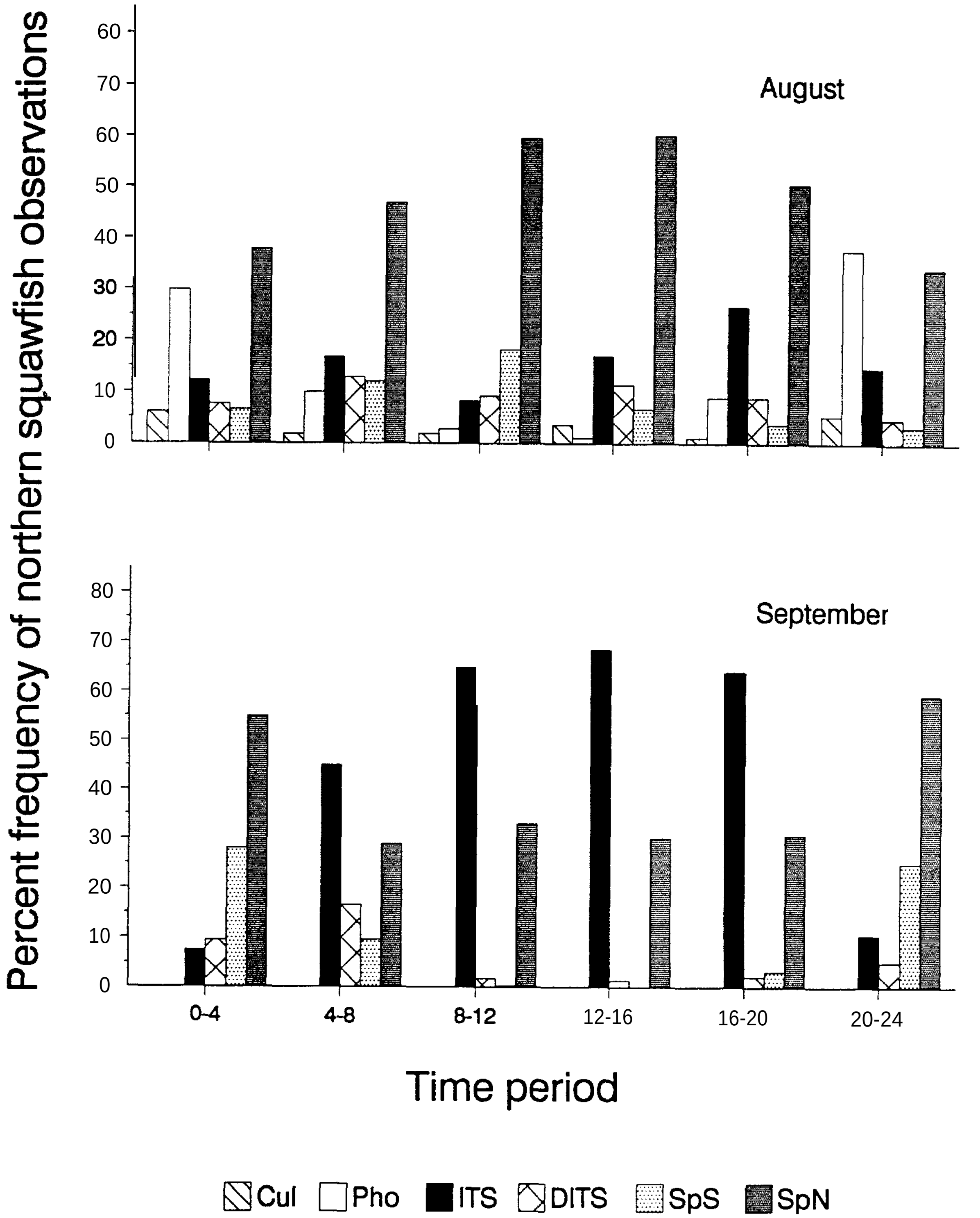


Figure 6. Continued.

logged at both these areas were highest from 0800-1600 in contrast to the low daytime percent frequencies seen at the powerhouse, In August, 60% of the total number of northern squawfish observations were recorded at the north spillbasin area from 0800-1600 whereas only 34-38% of the observations were logged from 2000-0400. The pattern of use at the south and north spillbasin areas were again similar in September but the periods of highest activity were opposite of those observed in August, this time in contrast to the higher periods of daytime activity at the sluiceway. The percentage of observations were greater than 55% at the north spillbasin from 2000-0400 and were approximately 30% from 0400-2000. The percentage of total northern squawfish observations at the south spillbasin exceeded 25% from 2000-0400 and were near 0% from 0800-1600.

The least discernable differences in the percent frequency of observations within a 24-h period were at the cul-de-sac and the downriver ice-trash sluiceway area (Figure 6). At both these areas differences between the lowest and highest percent frequencies of northern squawfish observations were rarely greater than 10%. The most apparent exception to this was at the downriver sluiceway area in September, where 17% of the observations of northern squawfish at the dam occurred from 0400-0800, but less than 2% of the observations were recorded from 1200-2000.

Movements in Relation to Sluiceway Operation at TDA

The Ice-trash sluiceway alternated between being opened or operational and closed on a routine schedule from 12 May to 30 September. During this time it was operational a total of 1234 hours. The number of hours the sluiceway was opened versus the number of hours it was closed in a 24-h period varied from month to month, but was consistent with few exceptions for many days of each month; deviating by only one or two hours on a few occasions. The one exception to this was July when the sluiceway was opened and closed on a more variable schedule. During all months the sluiceway was operated only during the daylight hours.

The mean percent frequency of individual northern squawfish observations in the immediate area surrounding the sluiceway were generally higher during June and July when the ice-trash sluiceway was opened (53 and 24%) than when it was closed (46 and 17%), however, these differences were not significant (Figure 7a; both MANOVA's., $P > 0.70$, angular transformation). Observations were pooled for all fish during May, August, and September when many fish logged had less than 30 observations under both sluiceway operating conditions. For these months, the distribution of northern squawfish observations among dam areas differed significantly between periods when the sluiceway was open and closed (Figure 7b; all χ^2's, $P < 0.001$). However, actual differences in the percentage of observations during periods when the ice-trash sluiceway was opened and closed were relatively small during May and September (< 9%). Only during August were the differences between modes of sluiceway operation great; 43% of the observations were recorded at the ice-trash sluiceway when the sluiceway was opened and 24% when it was closed. In contrast, 45% of the observations were recorded at the powerhouse when the sluiceway was closed, while 25% of the observations were logged at the powerhouse when the sluiceway was opened.

Seasonal Movements at JDA

Eighty-three radio-tagged northern squawfish were recorded by fixed stations for a total of 21,925 observations at the JDA tailrace (Appendix Table 3) between 13 May and 30 September. The majority of these fish (N=64) were tagged and released in the John Day Pool, whereas 23% (N=19) of the fish logged were tagged and released below TDA. Four out of the six tagged northern squawfish released at the Deschutes River were logged at JDA, whereas 89% (N=34) of the fish released outside the BRZ (primarily John Day Island) and 94% (N=31) of the fish released inside the JDA BRZ were recorded by fixed stations. Northern squawfish were logged for a mean of 264 ± 22 observations (mean ± 1 SE, N=83) and contacted a mean of 40 ± 3 days (mean ± 1 SE, N=83). A total of 40, 79,

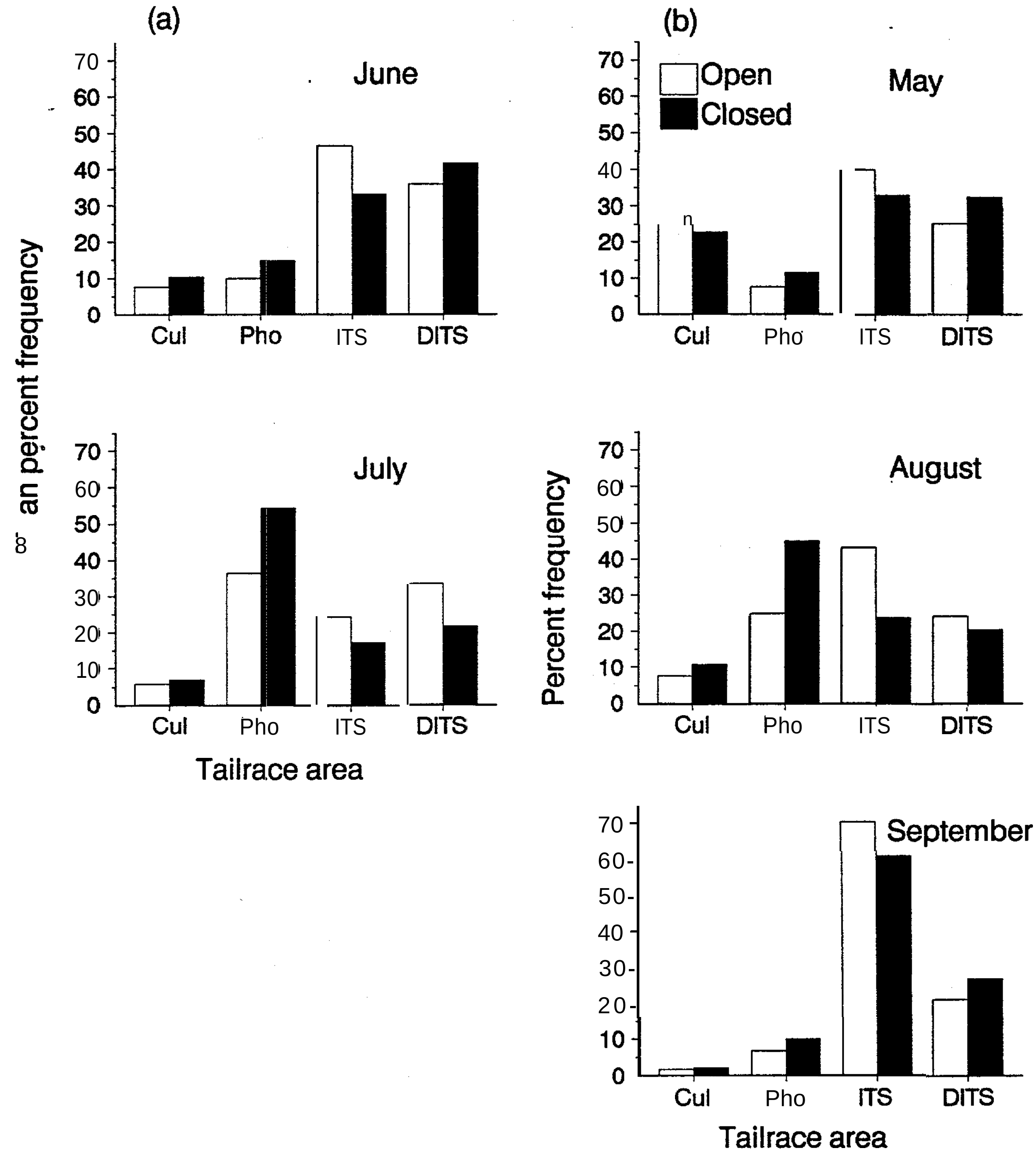


Figure 7. Variation in (a) mean percent frequency and (b) percent frequency of use of **tailrace** areas by **northen** squawfish at The Dalles Dam when the ice-trash sluiceway was opened, as compared with use by northern squawfish when the sluiceway was closed. All observations for individual northern squawfish were pooled during May, August, and September because few fish had at least 30 observations for each of the two modes of sluiceway operation. **Tailrace** areas: Cul = Cul-de-sac, Pho =: Powerhouse, ITS = Ice-Trash Sluiceway, **DITS** = Downriver Ice-Trash Sluiceway. More details on **tailrace** areas are given in Figure 1.

67, 48, and 29 different northern squawfish were recorded at JDA during May through September, respectively (Appendix Table 4). Once fish were recorded at the dam and then absent the following month they did not generally return, only 9% of these emigrants were logged again at JDA in later months. Ten tagged fish were caught by anglers and reported by the WDF sport bounty program or CRITFC personnel and returned.

The number of northern squawfish logged daily at fixed stations at JDA increased or decreased with dam operations and fluctuating numbers of out-migrating juvenile salmonids (Figure 8). A maximum of 60% (N=50) of the tagged fish tracked by fixed stations during the year at JDA were recorded on any one day. Most northern squawfish, including those released in the BRZ, were not logged by fixed receivers at JDA when they first began operating on 13 May.

The number of northern squawfish recorded at the dam increased as the daily number of early out-migrating salmonids passing the dam increased, but then fluctuated with increasing and decreasing numbers of smolts. Following a marked decrease in mean spill discharges due to reduced daytime spills beginning on 25 May and reduced nighttime spills beginning 6 June the number of tagged northern squawfish logged at the dam continued to fluctuate, but generally increased in spite of declining numbers of smolts (Figure 8). Numbers of tagged fish recorded at the dam peaked at 50 on 22 June coinciding with the arrival of large numbers of subyearling chinook salmon. Following this peak, however, the number of northern squawfish gradually declined even though relatively large numbers of subyearling chinook salmon continued to pass JDA. This decline was punctuated by fluctuations in the number of northern squawfish recorded at the dam that corresponded to variable smolt counts (Figure 8). By the end of the salmonid migration in early-September only 10 northern squawfish were recorded at JDA.

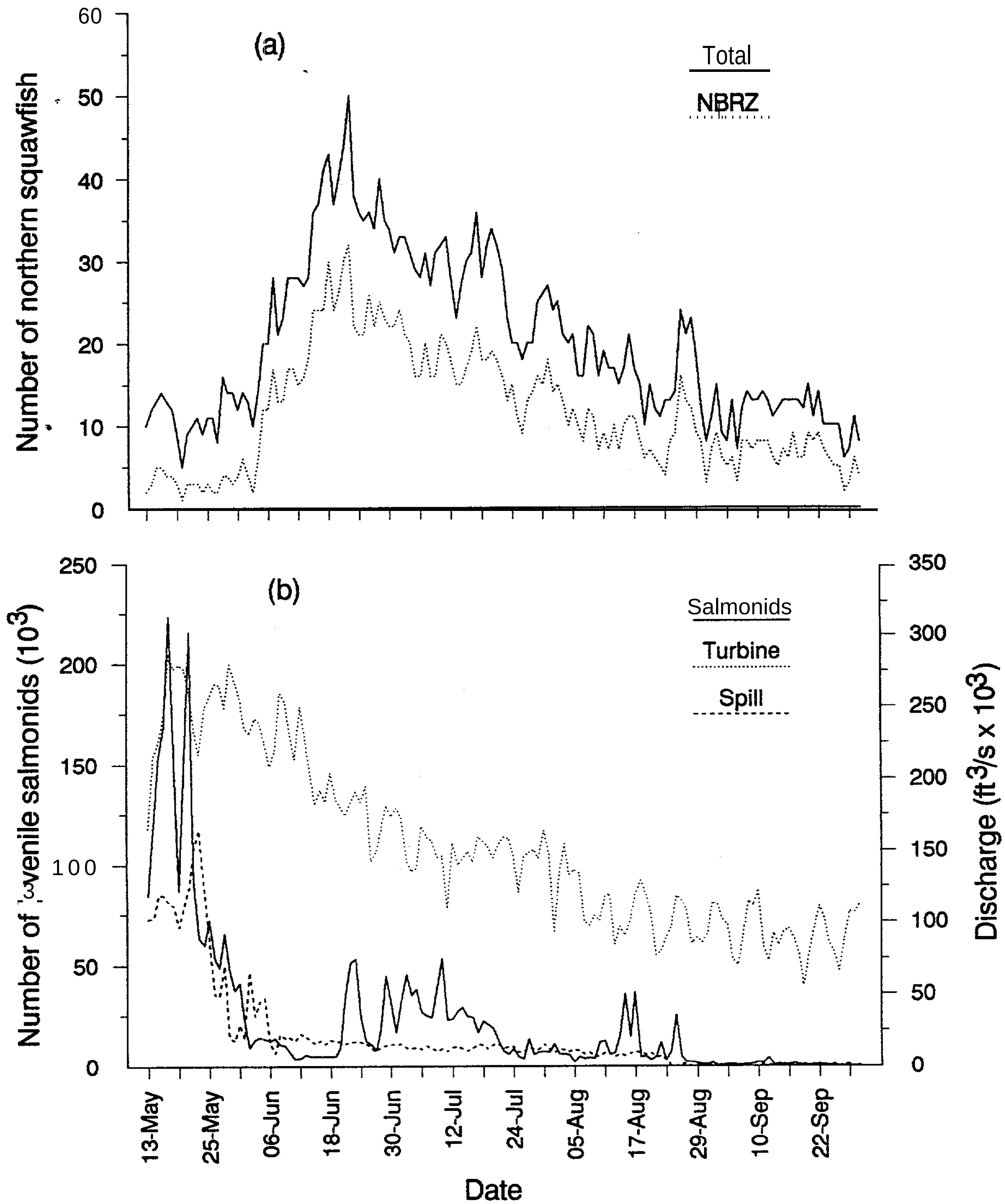


Figure 6. Total number of northern squawfish released downriver of John Day Dam and number of fish released only outside the boat restricted zone (NBRZ) recorded by fixed stations at John Day Dam (a), compared to juvenile salmonid index counts and turbine and spill discharges (b), 13 May - 30 September 1993.

Seasonal Use of JDA Tailrace Areas

Utilization of specific areas. by northern squawfish at JDA varied significantly among months (Figure 9; MANOVA, $F_{[28,553]} = 8.62$, $P < 0.001$, angular transformation). These differences resulted from changes in the pattern of relative use among months at all areas except for the bypass downriver area which differed only marginally (ANOVA, $P > 0.07$).

Areas on the north side of the river and farthest away from the dam received the greatest use by northern squawfish in May when the early downstream migrants were peaking and spill and turbine flows were the highest. The areas adjacent to John Day Island, tip of the navigation lock peninsula, and northwest of the spillbasin (Figure 2) accounted for means of 39, 23, and 21% of the individual northern squawfish observations, respectively (Figure 9). The bypass downriver area on the south side of the river recorded a mean of 15% of the observations and all other areas received a mean of less than 2% of the total observations (Figure 9). Northern squawfish moved into areas closer to the dam in June when mean turbine flows steadily declined and spill discharges were greatly reduced. The mean percentage of individual observations recorded at the northwest spillbasin area increased to 34% and the north spillbasin, powerhouse, and bypass rip-rap areas which had received little use in May now accounted for a mean of 11, 6, and 11% of the locations, respectively (Figure 9). In July and August when turbine and spill discharges continued to decline, use of areas nearer to the dam continued to increase and areas farther away from the dam received less use. The bypass rip-rap, powerhouse, and northwest spillbasin all received a mean usage of approximately 22% in July when the greatest proportion of subyearling chinook passed JDA, whereas other areas had means less than 10%. Also, during this time, northern squawfish were logged for the first time at the south spillbasin. In August when dam counts of subyearling chinook at JDA were declining, the mean percentage of northern squawfish observations at the powerhouse peaked at 3 1% and the northwest spillway received

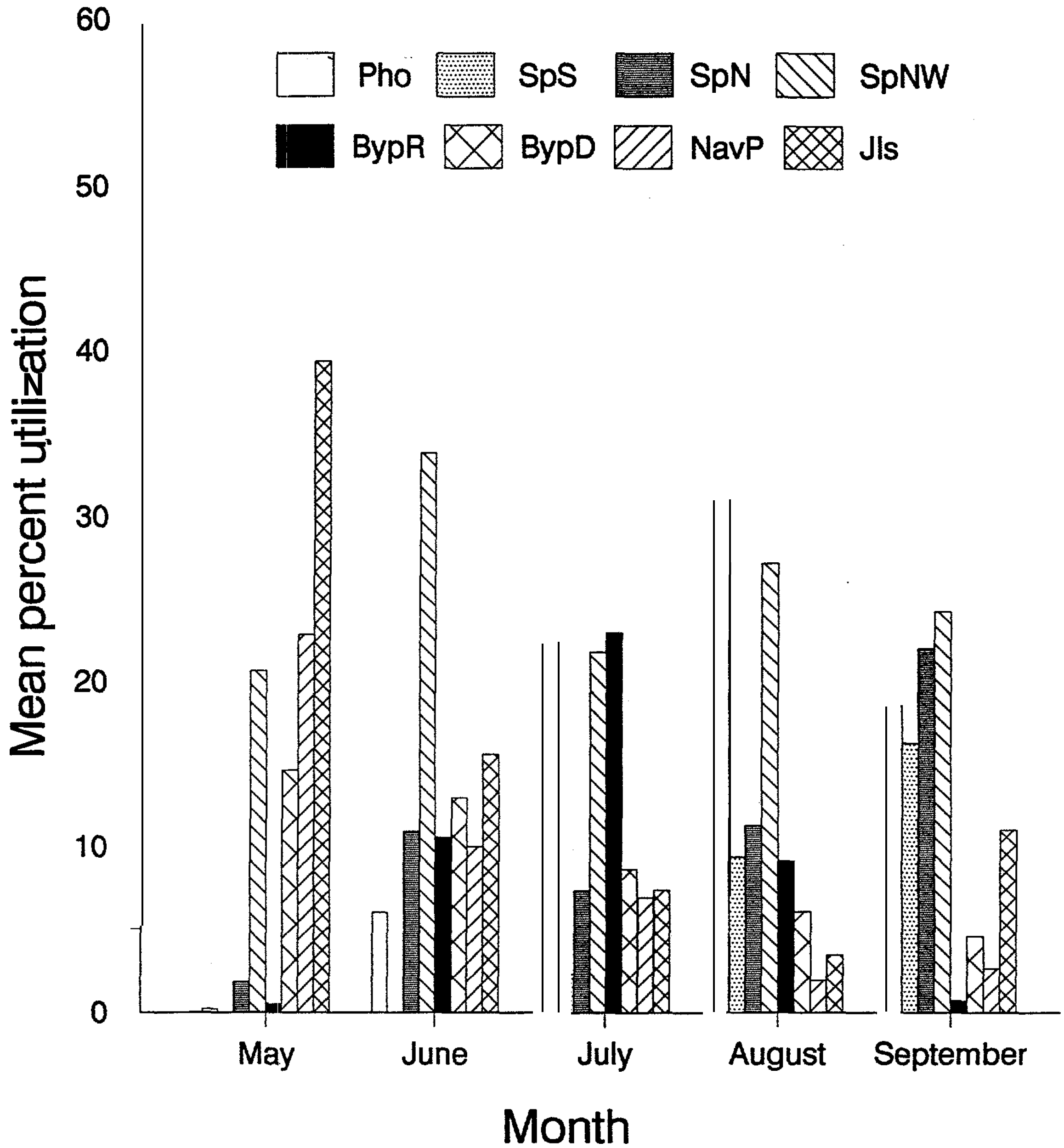


Figure 9. Seasonal variation in relative use of **tailrace** areas by northern squawfish at John Day Dam, May - September, 1993. **Tailrace** areas: Pho = Powerhouse, **SpS** = Spillbasin South, **SpN** = Spillbasin North, **SpNW** = Spillbasin Northwest, **BypR** = Bypass Rip-Rap, **BypD** = Bypass Downriver, **NavP** = Navigational Peninsula, Jls = John Day Island. More details on **tailrace** areas are given in Figure 2. Areas consistently having mean percents **<** 2 are not shown. Only Fish having at least 30 observations for a month were included in the analyses. N (number of northern squawfish) = 21 for May; N = 63 for June; N = 36 for July; N = 31 for August; N= 15 for September.

a mean of 27% of the observations. In contrast, the mean percentage of observations at the bypass rip-rap area declined by over half to 9%.

Following the juvenile salmonid migration, spill discharge was reduced to attraction flows for the adult fish ladder in September. The mean percentage of northern squawfish observations at the powerhouse dropped to 19%, whereas the mean percentage of fish-hours logged at the north spillbasin, south spillbasin, and John Day Island increased to 18, 17, and 27%, respectively.

Diel Use of JDA Tailrace Areas

The number of northern squawfish at JDA also fluctuated within a 24-h time period. The number of northern squawfish logged at the dam differed significantly among l-h intervals within a 24-h period during all months except May (all Kruskal-Wallis one-way ANOVAS, $P < 0.001$); in May the number of northern squawfish differed only marginally during the course of a day (Kruskal-Wallis one-way ANOVA, $P > 0.066$). However, this diel movement of tagged fish out of the range of the fixed station antennas was more pronounced during some months than others (Figure 10). The number of northern squawfish logged between 2000 and 0500 was as much as 3 to 4 times greater than the mid-afternoon counts at JDA during June and July (Figure 10). In comparison, counts of northern squawfish between 2100 and 0700 were no more than twice as great as the number of northern squawfish logged during other times of the day during August and September (Figure IO).

The distribution of northern squawfish observations among dam areas differed significantly for 4-h intervals during May through September (all Chi-squares, time period x dam area, $P < 0.001$). John Day Island was the most utilized area by northern squawfish during all time periods in May and the percentage of observations recorded at the island varied little among 4-h time periods (38-43%). Those areas nearer to the dam, however, showed more distinct diel patterns of relative use (Figure 11). Downstream of the spillway, both the tip of the navigation lock peninsula and the northwest spillbasin

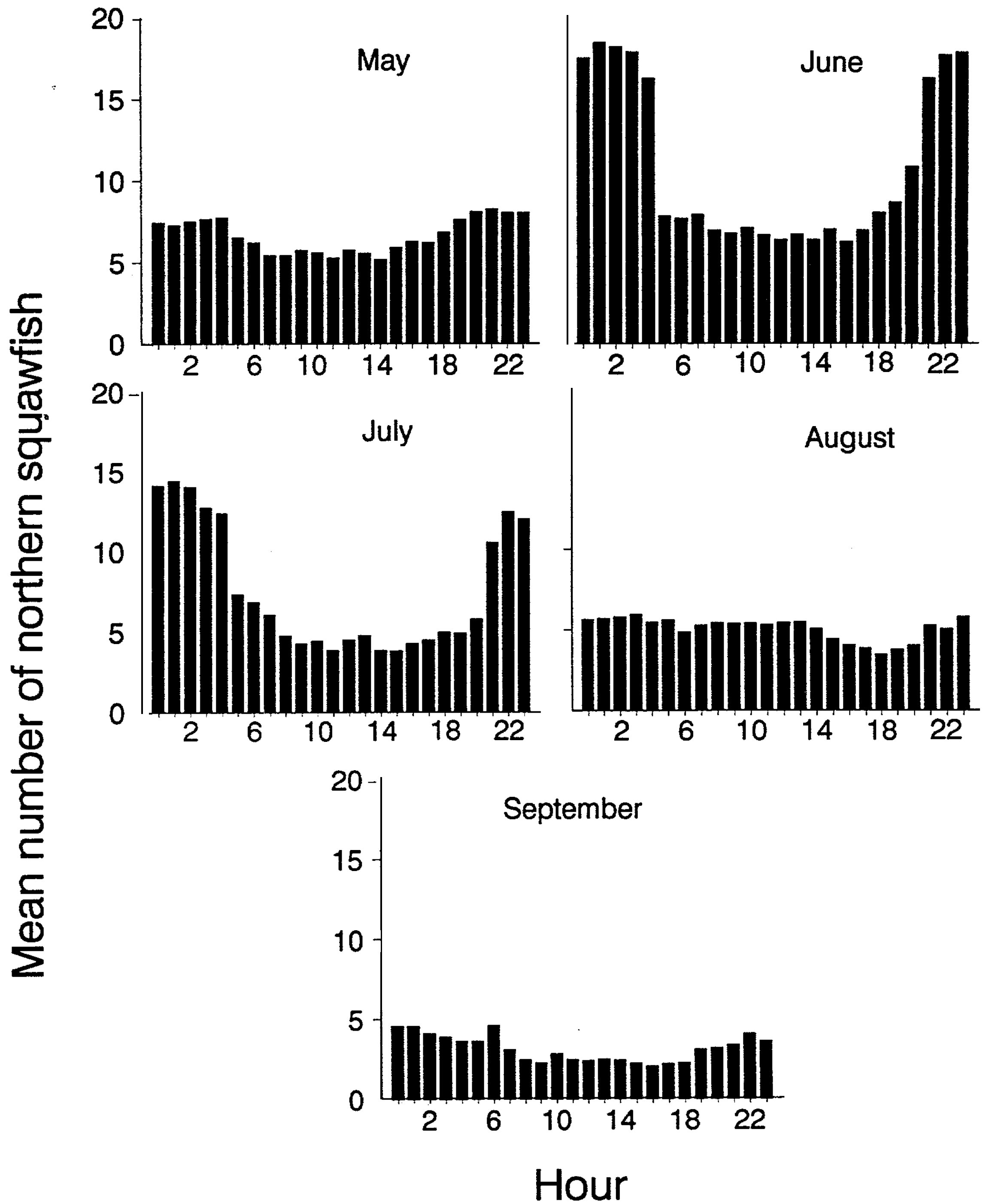


Figure 10. Diel variation in the mean number of radio-tagged northern squawfish at John Day Dam, May - September 1993. Days on which fixed station receivers failed were not included in the analyses. N (number of days) = 14 for May; N = 23 for June; N = 14 for July; N = 28 for August; N = 21 for September.

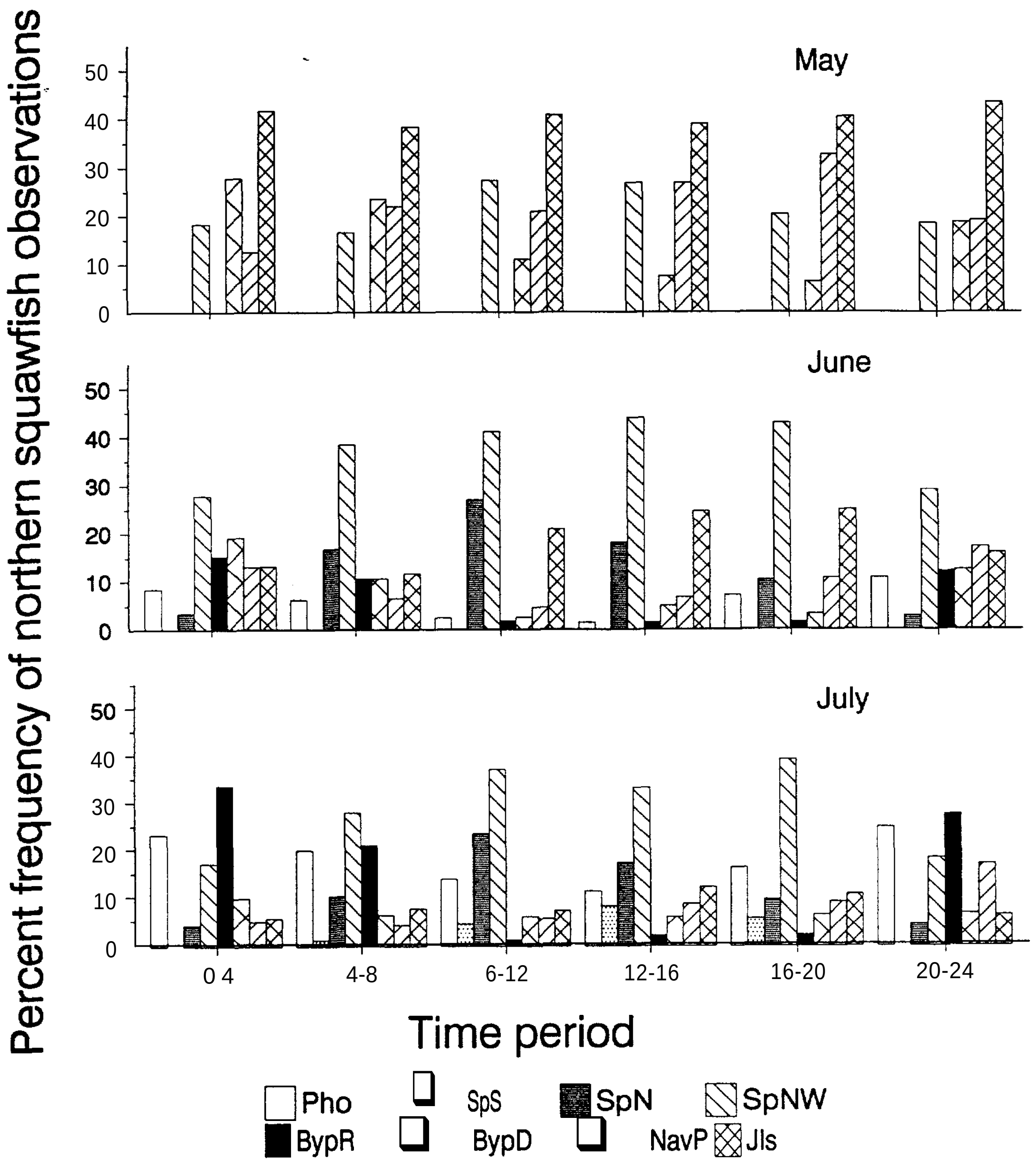


Figure 11. Diel variation in relative use (percent frequency of total observations) of tailrace areas by northern squawfish at John Day Dam, May - September 1993. Tailrace areas: Cul = Cul-de-sac, Pho = Powerhouse, ITS = Ice-Trash Sluiceway, SpS = Spillbasin South, SpN = Spillbasin North, SpNW = Spillbasin Northwest, BypR = Bypass Rip-rap, BypD = Bypass Downriver, NavP = Navigation Peninsula, Jls = John Day Island. More details on tailrace areas are given in Figure 2.

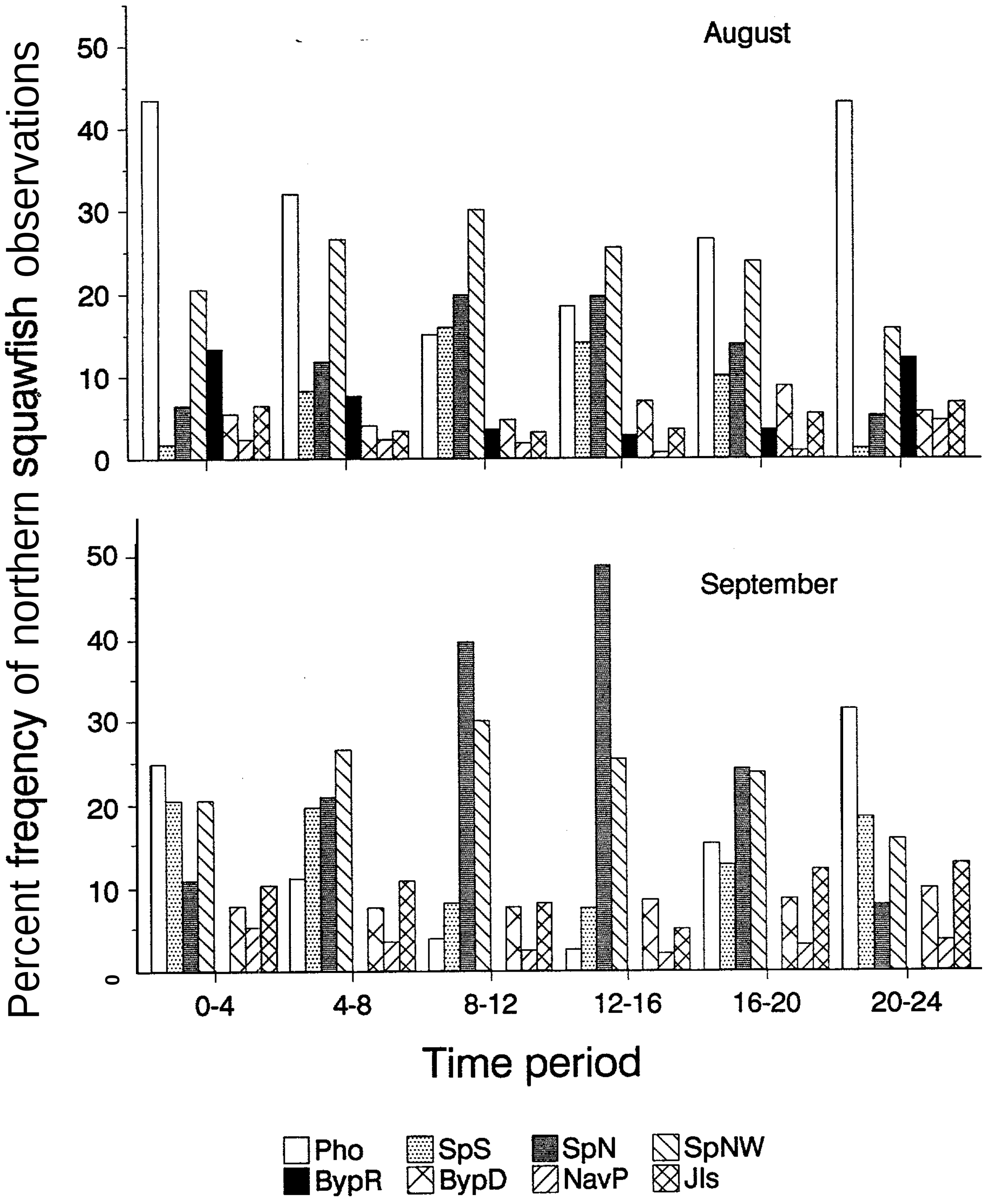


Figure 11. Continued.

areas had the highest percent frequency of northern squawfish observations during mid-day (26-33%), whereas the percent frequency of observations during the early morning and late-evening were the lowest (12-19%). Northern squawfish used areas downstream from the powerhouse more when powerhouse discharges were the lowest during the early-morning and late-evening and to a lesser degree when powerhouse discharges were the highest during mid-day.

Northern squawfish used areas increasingly closer to the dam as spill and turbine discharges were reduced in June, July, and August, but the basic pattern of use observed in May remained unchanged. The relative use of areas downstream of the spillgates (i.e. south, north, and northwest spillbasin) tended to peak during the daytime, whereas the relative use of areas downstream of the powerhouse (i.e. powerhouse, bypass rip-rap, bypass downriver) peaked at night.

Movements at JDA in Relation to the Juvenile Bypass System

The JBS was operated continuously over a 24-h period from 12 May to 30 September. Few northern squawfish were recorded in the bypass rip-rap area (Figure 2) immediately downstream of the bypass outfall in May, while the downriver bypass area accounted for a mean of 15% of individual n northern squawfish observations recorded. Northern squawfish moved closer to the dam and the bypass rip-rap area was used more as spill and turbine discharges decreased. A mean of 23% of the observations were at the bypass during July when most subyearling chinook were passing the dam, while during both June and August approximately 10% of the observations were recorded there. Most of these observations were recorded away from the immediate bypass structure; underwater antennas located on the cement pillars of the bypass recorded no fish, while those located near shore logged only 10 observations. Very few tagged fish were recorded at the bypass rip-rap area in September .

Use of the bypass area by northern squawfish was greatly influenced by the time of day. The downriver bypass area accounted for 19-28% of the total northern squawfish observations from 2000-

0400 during May, but less than 8% of the observations from 1200-2000. In July, 28-34% of the total observations at the dam between 2000 and 0400 were recorded at the bypass rip-rap area, while less than 2% of the total observations were recorded there between 0800 and 2000. Similar, but less pronounced patterns were seen between day and night at the bypass in both June and August.

Discussion

Fixed station data indicate the numbers and distribution of radio-tagged northern squawfish at TDA and JDA varied during the course of the juvenile salmonid out-migration in response to changing turbine and spill discharges and smolt abundance. Also, despite some differences in squawfish behavior between the two dams, due most likely to different dam designs, many similarities existed. At both dams, approximately 90% of the tagged northern squawfish were recorded by fixed receivers at least once and on average fish were contacted on about 40 days.

Relatively few northern squawfish were contacted by fixed stations at TDA and JDA during mid-May. However, subsequent increases in the number of fish recorded at the dams coincided with reductions in spill and/or turbine discharges and an increase in juvenile salmonid abundance. During this time, observations recorded by fixed stations at TDA indicated that northern squawfish were located predominantly just upstream and downstream of the powerhouse in areas of low water velocity (i.e. cul-de-sac, ice-trash sluiceway eddy, downriver sluiceway). At JDA, northern squawfish were located mostly away from the dam at the western, downstream edges of the BRZ and at the John Day Island outside the BRZ. We believe the distribution of fish at both dams reflects the availability of low water velocity areas preferred by northern squawfish (Beamesderfer 1983; Faler et al. 1988) and the availability of juvenile salnnonid prey. Because of the unique design of TDA, more low water velocity areas exist that allow :northem squawfish to take up residence in the BRZ even when flows are high and spill is maintained for 24 hours. There is more shoreline associated with the perimeter of the dam, the turbine discharge area is isolated from the spillbasin, and the turbine discharge is directed perpendicular to the shore. In comparison, at JDA, where the spillbasin and powerhouse are adjacent to one another and discharges are parallel to the shoreline, there are fewer areas of low water velocity near the dam where fish can reside under continuous high spill and turbine discharges.

As the season progressed, more fish were recorded by fixed stations and on 21 and 22 June the number of individual northern squawfish peaked almost simultaneously at both dams just prior to the arrival of large numbers of subyeariing chinook salmon at JDA. These peaks represented a climax to an influx of northern squawfish into the BRZ's following a precipitous drop in spill at both TDA and JDA in early-June. Habitat-use during this time of peak numbers of tagged fish at the dams was concentrated at the ice-trash sluiceway at TDA and at areas closer to the dam at JDA in the spillbasin. Prior to this reduction in spill volume and duration, we believe that many of these individuals were excluded from entering the BRZ's by higher water velocities. Faler et al. (1988) also reported that northern squawfish were excluded from areas of the tailrace BRZ at McNary Dam under high discharges when water velocities exceeded 70 cm/s.

In June, 23% of the northern squawfish that had been tagged and released immediately downstream of TDA arrived at JDA where they were recorded by fixed stations. Also, 4 of 6 fish tagged at the Deschutes River moved upriver to JDA. A similar upstream movement to TDA was not detectable because fewer numbers of tagged fish were released any appreciable distance downstream of TDA. The reasons for this upstream movement of northern squawfish are not well understood. It is unlikely that northern squawfish were attracted by increased salmonid densities since the bulk of the early migrants had passed and large numbers of subyearling chinook had not yet arrived at the dam, unless these fish are attracted even at low concentrations of smolts. Possibly, these observed movements may be related to an upriver spawning migration. Vigg et al. (1991) reported that spawning of northern squawfish in John Day Reservoir peaked in June. Following these June peaks in northern squawfish abundance, numbers of tagged fish decreased at the dams even though large numbers of juvenile salmonids 'were present.

In July and August the number of northern squawfish at TDA and JDA remained at reduced post peak levels. However, the average number of fish logged at JDA continued to decline throughout the summer while the average number of fish recorded at TDA stabilized. Fish were found increasingly in the vicinity of the powerhouse areas of both dams, as well as the areas of the spill basins close to the dams. Increased use of powerhouse areas was probably due to a combination of decreasing turbine discharges that would lower water velocities near the powerhouse and lower, guidance efficiencies of subyearling chinook at the dam that would increase the proportion of downstream migrants passing through the turbines. Other researchers have reported that subyearling chinook at JDA have lower fish guidance efficiencies than yearlings (Krcma et al. 1986, Brege et al. 1987) and that fish guidance efficiency for subyearlings at some other Columbia River dams decreases from late spring through summer (Gessel et al. 1990). These patterns of northern squawfish distribution at the dams generally continued into September after the salmonid out-migration had ceased and were probably sustained by out-migrating juvenile American shad.

Distinct diel differences at both TDA and JDA in the number of individual northern squawfish present at the dams and where they were distributed seasonally were probably due to changes in water velocities associated with dam 'operations and smolt availability. During May when high dam discharges were present 24 hours a day the number of fish recorded hourly varied little over a 24-h period at either dam. At TDA where northern squawfish were using areas isolated from the spill, fish were concentrated at the ice-trash sluiceway and cul-de-sac and distributions among time periods varied subtly. At JDA, the percent frequency of observations varied little at the downstream island away from the dam, but time of day had a greater effect at areas closer to the dam. Areas downstream of the spillgates (i.e. northwest spillbasin and the tip of the navigation lock peninsula) were used relatively more frequently during the day when spill discharge was the least and powerhouse discharge was the greatest. In contrast, the downriver bypass area received the highest percentage of observations at night when powerhouse discharge was reduced and spill discharge was the greatest.

At least twice as many northern squawfish were recorded at both dams during June and July at night as during the day after the amount and duration of spill were reduced in June. These nighttime peaks in abundance at the dams coincide with times of peak smolt passage and consumption of juvenile salmonids by northern squawfish. Numerous investigators have reported that most juvenile salmonids pass the dams between dusk and dawn (Long et al. 1968; Gessel et al. 1986; Brege et al. 1987) and at McNary Dam consumption of juvenile salmonids has been shown to have a nocturnal feeding mode (Vigg et al. 1991). Movement of northern squawfish into deeper water or away from the dam during the daylight hours once daytime spill ceased may have been a result of reduced smolt availability and increased powerhouse discharge. During August and September differences in the number of fish at the darns between night and day were less pronounced. These changes may be related to reduced numbers of northern squawfish and juvenile salmonids at the dam, increasing numbers of juvenile American shad that may have different passage characteristics, and decreasing volumes of turbine discharge.

Northern squawfish had similar diel distributions at both TDA and JDA during June through September. Generally, the powerhouse area at both dams received a relatively higher percentage of usage during the late-evening and early-morning hours when powerhouse discharge was lowest and passage of juvenile salmonids was the highest; whereas areas directly downstream of the spillgates tended to receive the highest percentage of observations during mid-day after the nighttime spill had ceased. These diel differences intensified as numbers of subyearling chinook salmon increased and mean powerhouse discharges decreased. At TDA, areas downstream of the powerhouse had peak use during the midday when turbine flows were highest and the sluiceway was in operation. The diel pattern of use at the dams changed slightly during September when all spill ceased except for adult attraction flows at the fish ladders and the downstream salmonid migration had ended. At ‘IDA, northern squawfish used the sluiceway primarily during the daytime when it was operational, but switched to the spillbasin at night.

Distribution of Northern Squawfish at Bypass Outfall Areas

Distribution of northern squawfish differed in the areas of the current juvenile bypass outfalls at TDA and JDA. The ice-trash sluiceway has been reported to pass up to 40% of the juvenile salmonids at TDA during periods of no spill (Willis 1982; Johnson et al. 1987). Northern squawfish used the ice-trash sluiceway area most during May and June (mean percent use 28 and 42%) when steelhead and yearling chinook were abundant and powerhouse discharges were high. In July and August mean percent use was about 15% when large numbers of subyearling chinook were in the river and powerhouse discharges were reduced. In contrast, relative use of the JDA bypass outfall area tended to be less, mean percent utilization at the bypass rip-rap area was greatest during July (23%) and low during all other months (< 10%).

The diel pattern of use at the bypass outfall areas by northern squawfish also differed between dams. At IDA, relative use of the ice-trash sluiceway area was greater during the day when the sluiceway was opened than at night when it was closed for all months, however, these differences were not generally significant. In comparison, northern squawfish were found in the proximity of the smolt bypass at JDA more often at night when most juvenile salmonids pass the dam and powerhouse discharges are the lowest.

The lack of significant difference in use at the ice-trash sluiceway could possibly be due to northern squawfish using this area for both feeding and a low-velocity resting area. In comparison, at JDA the only benefit from utilizing the area near the bypass outfall would be for feeding since few low water velocity areas exist (NBS unpublished data). However, the prevalence of observations in the vicinity of the JDA bypass outfall must be approached with caution since a similar pattern of use was not seen while mobile tracking and may be due to "over" coverage by fixed antennas in the area of the bypass (Shively et al. 1994). Some northern squawfish recorded as being in the area of the bypass may actually have been farther offshore feeding on juvenile salmonids passing through the turbines. Use of the powerhouse area during July was also high and utilization of the JDA bypass area by northern squawfish may have been overestimated.

Our preliminary results thus far suggest a dynamic flux of individual northern squawfish movements within the TDA and JDA tailraces. The number of individual fish at the dams and where they were distributed varied both seasonally and within a 24-h period. Generally, northern squaw&h were concentrated near major fish passage routes in areas of low water velocities; distributions varied most likely as a result of changing dam operations and river flows that affected local water velocities and changing juvenile salmonid out-migration characteristics. During 1994 we plan to further examine our current fixed station and mobile tracking data for individual fish response to changing operations. In the field we hope to increase efficiencies of our fixed stations and reduce downtime. We will also increase the number of hours of mobile tracking at night to obtain more data on individual fish movements at important fish passage routes during times of changing conditions at the dam. Increased numbers of tagged fish will be released farther away from the dams to monitor upstream movements of northern squawfish to the tailrace areas and increase sample sizes.

REFERENCES

Beamesderfer, R.C. 1983. Reproductive biology, early life history and microhabitat of northern squawfish (*Ptychocheilus oregonensis)* in the St. Joe River, Idaho. Master's thesis. University of Idaho, Moscow.

Brege, D.A., D.R. Miller, and R.D. Ledgerwood. 1987. Evaluation of rehabilitated juvenile salmonid collection and passage system at John Day Dam. Report to the U.S. Army Corps of Engineers, Contract DACW57-86-F-024537, 37p.

Dawley, E.M., R.D. Ledgerwood, L.G. Gilbreath, P.J. Bentley, and S.J. Grabowski. 1994. Do bypass systems protect juvenile salmonids at dams? Fish Passage Policy and Technology, Proceedings of a symposium at the American Fisheries Society annual meeting, September 1993, Portland, Oregon.

Faler, M.P., L.M. Miller, and K.I. Welke. 1988. Effects of variation in flow on the distribution of northern squawfish in Columbia River below McNary Dam. North American Journal of Fisheries Management, 8:30-35.

Gessel, M.H., L.G. Gilbreath, W.D. Muir, and R.F. Krcma. 1986. Evaluation of the juvenile collection and bypass systems at Bonneville Dam - 1985. Report to the U.S. Army Corps of Engineers, Contract DAC W57-85-H-0001, 68p.

Gessel, M.H., D.A. Brege, B.H. Monk, and J.G. Williams. 1990. Continued studies to evaluate the juvenile bypass systems at Bonneville Dam - 1989. Report to the U.S. Army Corps of Engineers, Contract E8689095, 34p.

Johnson, W.R., L. Johnson, and D.E. Weitkamp. 1987. Hydroacoustic evaluation of the spill program for fish passage at The Dalles Dam in 1986. Report to the U.S. Army Corps of Engineers, Portland district, Portland OR, 68p.

Krcma, R.F., D.A. Brege, and R.D. Ledgerwood. 1986. Evaluation of the rehabilitated juvenile salmonid collection and passage system at John Day Dam - 1985. Report to the U.S. Army Corps of Engineers, Contract DAC W57-85-H-000 1, 25p.

Ledgerwood, R.D., E.M. Dawley, L.G. Gilbreath, P.G. Bentley, B.P. Sanford, and M.H. Schiewe. 1992. Relative survival of subyearling chinook salmon which have passed through the turbines of bypass system of Bonneville Dam Second Powerhouse, 1990. Report to the U.S. Army Corps of Engineers, Contract E86900104, 33p.

Long, C.W. 1968. Diel movement and vertical distribution of juvenile anadromous fish in turbine intakes. U.S. Fish and Wildlife Service Fishery Bulletin 66:599-609.

Matthews, G.M., D. L. Park, S. Achord, and T.E. Ruehle. 1986. Static seawater challenge test to measure relative stress levels in spring chinook salmon smolts. Transactions of the American Fisheries Society 115:236-244.

Maule, A.G., C.B. Schreck, C.S. Bradford, and B.A. Barton. 1988. Physiological effects of collecting and transporting emigrating juvenile chinook salmon past dams on the Columbia River. Transactions of the American Fisheries Society 117:245-26 1.

Mesa, M.G. and T.M. Olson. 1'993. Prolonged swimming performance of northern squawfish. Transactions of the American Fisheries Society, 122: 1104-l 110.

Mesa, M.G. 1994. Effects of multiple acute stressors on the predator avoidance ability and physiology of juvenile chinook salmon. Transactions of the American Fisheries Society 123:786-793.

Shively, R.S., S.R. Hirtzel, L.L. Mann, T.L. McGuire, and G. Holmberg. 1994. Movements and distribution of radio-tagged northern squawfish near The Dalles Dam. Annual Report of Research, 1992. Bonneville Power Administration, Portland, Oregon.

Shively, R.S., M.B. Sheer, G.S. Hohnberg. This volume. Description and performance of an automated radio telemetry system to monitor the movement and distribution of northern squawfish at Columbia River dams. In Poe, T.P. (ed.) Significance of selective predation and development of prey protection measures for juvenile salmonids in the Columbia and Snake River reservoirs. Annual report of research, 1993. Bonneville Power Administration, Portland, Oregon.

Tabachnick, B.G. and L.S. Fidell. 1983. Using multivariate statistics. Harper and Row, Publishers, New York, New York USA.

Vigg, S., T.P. Poe, L.A. Prendergast, and H.C. Hansel. 1991. Rates of consumption of juvenile salmonids and alternative prey fish by northern squawfish, walleyes, and smallmouth bass in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society, 120:421-438.

Willis, C.F. 1982. Indexing of juvenile salmonids migrating past The Dalles Dam, 1982. Report to the U.S. Army Corps of Engineers, Contract DACW57-78-C-0056, 50p.

Zar, J.H. 1984. Biostatistical Analysis, 2nd edition. Prentice-Hall, Englewood Cliffs, New Jersey.

Appendix Table 1. Summary of radio-tagged northern squawfish recorded by fixed station receivers at The Dalles Dam **tailrace,** 12 May - 30 September 1993.

Fish Number	Fork Length	Release Site	Hours Fixed	First Day Contacted	Last Day Contacted	Days Contacted
2250	445	TDBRZ	277	May 20	Jun 13	22
2254	476	TDBRZ	1224	May 27	Sep 30	118
2256	359	TDISL	148	Jun 21	Aug 8	26
2258	461	TDBRZ	145	May 21	Jun 21	16
2260	387	TDISL	52	Jul 14	Aug 10	5
2262	465	TDNBZ	15	Jun 17	Jun 18	2
2350	399	TDBRZ	617	May 30	Jul 20	53
2356	462	TDBRZ	507	May 17	Jul 11	46
2360	421	TDBRZ	225	Jun 10	Jul 9	14
2362	475	TDBRZ	879	Jun 11	Sep 30	92
2363	443	DESCH	16	Jun 20	Jun 21	2
2450	464	TDBRZ	382	May 29	Jun 30	27
2454	380	TDBRZ	10	Jun 21	Jun 22	2
2456	477	TDBRZ	1586	May 12	Sep 30	124
2458	475	TDISL	670	Jun 20	Sep 30	75
2460	466	TDBRZ	702	Jul 3	Sep 29	74
2462	472	TDBRZ	97	May 26	May 31	6
2550	470	TDBRZ	63	May 25	May 30	6
2554	490	TDBRZ	18	May 26	Aug 10	4
2556	451	TDBRZ	720	Jun 4	Sep 30	63
2560	474	TDBRZ	856	May 22	Sep 30	82
2562	408	TDBRZ	13	May 19	May 21	3
2650	455	TDBRZ	1591	May 15	Sep 30	133
2656	388	TDBRZ	441	May 22	Sep 30	48
2658	365	TDNBZ	285	Jun 19	Sep 26	40
2662	451	TDBRZ	301	May 15	Jun 9	23
2666	457	TDBRZ	381	May 19	Jun 15	27
2750	461	TDBRZ	1308	May 26	Sep 30	113
2756	408	TDBRZ	317	Jun 1	Sep 30	37
2758	414	TDISL	64	Jun 13	Jun 21	8
2760	497	TDBRZ	1044	Jun 5	Sep 18	94
2766	540	TDNBZ	33	Jun 11	Sep 30	6
2850	493	TDBRZ	221	May 19	Jul 10	16
2854	410	TDISL	43	Jun 21	Jun 25	5

Appendix Table 1. Continued.

Fish Number	Fork Length	Release Site	Hours Fixed	First Day Contacted	Last Day Contacted	Days Contacted
2856	408	TDISL	26	Jun 13	Jun 22	3
2860	462	TDBRZ	1264	May 19	Aug 22	92
2864	481	TDISL	426	Jun 16	Sep 29	61
2866	508	TDBRZ	684	Jun 6	Sep 28	92
2950	513	TDBRZ	485	May 26	Sep 30	57
2956	465	TDNBZ	1091	May 30	Sep 29	69
2958	405	TDISL	27	Jul 3	Sep 22	6
2960	550	TDBRZ	278	Jun 21	Sep 29	51
2962	431	TDBRZ	141	May 26	Aug 18	13
2964	505	TDBRZ	244	May 15	May 30	16
2966	459	TDBRZ	1174	Jun 3	Sep 30	116
3050	481	TDBRZ	1265	Jun 7	Sep 30	108
3054	502	TDBRZ	3	May 21	May 21	1
3056	425	TDBRZ	141	Jun 14	Jul 19	20
3060	392	TDBRZ	426	May 21	Sep 30	42
3062	360	TDNBZ	29	Jun 24	Jul 13	5
3064	406	TDBRZ	3	Jun 8	Jun 8	1
3154	501	TDBRZ	863	May 12	Sep 30	71
3156	510	TDISL	811	Jun 15	Sep 30	75
3160	470	TDNBZ	63	Jul 9	Aug 3	10
3162	525	TDBRZ	1008	Jun 6	Sep 30	108

Appendix Table 2. Individual northern squawfish recorded by fixed stations at The Dalles Dam, May - September 1993.

Fish Number	May	June	July	August	September
2250	X	X			
2254	X	X	X	X	X
2256		X	X	X	
2258	X	X			
2260			X	X	
2262		X			
2350	X	X	X		
2356	X	X	X		
2360		X	X		
2362		X	X	X	X
2363		X			
2450	X	X			
2454		X			
2456	X	X	X	X	X
2458		X	X	X	X
2460			X	X	X
2462	X				
2550	X				
2554	X			X	
2556		X		X	
2560	X	X	X	X	X
2562	X				
2650	X	X	X	X	X
2656	X	X		X	X
2658		X	X	X	X
2662	X	X			
2666	X	X			

Appendix Table 2. Continued.

Fish Number	May	June	July	August	September
2750	X	X	X	X	X
2756		X			X
2758		X			
2760		X	X	X	X
2766		X			X
2850	X	X	X		
2854		X			
2856		X			
2860	X	X	X	X	
2864		X	X	X	X
2866		X	X	X	X
2950	X	X	X	X	X
2956	X		X	X	X
2958			X		X
2960		X	X	X	X
2962	X	X	X	X	
2964	X				
2966		X	X	X	X
3050		X	X	X	X
3054	X				
3056		X	X		
3060	X			X	X
3062		X	X		
3064		X			
3154	X	X		X	X
3156		X	X	X	X
3158	X	X	X		

Appendix Table 2. Continued.

Fish Number	May .	June	July	August	September
3160			X	X	
3162		X	X	X	X

Appendix Table 3. Summary of radio-tagged northern squawfish recorded by fixed station receivers at John Day Dam tailrace, 13 May - 30 September 1993.

Fish Number	Fork Length	Release Site	Hours Fixed	First Day Contacted	Last Day Contacted	Days Contacted
2250	445	TDBRZ	314	Jun 18	Aug 12	27
225 1	460	JDBRZ	72	May 28	Aug 18	19
2253	350	JDISL	98	May 13	Jul 18	12
2255	390	JDBRZ	62	Jun 9	Jun 30	11
2257	430	JDISL	737	May 13	Sep 12	93
2259	435	JDISL	199	May 30	Jun 24	21
2261	450	JDISL	643	Jun 7	Sep 30	86
2262	465	TDNBZ	84	Jun 22	Aug 5	13
2263	437	JDISL	483	May31	Sep 20	58
2349	445	JDBRZ	323	May 25	Sep 30	66
2351	367	JDBRZ	341	May 26	Jul 31	45
2353	362	JDBRZ	41	May 13	Ju123	10
2355	395	JISLZ	479	May 13	Sep 29	92
2357	380	JDBRZ	310	Jun 2	Sep 30	54
2360	421	TDBRZ	111	Jun 22	Jul 2	10
2361	410	JDBRZ	67	Jun 14	Aug 1	19
245 1	465	DESCH	802	Jun 1	Sep 30	108
2453	360	JDNAV	76	Jun 20	Aug 6	27
2455	515	JDBRZ	163	May 25	Jun 8	13
2457	400	JDBRZ	780	May 13	Sep 26	83
2459	351	JDBRZ	168	Jun 22	Sep 18	39
2461	360	JDISL	26	Jun 13	Jun 15	3
2462	472	TDBRZ	75	Jun 8	Jul 2	13
2463	490	JDBRZ	102	May 16	Jul 5	14
2550	470	TDBRZ	132	Jun 11	Aug 28	32
2551	425	JDBRZ	326	May 13	Jun 9	28
2553	373	JDBRZ	633	May 13	Sep 7	75
2554	490	TDBRZ	16	Jul 17	Jul 22	3
2555	427	JDBRZ	677	Jun 3	Sep 29	85
2556	451	TDBRZ	90	Jun 13	Jul 11	11
2557	510	JDBRZ	7	Jun 21	Jun 24	2
2559	360	JDNAV	249	May 13	Ju126	50
2561	500	JDISL	387	May 13	Sep 30	64
2562	408	TDBRZ	193	May 25	Jul 13	41

Table 3. Continued.

Fish Number	Fork Length	Release Site	Hours Fixed	First Day Contacted	Last Day Contacted	Days Contacted
2563	460	JDISL	281	Jun 25	Sep 26	48
2651	480	JDISL	152	May 13	Jul 6	28
2653	350	JDNAV	207	May 15	Jul 20	36
2654	379	TDISL	227	Jun 10	Jun 29	20
2655	480	DESCH	48	May 30	Jun 30	13
2656	388	TDBRZ	99	Jun 9	Aug 5	31
2657	370	JDBRZ	106	Jun 12	Sep 27	27
2659	352	JDISL	219	Jun 14	Sep 22	47
2661	420	JDISL	290	May 13	Jul 23	44
2663	460	JDBRZ	124	May 16	Jun 12	16
2665	411	JDBRZ	209	Jun 9	Jul 16	32
2749	350	JDBRZ	202	Jun 6	Aug 17	38
2751	405	DESCH	73	Jun 18	Aug 9	17
2753	380	JDBRZ	177	May 13	Sep 11	29
2756	408	TDBRZ	166	Jun 24	Aug 29	39
2757	347	JDBRZ	160	May 13	Sep 18	34
2758	414	TDISL	34	Jun 24	Jul 8	9
2761	422	JDISL	64	Jun 5	Jun 21	14
2763	410	JDBRZ	91	May 19	Jun 12	21
2849	340	JDISL	267	Jun 16	Sep 24	67
2853	508	JDISL	130	May 30	Jun 18	18
2855	395	JDISL	315	May 14	Aug 9	53
2856	408	TDISL	322	Jun 25	Jul 26	29
2857	415	JDISL	593	May 13	Sep 30	90
2859	345	JDISL	281	May 14	Jul 27	51
2865	365	JDISL	241	Jun 9	Aug 27	52
2951	410	JDBRZ	287	Jun 9	Aug 29	47
2953	500	DESCH	211	May 28	Aug 5	45
2955	453	JDBRZ	131	May 24	Sep 29	33
2956	465	TDNBZ	147	Jun 5	Jul 18	24
2957	370	JDISL	447	May 13	Sep 22	58
2959	405	JDNAV	129	May 13	Sep 30	23
2961	443	JDISL	41	May 15	Jul 12	9
2962	431	TDBRZ	191	Jul 7	Aug 11	27
2963	480	JDBRZ	566	May 16	Aug 14	63

Table 3. Continued.

Fish Number	Fork Length	Release Site	Hours Fixed	First Day Contacted	Last Day Contacted	Days Contacted
2965	434	JDBRZ	640	May 13	Sep 30	89
3049	460	JDBRZ	468	May 13	Aug 22	47
3053	410	JDISL	192	May 13	Jul 18	30
3055	345	JDBRZ	378	May 14	Sep 30	69
3057	400	JDISL	624	May 13	Aug 16	57
3060	392	TDBRZ	218	Jun 7	Aug 17	28
3064	406	TDBRZ	187	Jun 12	Sep 28	43
3065	385	JDISL	204	Jun 4	Sep 26	41
3151	490	JDBRZ	845	Jun 8	Sep 30	95
3153	470	JDBRZ	550	Jun 7	Sep 28	82
3154	501	TDBRZ	213	Jun 9	Aug 6	36
3157	395	JDISL	228	Jun 10	Sep 29	48
3161	370	JDBRZ	202	Jun 14	Jul 20	36
3163	475	JDISL	482	May 13	Sep 29	86

Appendix Table 4. Individual northern squawfish recorded by fixed stations at John Day Dam tailrace, May - September 1993.

Fish Number	May	June	July	August	September
2250		X	X	X	
2251	X	X	X	X	
2253	X	X	X		
2255		X			
2257	X	X	X	X	X
2259	X	X			
2261		X	X	X	X
2262		X		X	
2263	X	X	X	X	X
2349	X	X	X	X	X
2351	X	X	X		
2353	X		X		
2355	X	X	X	X	X
2357		X	X	X	X
2360		X	X		
2361		X	X	X	
2451		X	X	X	X
2453		X	X	X	
2455	X	X			
2457	X	X	X	X	X
2459		X	X	X	X
2461		X			
2462		X	X		
2463	X	X	X		
2550		X	X	X	
2551	X	X			
2553	X	X	X	X	X

Appendix Table 4. Continued.

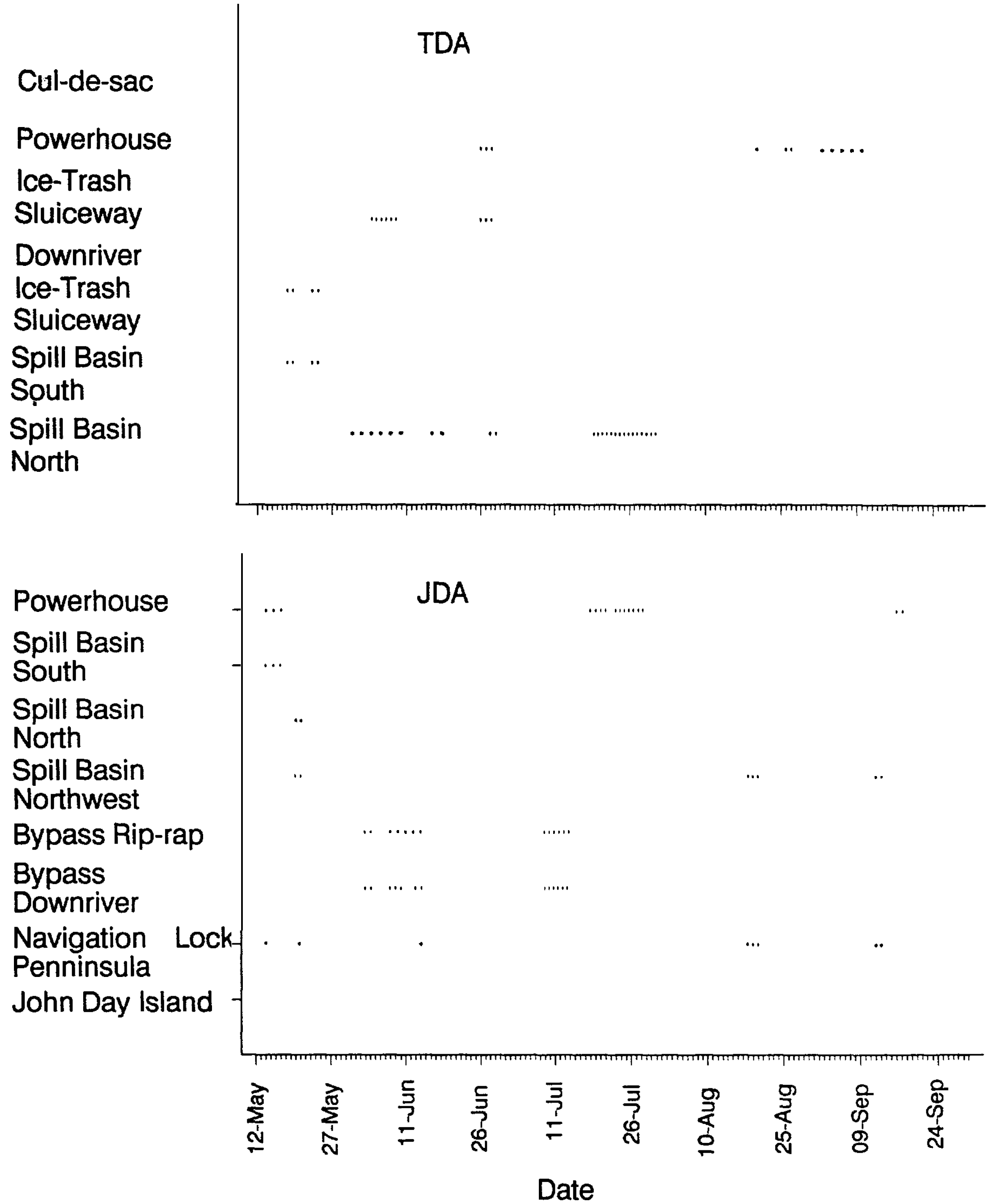
Fish Number	May	June	July	August	September
2554			X		
2555		X	X	X	X
2556		X			
2557		X			
2559	X	X	X		
2561	X	X	X	X	X
2562	X	X	X		
2563		X	X	X	X
2651	X	X	X		
2653	X	X	X		
2654		X			
2655	X	X			
2656		X	X	X	
2657		X	X	X	X
2659		X	X	X	
2661	X	X	X		
2663	X	X			
2665		X	X		
2749		X	X	X	
2751		X	X	X	
2753	X	X		X	
2756		X	X	X	
2757	X	X	X	X	X
2758		X	X		
2761		X			
2763	X	X			
2849		X	X	X	X

Appendix Table 4. Continued.

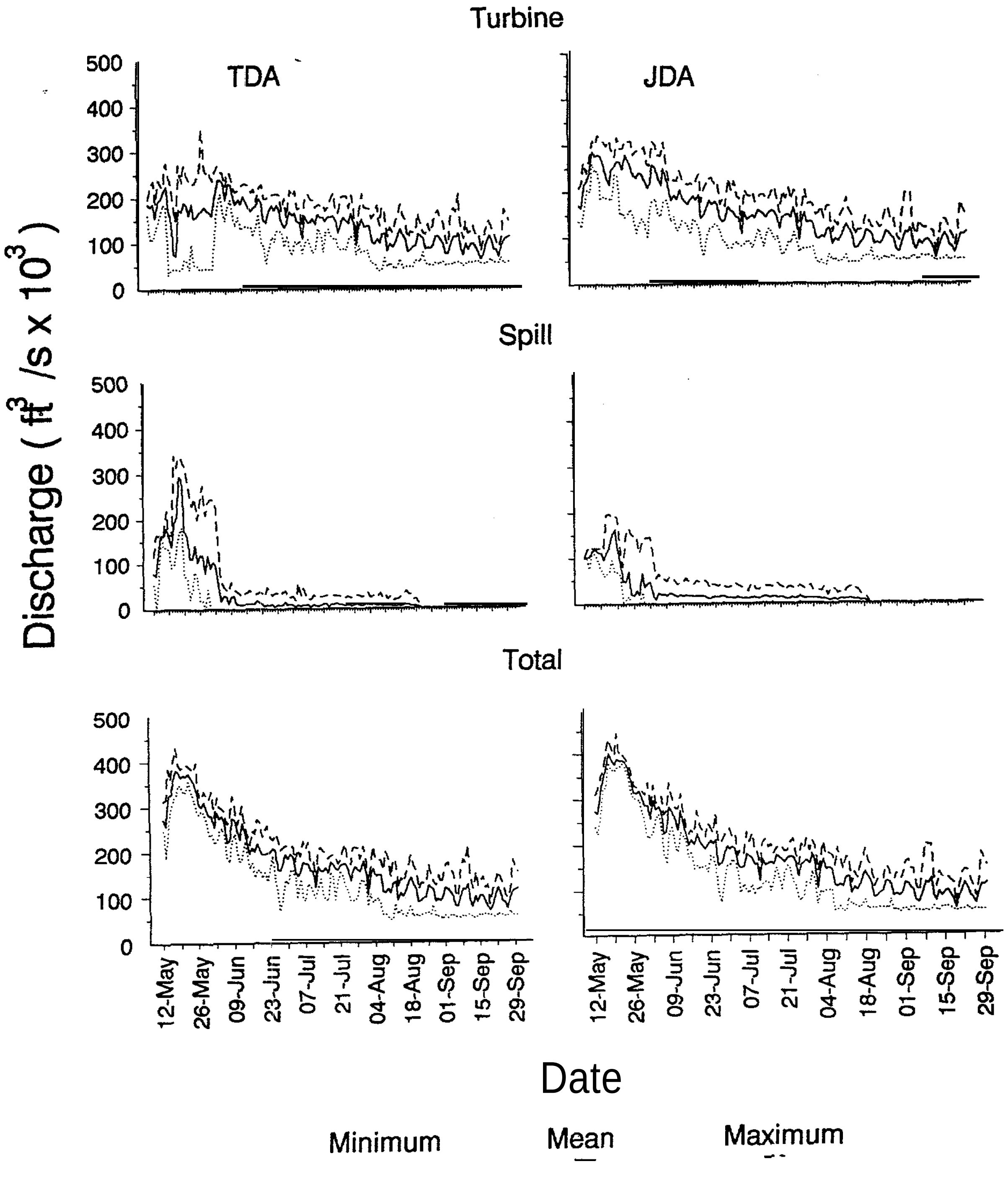
Fish Number	May	June	July	August	September
2853	X	X			
2855	X	X	X	X	
2856		X	X		
2857	X	X	X	X	X
2859		X	X		
2865		X	X	X	
2951		X	X	X	
2953	X	X	X	X	
2955	X		X	X	X
2956		X	X		
2957	X	X	X	X	X
2959	X	X	X		X
2961	X	X			
2962			X	X	
2963	X	X	X	X	
2965	X	X	X	X	X
3049	X	X	X	X	
3053	X	X	X		
3055	X	X	X	X	X
3057	X	X	X	X	
3060		X	X	X	
3064		X	X	X	X
3065		X	X	X	X
3151		X	X	X	X
3153		X	X	X	X
3154		X	X	X	
3157		X	X	X	X

Appendix Table 4. Continued.

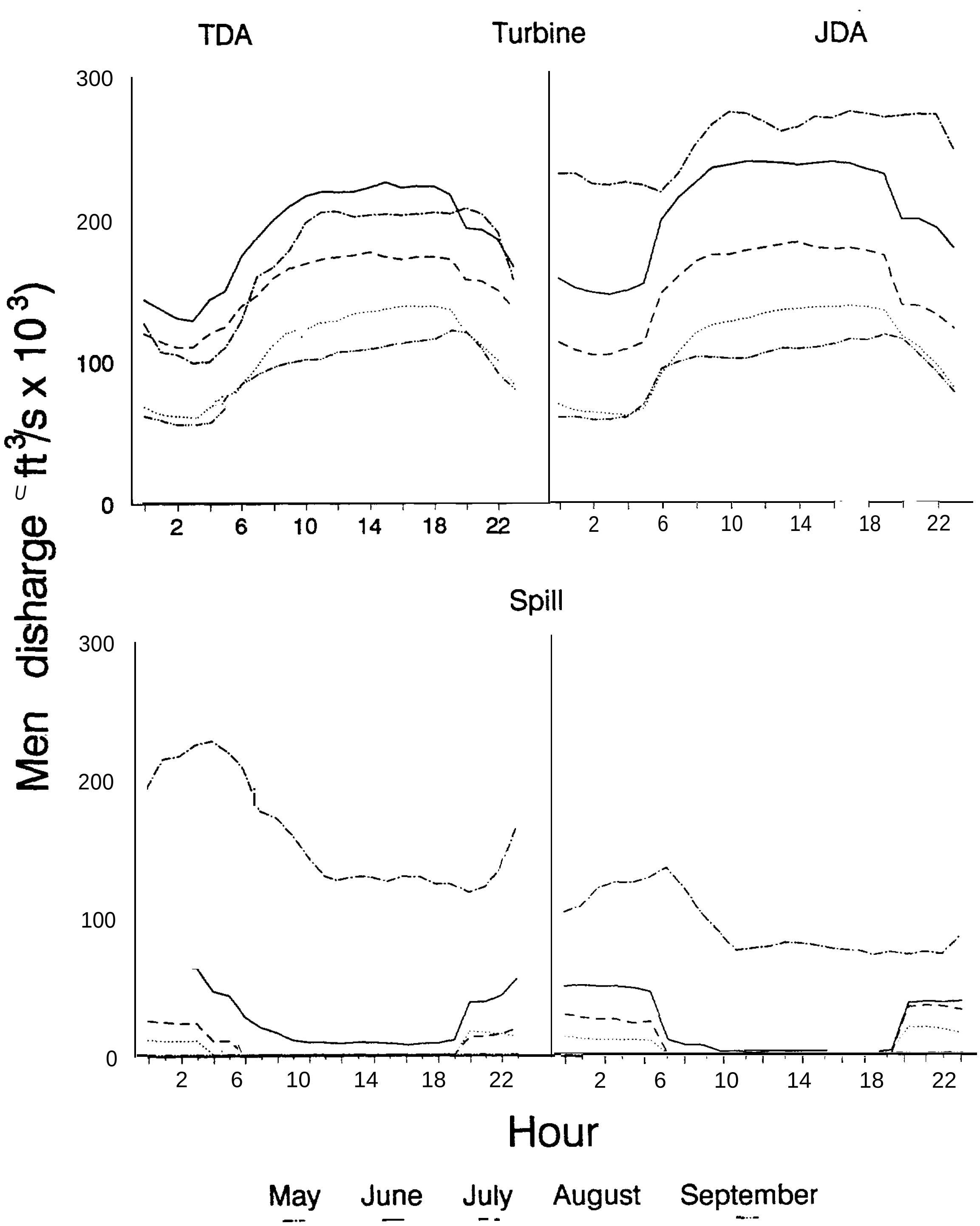
Fish Number	May	June	July	August	September
3161		X	X		
3163	X	X	X	X	X



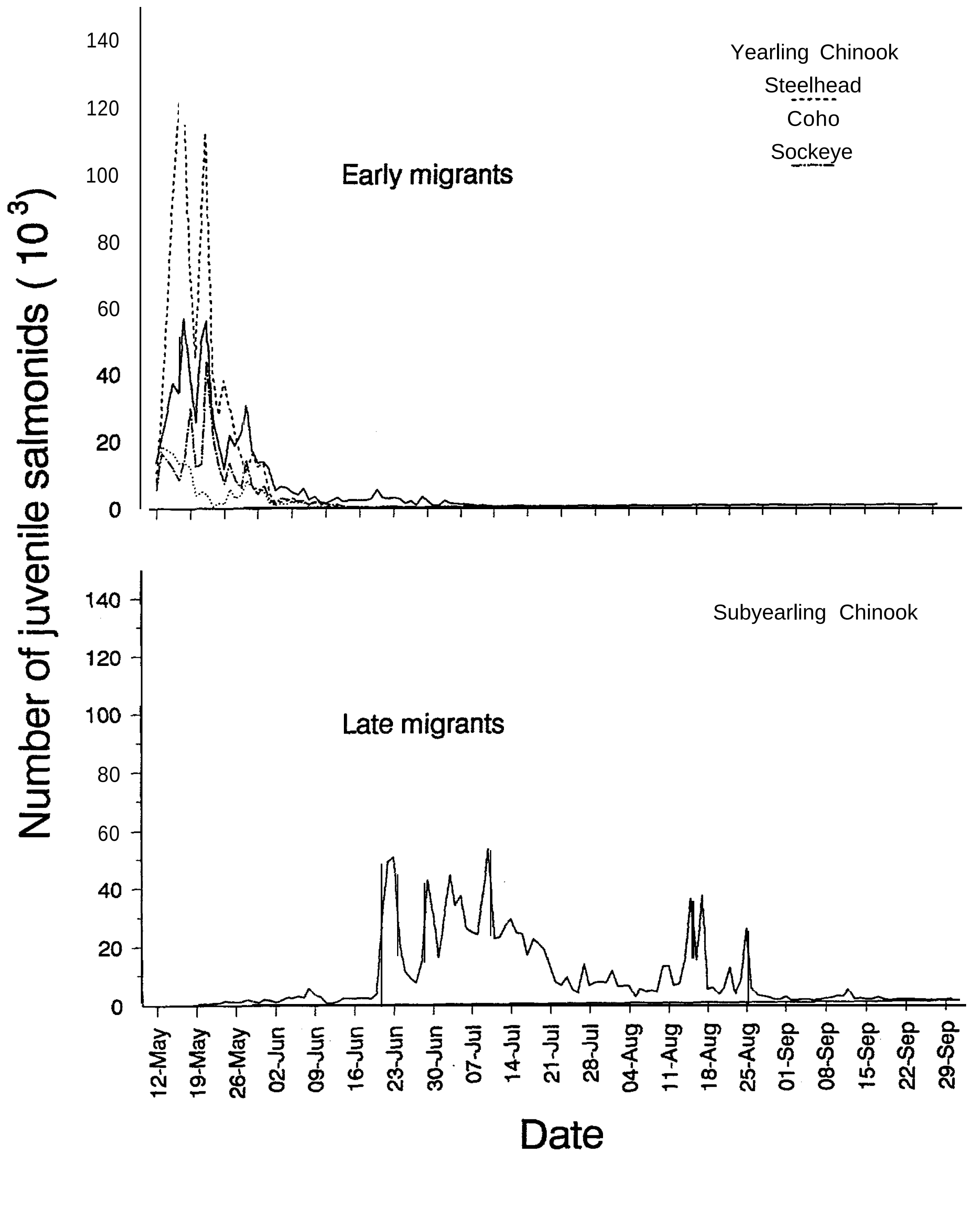
Appendix Figure 1. Dates of fixed station failure (*) by tailrace area at The Dalles (TDA) and John Day (JDA) Dams, May - September 1993.



Appendix Figure 2. Daily minimum, mean, and maximum dam discharges at The Dalles (TDA) and John Day (JDA) dams, 12 May - 30 September 1993.



Appendix Figure 3. Mean hourly turbine and spill discharges at The Dalles (TDA) and John Day dams, May - September 1993.



Appendix Figure 4. Daily index-counts for early and late out-migrating juvenile salmonids at John Day Dam, 12 May - 30 September 1993.

PART 3

Description and performance of an automated radio telemetry system to monitor the movement and distribution of northern squawfish at Columbia River Dams

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Abstract.-We describe an automated data-logging radio telemetry system that employs fixed location yagi antennas to monitor the general movements (± 50m) and distribution of radio-tagged northern squawfish near hydroelectric dams on the Columbia River. We established two similar systems at The Dalles and John Day dams, Columbia River, that were designed for continuous monitoring of fish movements around the dams limited to the area of coverage by antennas. We compared the data recorded by fixed stations to data collected by mobile (boat) tracking to determine the relative efficiency and reliability of information collected by fixed stations as well as the benefits and limitations of each method of data collection. Efficiency estimates (i.e. the number fish recorded by fixed stations and mobile tracking divided by the total number of mobile contacts) were determined for each receiving station and ranged from 36-60% (mean=56%) for O-l h after mobile contact to 55-90% (mean 81%), O-12h after mobile contact indicating that fish were not always immediately detected by fixed stations. The number of individual fish contacted by fixed stations was not significantly different from mobile tracking when both methods were conducted simultaneously (Wilcoxen paired-sample test; The Dalles P=0.756, John Day P=0.885) suggesting adequate detection of individuals in the tailrace area with fixed stations. Our results indicate that fixed stations were capable of continuous monitoring of northern squawfish in localized areas, though only general movements are recorded and coverage of certain areas can be reduced by electromagnetic interference. Mobile tracking provided precise locational data on northern squaw-fish, though relatively few data points are obtained per fish and the spatial scale of the data collected is limited due to personnel constraints. We believe that a combination of mobile tracking and fixed stations provides the most complete description of northern squawfish movements and distribution near hydroelectric dams on the Columbia River and we recommend the use of both methods when detailed behavioral data are desired for fish in localized areas.

Automated radio telemetry equipment has been used to monitor the movements and behavior of a variety of animals including: *Roe* deer **(*Capreolus capreolus*)** @eat et al. **1980),** chinook salmon **(*Oncorhynchus tshawytscha*)** and steelhead **(*Oncorhynchus mykiss*) (Bjornn** et al. **1992),** and **atlantic** salmon **(*Salmo salar*)** (Solomon and Potter 1988). Recent technological advances in telemetry equipment have improved researchers' ability to obtain specific information regarding animal movements and behavior with automated data collection systems. Such advances include: monitoring of multiple antennas, increased data-logging memory, multiple transmitters per frequency, and the ability to scan multiple frequencies simultaneously. Automated telemetry systems allow for continuous monitoring of animal movements for a larger number of individuals and for longer periods of time than would be possible with more conventional radio tracking methods. Also, personnel requirements are greatly reduced with the use of automated systems.

In order to identify the factors influencing northern **squawfish (*Ptychocheilus oregonensis*)** distributions near hydroelectric facilities on the Columbia River, we needed to develop and test a radio telemetry system that was capable of monitoring northern squawfish movements within the boat restricted zone **(BRZ)** of **tailrace** areas. Such a system must be capable of monitoring fish continuously, providing information on specific short term movements and specific habitat use that can be related to a variety of changes in dam operations. In this section we present a description of an automated data-logging radio telemetry system that employs fixed location yagi antennas to monitor the general movements (± 50m) and distribution of radio-tagged northern squawfish near hydroelectric dams on the Columbia River. The objectives of this section are: 1) determine the efficiency and reliability of information collected by fixed site receiver stations (fixed stations), 2) compare results obtained with fixed stations to data collected by mobile tracking methods and determine the benefits and limitations of each method of data collection, and 3) determine the area within the range of the fixed receivers where northern squawfish were most likely to be located with position estimates obtained by mobile tracking.

Methods

We established fixed stations at The Dalles and John Day dam tailraces, Columbia River (Figures 1 and 2). We configured these fixed stations to monitor juvenile salmonid passage routes through the dams as well as other areas where northern squawfish may be located (e.g. areas of low water velocity). A fixed station consisted of a Lotek[2] SRX 400 receiver, an antenna switchbox (that allowed the receiver to monitor up to eight different antennas), an array of four- or six-element yagi or coaxial cable antennas, and a 12 v deep cycle battery. Individual antennas were mounted on a lm extension attached to a 3.0-4.6m mast (Figure 3). Individual antennas were mounted in this fashion so we could focus the antenna on the intended area of coverage and to separate the antenna 1/2 wave-length (150MHz) from the mast.

At The Dalles Dam, five fixed stations with 34 yagi and one coaxial cable antennas were established to monitor northern squawfish movements in the boat restricted zone (BRZ). At John Day Dam we established seven fixed stations with a total of 34 yagi antennas and 16 coaxial cable antennas. The majority of yagi antennas were four element antennas with the exception of several six-element antennas that provided a modest increase in signal reception range and were more durable in areas prone to high winds. Coaxial cable antennas were employed to monitor very specific (1 Om) areas where coverage on a fine scale was desired such as near the bypass outfall at John Day Dam (Figure 2).

[2] Use of brand names does not constitute endorsement by the U.S. Government.

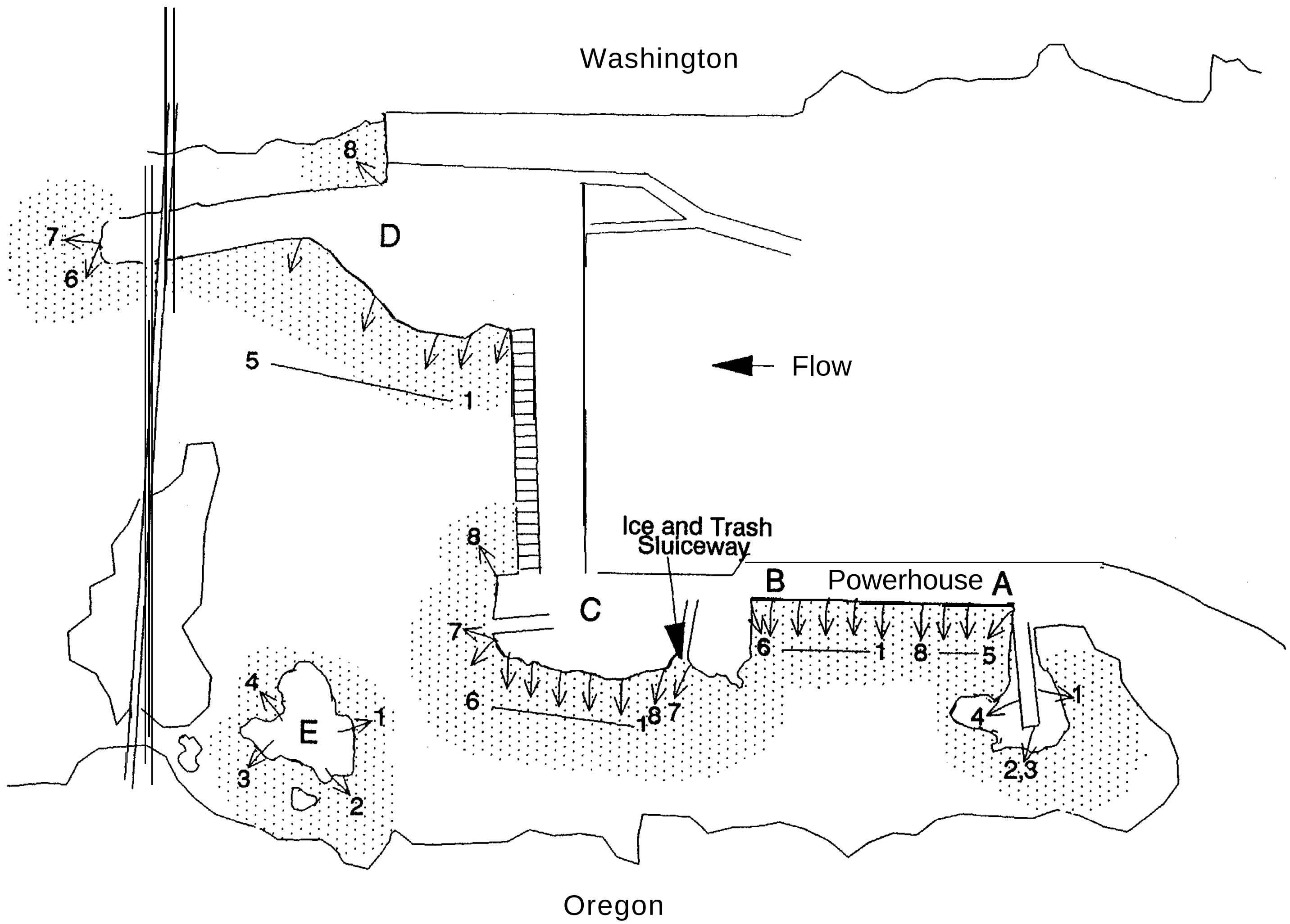


Figure 1. Location and orientation of fixed site receivers and antennas at The Dalles Dam. Areas of intended antenna coverage are indicated by the shaded regions.

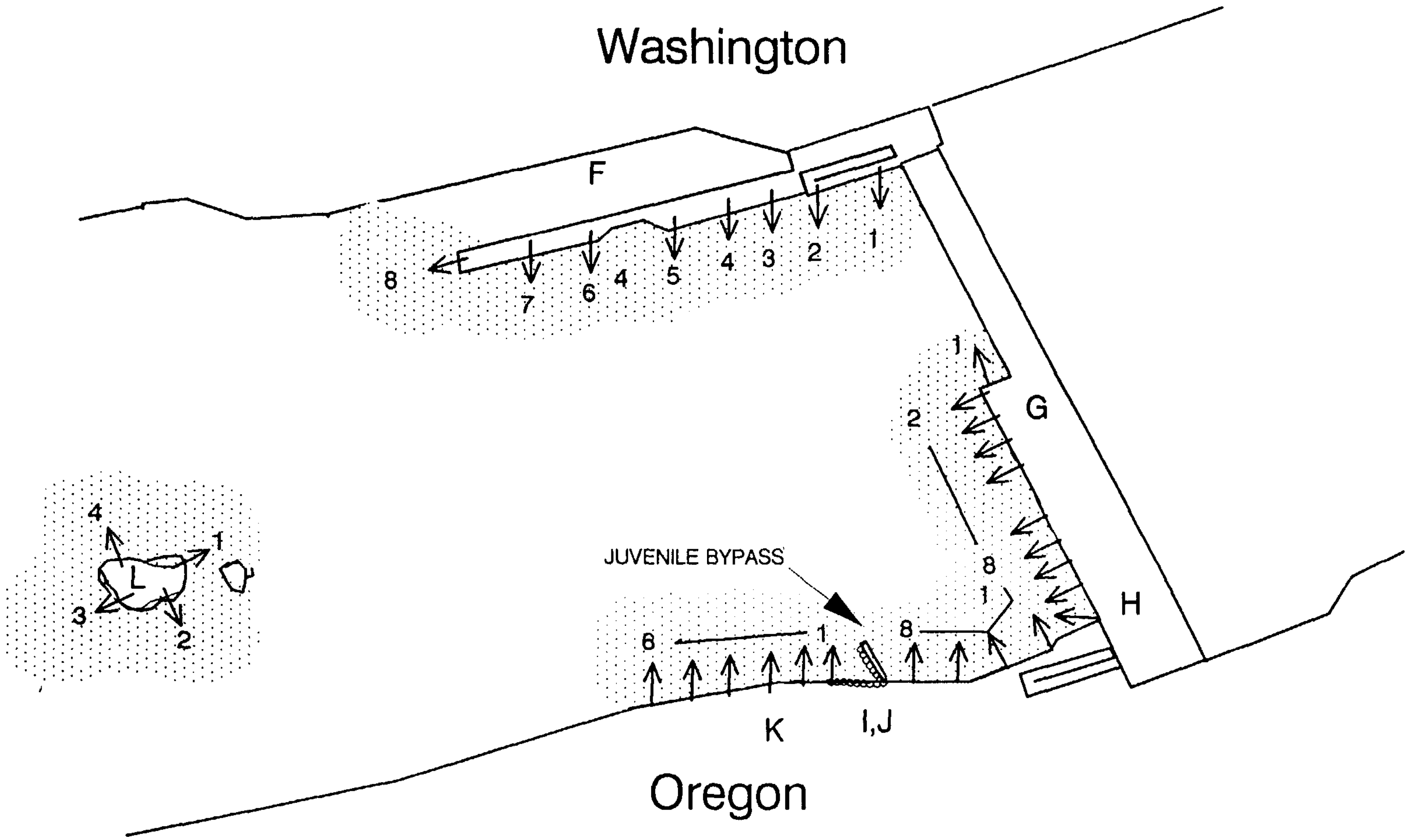


Figure 2. Location and orientation of fixed site receivers and antennas at John Day Dam. Areas of intended coverage are indicated by the shaded regions. Underwater coaxial cable antennas are represented by circles (see I and J).

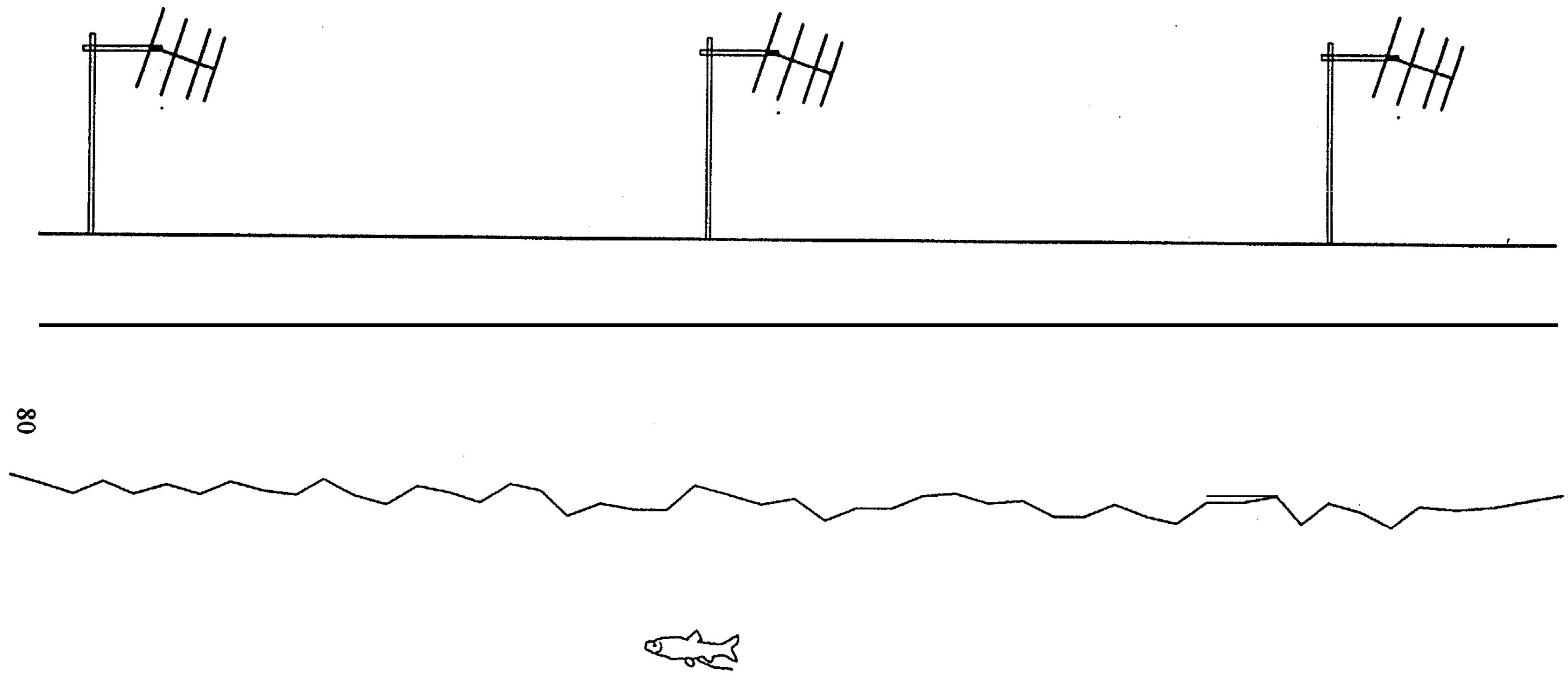
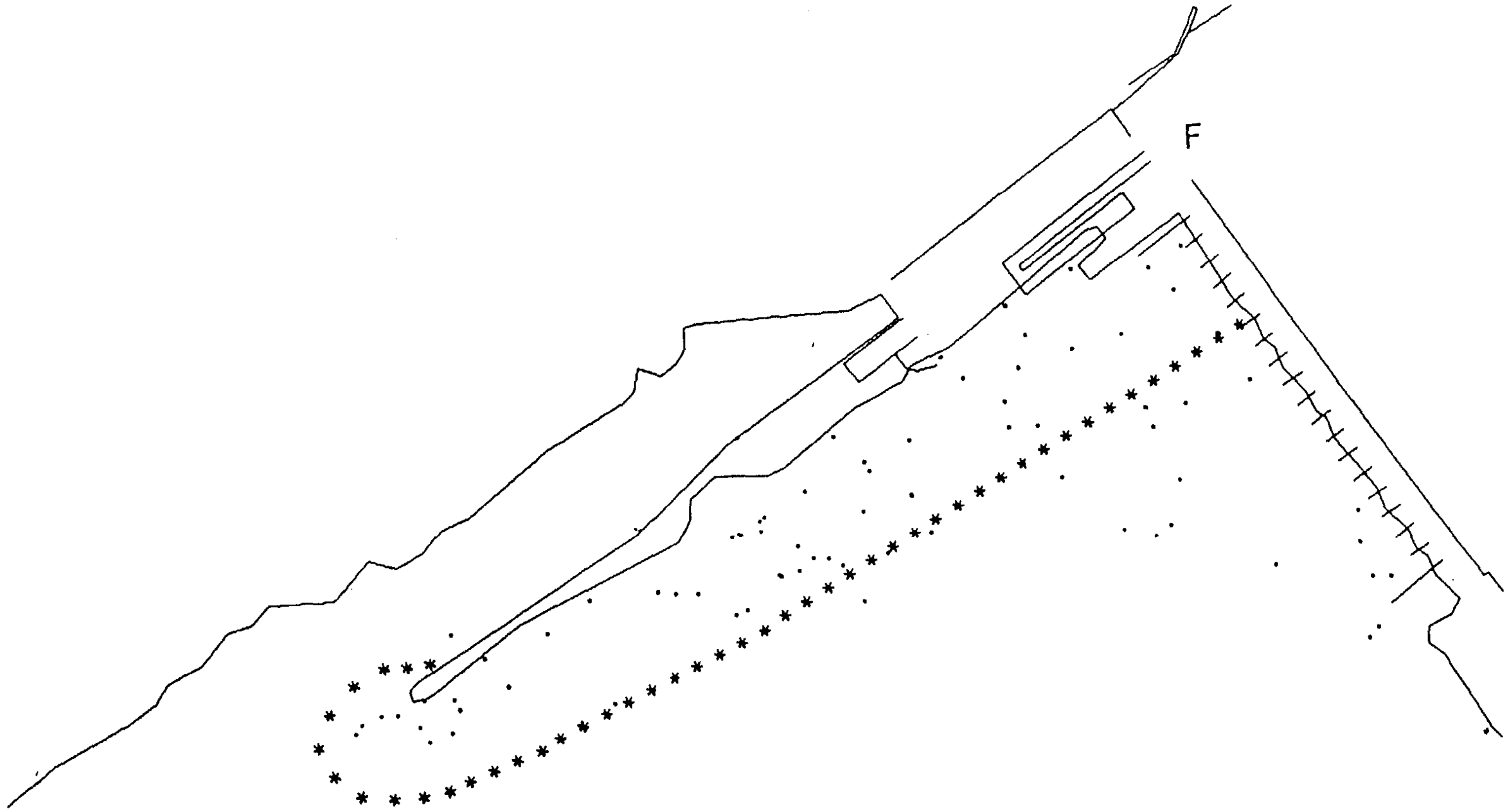


Figure 3. Example of individual yagi antenna mounting configurations at The Dalles and John Day dams, Columbia River,

Radio transmitters were digitally-encoded and frequencies were spaced 20 KHz apart from 149.820-150.000 MHz. Digitally-encoded transmitters allow for multiple transmitters on one frequency that can be individually identified by receivers. We programmed receivers to sequentially scan individual antennas for each frequency. Typically, receivers would scan all frequencies within 4-8 min depending on the number of antennas in the array, after which, receivers were programmed for a 5 min delay before scanning resumed to reduce the volume of data collected.

Several steps were necessary in order to establish an operational fixed station. First, we established individual antenna sensitivities (gains) by determining the level of electromagnetic interference (noise floor) at each antenna location at various time periods. Once established, we decreased the individual antenna gains below the noise floor to reduce the possibility of electromagnetic interference affecting our ability to record fish activity. By configuring fixed stations in this manner, we reduced the area of individual antenna coverage, however, data collected by fixed stations was more reliable. Once individual antenna gains were established, we placed a reference transmitter at several locations close to the antenna to determine if signal reception was high enough to saturate the receivers ability to determine the appropriate signal strength. If the signal saturated the receiver, we reduced antenna gains. In most cases signal reception was more than adequate when transmitters were placed close to the antennas. In the event signal reception was not adequate, we could normally improve signal reception by improving the quality of connections and changing the angle of the antenna. Once individual antenna gains were tested in this manner, we would repeatedly drift a transmitter through our intended areas of coverage to assess our ability to monitor these areas. Individual antennas were spaced 60-80m apart to reduce the amount of overlap in coverage between antennas (Figure 3).

To determine the efficiency of the fixed stations, we compared records collected by mobile tracking in the areas of fixed station coverage to data recorded by fixed stations. As part of our standard mobile tracking procedure, once a fish was located within the BRZ an estimate of fish position was recorded with a Global Positioning System (GPS) receiver (Martinelli et al. this volume). These locations were then imported into a Geographic Information System (GIS) and plotted on an overlay map of the tailrace areas of each dam. We established a zone of coverage for each fixed station by plotting mobile tracking observations that were also recorded by the intended fixed station within 1 h of the mobile tracking observation (Figure 4). Zones of coverage were assigned by examining plots of the data and determining where the density of observations began to decrease (Figure 4). The 1 h time criteria was used as a compromise between obtaining fixed station and mobile records with close comparisons in time but yet still have a sufficient number of contacts to determine an area of coverage. We believe a 1 h time frame is appropriate because many of our observations and data from northern squawfish at Lower Granite Dam tailrace (Isaak and Bjomn 1994), indicate that northern squawfish do not readily move from one location to another within the BRZ, staying in an area for several hours before moving to another location. Once zones of coverage were established for all fixed stations, we assessed fixed station efficiency by examining all mobile tracking contacts within the zones of coverage and comparing them to fixed station data to determine if the fish had been recorded. We used the time and location of each mobile contact to query relevant fixed station data to determine if fish were recorded by fixed stations within O-l, O-3, or O-12 h from the time contacted by mobile tracking. We analyzed individual mobile tracking records and determined if the fish was recorded by the appropriate fixed station within one of the defined time categories. We summed the total number of mobile contacts within each zone of coverage and compared these records to observations recorded by the fixed receivers. Fixed receiver efficiencies were calculated by comparing the number of observations where fish were recorded by both methods, divided by the total number of mobile records in the zone of coverage.



F igure 4. GIS display of mobile contacts near the navigation lock peninsula at John Day Dam. The plotted mobile points are those that were recorded by the fixed receiver (F bank) within 0-1 hour of the mobile contact. The distribution of the points around the navigational lock peninsula was used to estimate an actual zone of coverage to be used for efficiency estimates. The dashed line indicates the zone of coverage. This process was repeated for all receiver banks at each dam.

In addition to determining fixed station efficiency, we compared the total number of fish contacted by mobile tracking and fixed stations within the BRZ when both were conducted simultaneously. Also, we compared the distribution of observations within the habitat areas of the BRZs (Hansel et al. this volume) collected by mobile tracking and fixed stations. Comparisons of the total number of fish contacted by each method were conducted with median tests and overall distributions of observations obtained by boat tracking and with fixed stations were compared with log-likelihood tests (G-test; Zar 1984).

Results

Typically, zones of coverage extended beyond the areas we originally intended our fixed stations to monitor. Most fixed stations were configured to monitor radio-tagged northern squawfish movements up to 75m from the antennas, while zones of actual coverage extended as far as 300m. We considered a total of 7 17 and 724 mobile tracking observations for fixed station efficiency analysis from The Dalles and John Day dams, respectively (Figures 5 and 6). Sufficient numbers of observations existed for all fixed stations except station E (the island station, n=5) at The Dalles Dam, therefore this station was not included for analysis. Also, due to the large number of observations recorded in the area of the ice-trash sluiceway at The Dalles Dam (n=223), we calculated efficiency estimates for the two antennas (B7 and B8) monitoring this area. Efficiency estimates ranged from 36-60% for O-1 h (mean=54%) to 55-90% for O-12 h (mean 81%; Figure 7). Fixed station efficiency increased as time between fixed and mobile contacts increased at all fixed stations. At The Dalles Dam, receiver station efficiency at O-l h was highest at the antennas monitoring the ice-trash sluiceway and lowest at receiver station A (monitoring the cul-de-sac and east end of the powerhouse). The remaining stations had relatively equal efficiencies. At John Day Dam, receiver station efficiency was

THE DALLES DAM

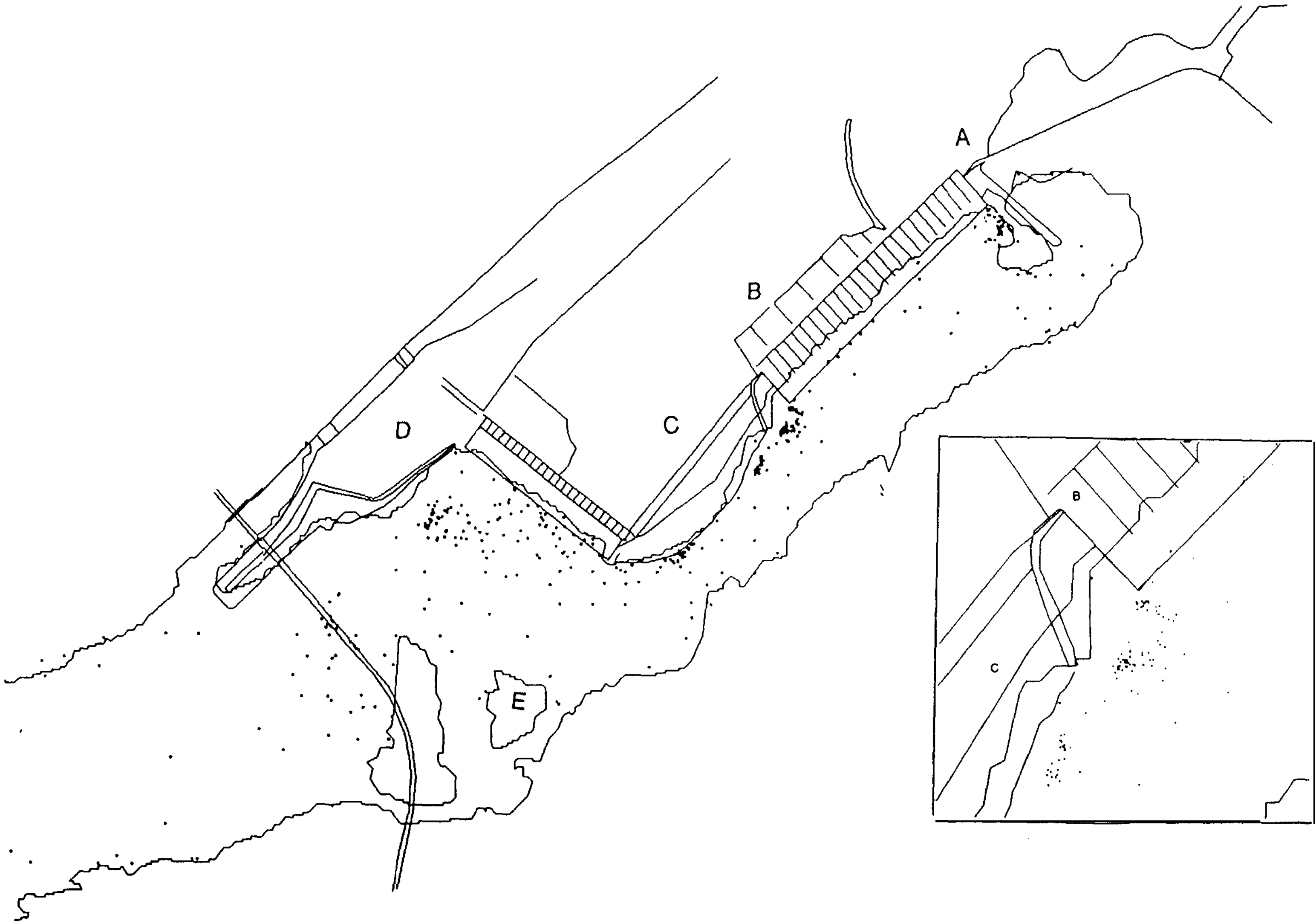


Figure 5. Location of mobile tracking contacts at The Dalles Dam (includes contacts with GPS positions and visual state plane positions, n = 717). Each single dot may may represent more than one fish contact; similar GPS fixes were taken at some locations around the dam, causing some fish locations to overlap on the GIS display (see inset, sluiceway area, n=223).

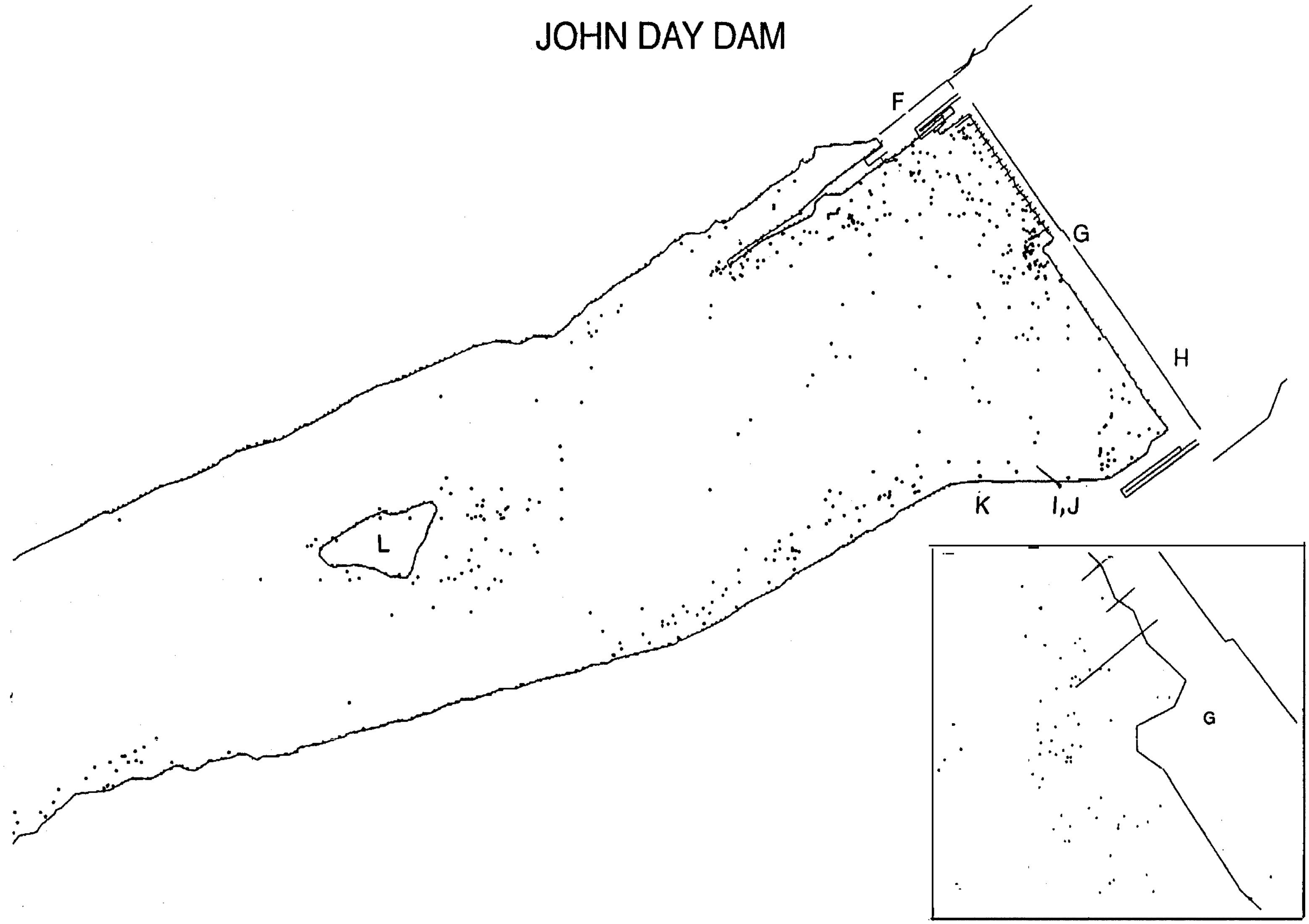


Figure 6. Location of mobile tracking contacts at John Day Dam (includes contacts with GPS positions and visual state plane postions, n = 724). Each single dot may represent more than one fish contact; multiple GPS fixes were taken at some locations around the dam, causing some fish locations to overlap on the GIS display (see inset, junction of the powerhouse and spillgates, n = 135).

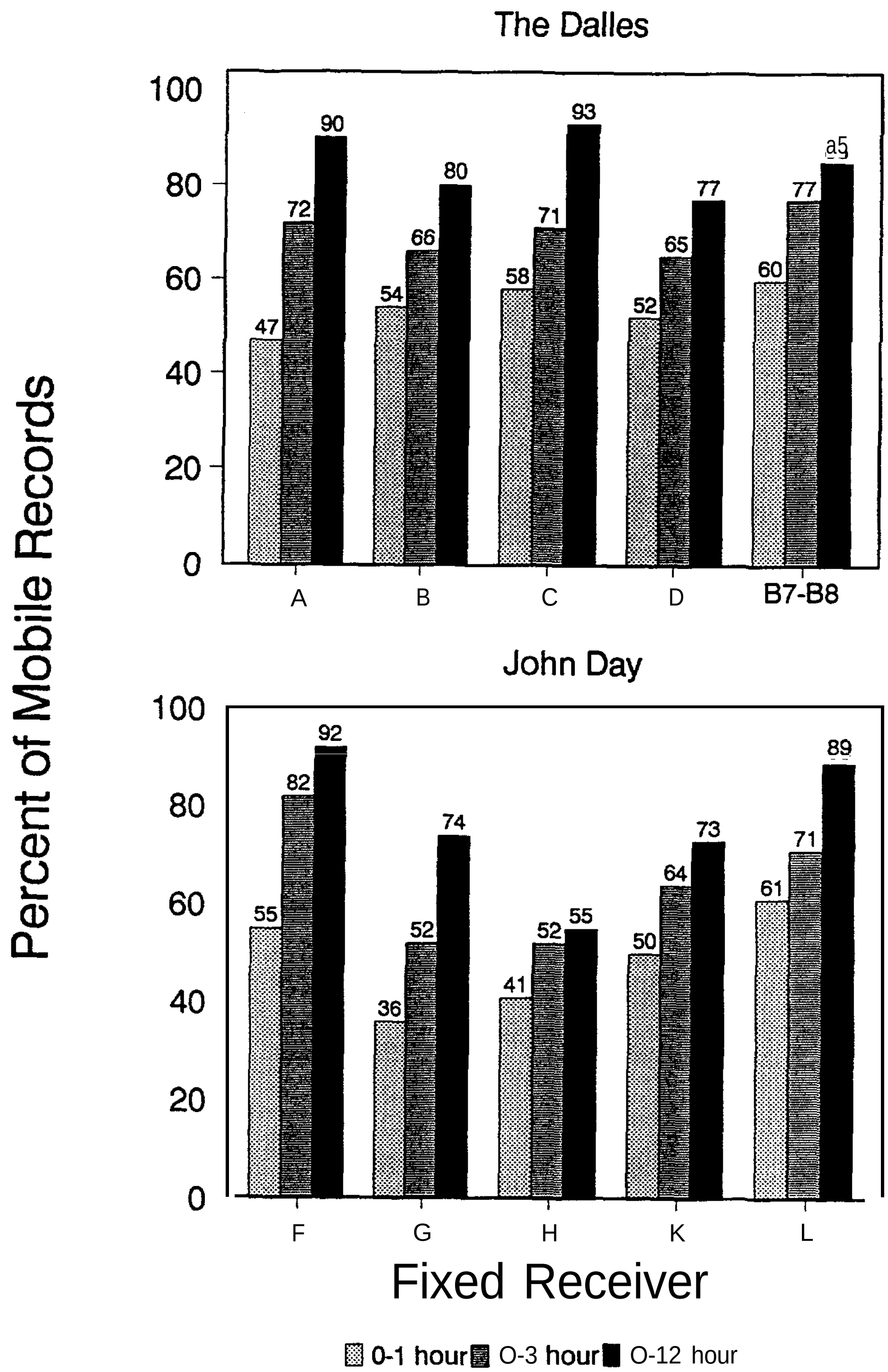


Figure 7. Fixed site receiver efficiency percentages, The Dalles and John Day Dams. Percents are based on the number of mobile records picked up by the appropriate fixed receiver site.

lowest at stations monitoring the area of the powerhouse (stations G and H) and highest at the island station (L) located about 1 km downriver of the BRZ.

Median numbers of fish contacted by mobile tracking and fixed stations were not significantly different at either dam (Wilcox.on paired-sample test; The Dalles $P=0.756$, John Day $P=0.885$, Figure 8). The overall distribution of observations collected by mobile tracking and fixed receivers was significantly different at both dams (The Dalles $P< 0.001$, John Day $P< 0.001$). The largest differences in the distribution of mobile tracking and fixed station observations at The Dalles Dam were in the area of the north spill basin and cul-de-sac. At John Day Dam, the differences in percent of observations were most pronounced at the powerhouse, northwest comer of the spill basin, and the aerial antennas monitoring the juvenile bypass outfall (Figure 9).

Plots of all mobile tracking observations indicate that several areas exist at each dam where northern squawfish are likely to be located. The remainder of observations are dispersed throughout the BRZ (Figures 5 and 6). AI: The Dalles Dam, fish were commonly located in the area of the ice-trash sluiceway, the north comer of the spill basin, and the east end of the powerhouse. At John Day Dam, northern squawfish were commonly located at the junction of the powerhouse and spillgates, and along the south side of the navigational lock peninsula.

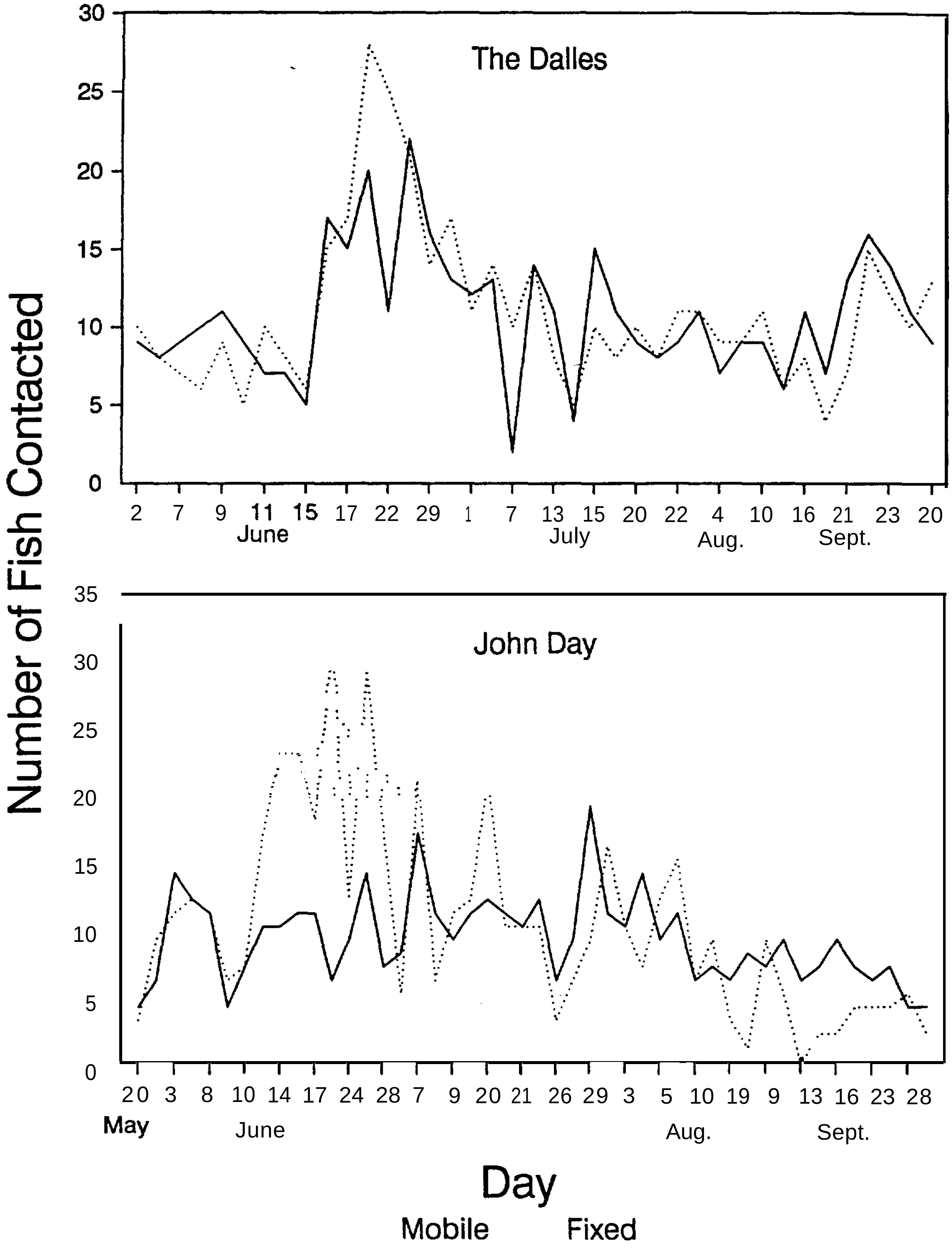


Figure 8. Number of fish contacted at the Dalles Dam and John Day Dam tailraces by mobile tracking and fixed receivers, May through September, 1993. There were no BRZ fish contacted (by mobile) at TDA for the month of May. The comparison only reflects those mobile contacts within the BRZ of both dams.

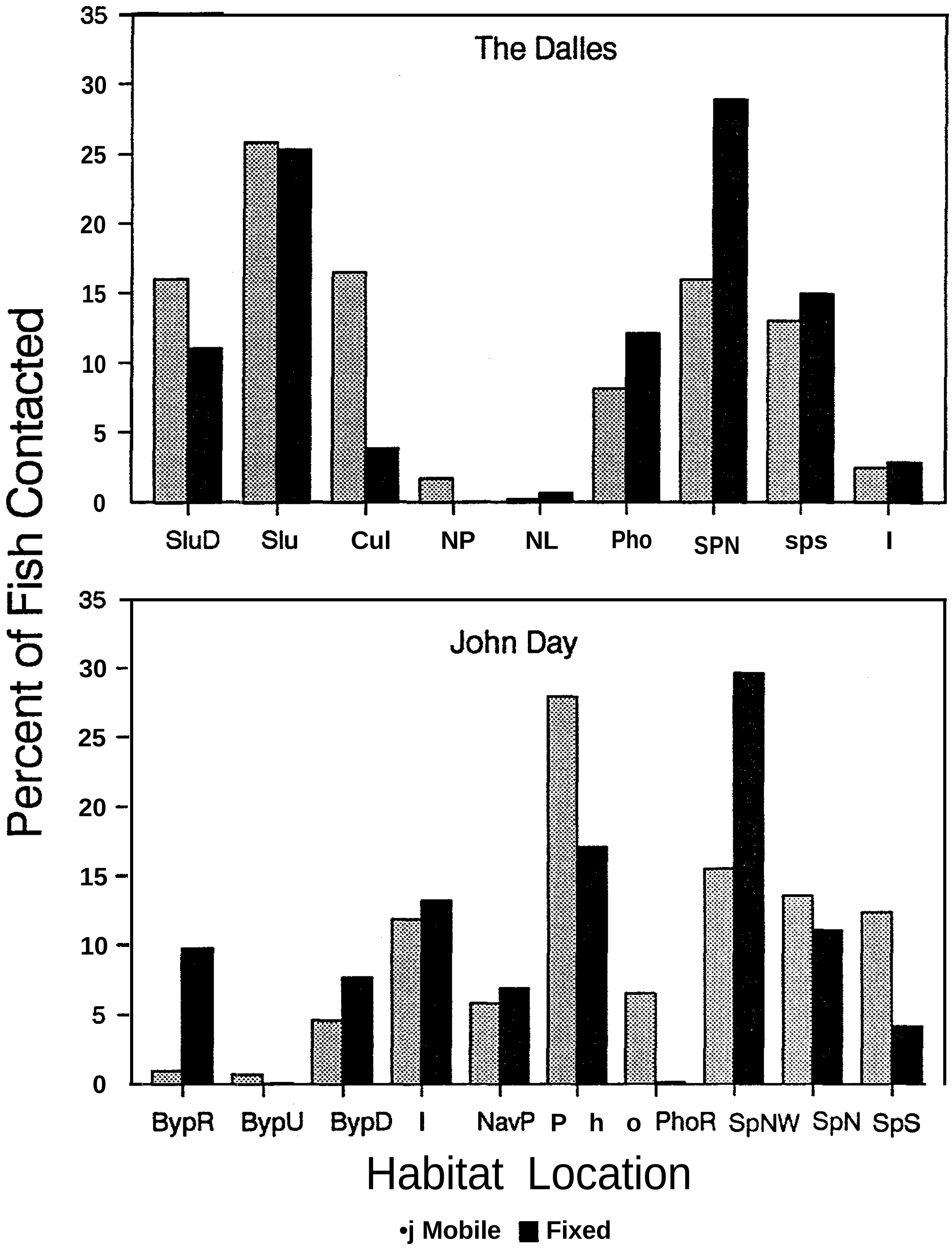


Figure 9. Difference in percent distribution between two methods of radio tracking at The Dalles and John Day dams. Habitat descriptions are listed in Hansel et. al., this volume. Percentages include fish contacted June through September, 1993.

Discussion

Fixed station efficiencies for the O-lh time category were similar for most locations, with the exception of fixed receivers at John Day Dam powerhouse (receivers G and H). The lower efficiencies at receivers G and H may be explained by electromagnetic interference from turbines and overhead power lines and our inability to position antennas effectively over the water's edge. We did not experience similar problems along the powerhouse at The Dalles Dam, which we attribute to our ability to position antennas under the powerhouse deck, partially shielding them from sources of electromagnetic interference. Other fixed stations were affected by electromagnetic interference to some degree, however, we believe our system configuration minimized the impacts of this interference (Hansel et al. this volume)

Our estimates of efficiency are most likely conservative (i.e. underestimates) because we considered observations for analysis that were outside our intended zone of coverage. Actual areas of coverage were larger than our intended areas for two reasons. First, due to attenuation of radio waves in water, the three dimensional area in which transmitters can be detected changes with respect to distance from the receiving antenna. Fish located near the surface of the water have a greater probability of being recorded by fixed stations than fish at the same distance from the antenna but deeper in the water column. Therefore, a fish close to the surface but outside the intended area of coverage could still be recorded. Second, since coverage boundaries were determined by mobile tracking observations, it is possible for fish to have been contacted by mobile tracking and subsequently move closer to fixed receivers and be recorded. Within the areas of intended coverage, receiver efficiency estimates will most likely be higher because fish will be closer to receiving antennas. Once our knowledge of GIS integration is expanded, estimates of efficiency will be determined by linear distance from the antennas rather than clustering of mobile tracking contacts.

Even though efficiency estimates were conservative, fixed receivers were effective in monitoring northern squawfish movements in the BRZs and provided more information than mobile tracking alone. Mobile tracking provides accurate estimates of fish position, however, typically only l-2 contacts per fish are obtained in an 5-7 h sampling period, while fixed receivers are capable of 24 h monitoring and provide multiple contacts per fish. Comparing the number of fish contacted by mobile tracking and fixed stations over periods when both were conducted simultaneously indicates that fixed receivers recorded slightly higher numbers of fish at both dam locations. This is probably best explained by the fact that fixed receivers are monitoring all areas at once, while mobile tracking must be conducted in a stop and search manner. Northern squawfish are not normally highly mobile within the BRZ, and this behavior may account for the slight difference between the number of individuals contacted by mobile tracking and fixed stations. The overall distribution of contacts by mobile tracking and fixed stations in tailrace areas was significantly different at each dam due to limitations of both fixed stations and mobile tracking. The largest differences occurred in the spill basin of each dam where mobile tracking was limited during times of spill and because fixed stations were not configured to monitor the entire spill basin. There were also differences in the area of the powerhouse at JDA where fixed receiver efficiencies were low due to electromagnetic interference, the area of the juvenile bypass outfall at JDA where the fixed station was most likely exceeding the intended area of coverage due to the lack of mobile tracking observations in this area, and the cul-de-sac area at TDA where water depth probably limited tag reception by fixed receivers. For 1994, we will add additional fixed stations or alter the configuration of existing stations to improve coverage of certain areas. Nonetheless, discrepancies between the two methods will still remain due to the limitations encountered with both methods of data collection.

We were not able to predict where northern squawfish were likely to be located once recorded at most antenna locations due to a low number of observations (mobile and fixed station) in certain areas. However, at other areas where northern squawfish were commonly located we are confident in our ability to determine location. For example, northern squawfish were commonly located by mobile tracking on the east side of the ice-trash sluiceway at The Dalles Dam. Fish recorded in this area were usually detected by receiver B, antenna seven, and 90% of these mobile tracking observations were within a 15-20m radius. In order to predict northern squawfish locations in other areas monitored by fixed stations, more fixed station and mobile contacts would have to be collected.

Our results demonstrate the need for both mobile tracking and fixed stations to monitor northern squawfish activity near hydroelectric dams. Fixed stations are capable of continuous monitoring within localized areas and contact similar numbers of individuals as mobile tracking. However, information on precise fish locations is limited and electromagnetic interference can limit coverage of certain areas. With mobile tracking we can obtain accurate estimates of fish location and avoid most of the effects of electromagnetic interference. Mobile tracking is limited in that relatively few data points are obtained per fish, and the spatial scale of the data collected is limited due to personnel constraints. We believe that a combination of mobile tracking and fixed stations provides the most accurate description of northern squawtish movements near hydroelectric dams on the Columbia River and we recommend the combination of fixed stations and mobile tracking when detailed behavioral data are desired for fish in localized areas.

Acknowledgements

We thank S. Hirtzel, T. King, B. Klatte, and T. Martinelli who assisted in collection of radio-tracking data. C. Grant provided invaluable assistance and advice in the design and setup of fixed receiving equipment. T. Poe and J. Beeman provided helpful comments on earlier drafts of this report. This work was funded by Bonneville Power Administration (contract DE-AI79-88BP91964) and administered by W. Maslen.

References

Bjornn, T.C., R.R. Ringe, K.R. Tolotti, P.J. Keniry, and J.P.Hunt. 1992. Migration of adult chinook salmon and steelhead past dams and through reservoirs in the Lower Snake River and tributaries using radio telemetry and fish tagging. 199 1. Annual report of research to the U.S. Army Corps of Engineers, Walla District, 55pp.

Deat, A., C. Mauget, R. Mauget, D. Maurel, and A. Sempere. 1980. The automatic, continuous and fixed radio tracking system of the Chize forest: theoretical and practical analysis. In Amlaner Jr., C.J. and D.W. Macdonald (eds.) A handbook on biotelemetry and radio tracking. pp 439-451. Pergamon Press, Oxford.

Hansel, H.C., R.S. Shively, G. Holmberg, T.P. King, and M. Sheer. This Volume. Movements and distributions of radio-tagged northern squawfish near The Dalles and John Day dams. Annual Report of Research, 1993. Bonneville Power Administration, Portland, Oregon.

Isaak, D.J. and T.C. Bjornn. In Press. Movements of Northern squawfish in the Lower Snake River during 1992. In Poe, T.P. and D.M. Gadomski (eds.) Significance of selective predation and development of prey protection measures for juvenile salmonids in the Columbia and Snake river reservoirs. Annual report of research, 1992. Bonneville Power Administration, Portland, Oregon.

Martinelli, T.L., R.S. Shively, and T.P. King. This volume. Mobile tracking of radio-tagged northern squawfish near The Dalles and John Day dams. In Poe, T.P. (ed.) Significance of selective predation and development of prey protection measures for juvenile salmonids in the Columbia and Snake river reservoirs. Annual report of research, 1994. Bonneville Power Administration, Portland, Oregon.

Solomon, D.J. and C.E. Potter. 1988. First results with a new estuarine fish tracking system. Journal of Fish Biology 33 (Supplement A): 127- 132.

Zar, J.H. 1984. Biostatistical analysis, 2nd edition. Prentice-Hall, EnglewoodCliffs, New Jersey.

Part4

Distribution, movement, and behavior of radio-tagged northern squawfish near The Dalles and John Day dams as determined by radio-tracking

Annual Report of Research

1993

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Project No. 82-003

Contract No.
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Abstract.-Northern squawfish are the most significant predator on out-migrating salmonids in the Columbia River, however, little'information is available regarding the behavior and limitations of this predator. We tracked 135 radio-tagged northern squawfish *Ptychocheilus oregonensis* released near The Dalles and John Day dams to monitor their movement and behavior in tailrace areas. Using a six-element yagi antenna mounted in a boat, we tracked four to five times each week from May to September. Aerial surveys of Bonneville and The Dalles reservoirs were conducted every two weeks from May to January. Overall, 92% of the released fish were contacted by mobile tracking, with a mean of 12 contacts per fish. Average maximum displacement from the release site was 11 km. Aerial surveys indicated that most tagged fish were located near the dams, with a few individuals in tributaries and in areas away from the dams. Of the northern squawfish released near The Dalles Dam, 28% were later contacted at John Day Dam. Of this group, half returned to The Dalles Dam. Half of the movements from one tailrace to another occurred in June, suggesting that they may be related to spawning. Northern squawfish frequently moved between the John Day boat restricted zone and downstream areas near the boat restricted zone. Tagged fish contacted outside of the boat restricted zones were commonly associated with water less than 5 m deep and were located near shore or structure. Reduced mobile tracking and aerial contacts in the fall suggest that northern squawfish move into deeper water during this time.

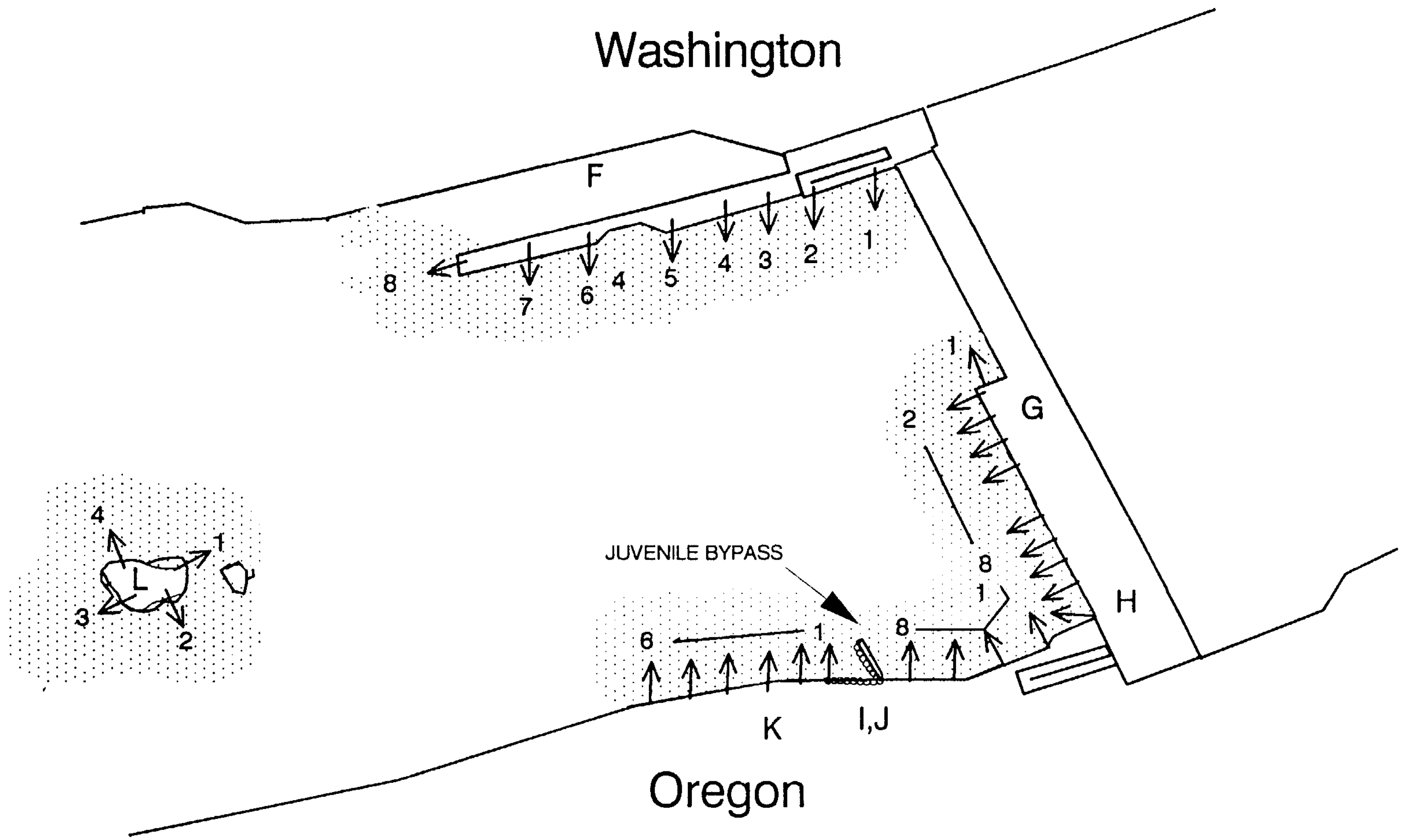


Figure 2. Location and orientation of fixed site receivers and antennas at John Day Dam. Areas of intended coverage are indicated by the shaded regions. Underwater coaxial cable antennas are represented by circles (see I and J).

Methods

We used mobile tracking by boat to monitor the movement, behavior, and distribution of 135 radio-tagged northern squawfish released into Bonneville (n=64) and The Dalles (n=71) reservoirs. Mobile tracking was conducted in both reservoirs with efforts concentrated near tailrace areas, particularly within the BRZs. Tracking was conducted four to five times a week starting in May and continuing through September. After September, mobile tracking continued on a limited basis with emphasis on obtaining locations of fish that had dispersed away from tailrace areas. We rotated the time period of tracking to cover all 24 hours every month, and to obtain location estimates of fish over a range of dam operating and environmental conditions.

For mobile tracking, we mounted a six-element yagi antenna to a three meter mast capable of rotating 360 degrees. When a signal was received, we followed the direction of strongest signal strength until a reasonable estimate of the fish location was made (approximately $\pm$ 50 m). Then, if possible, a more accurate location ($\pm$ 5 m) was obtained with a coaxial cable antenna held underwater. In most cases an accurate estimation of the location was made, although at times we were unable to obtain a precise estimate due to depth constraints, inaccessibility of certain areas, or fish moving when approached by the tracking boat. When an accurate location of a fish was obtained, the position was recorded using a global positioning system (GPS) capable of fixing a position with 3-5 m accuracy. In addition, state-plane coordinates were assigned to the location using a grid map of the tailrace area. We recorded date, time, fish identification, state-plane coordinates, water depth, and distance from shore, dam or island at each contact. Our mobile tracking efforts were focused in areas within 5-10 km of the darns and areas further downriver were covered by a single boat crew from Oregon Department of Fish and Wildlife (ODFW).

Radio transmitters were digitally-encoded and frequencies were spaced 20 KHz apart from 149.820-150.000 MHz. Digitally-encoded transmitters allow for multiple transmitters on one frequency that can be individually identified by receivers. We programmed receivers to sequentially scan individual antennas for each frequency. Typically, receivers would scan all frequencies within 4-8 min depending on the number of antennas in the array, after which, receivers were programmed for a 5 min delay before scanning resumed to reduce the volume of data collected.

Several steps were necessary in order to establish an operational fixed station. First, we established individual antenna sensitivities (gains) by determining the level of electromagnetic interference (noise floor) at each antenna location at various time periods. Once established, we decreased the individual antenna gains below the noise floor to reduce the possibility of electromagnetic interference affecting our ability to record fish activity. By configuring fixed stations in this manner, we reduced the area of individual antenna coverage, however, data collected by fixed stations was more reliable. Once individual antenna gains were established, we placed a reference transmitter at several locations close to the antenna to determine if signal reception was high enough to saturate the receivers ability to determine the appropriate signal strength. If the signal saturated the receiver, we reduced antenna gains. In most cases signal reception was more than adequate when transmitters were placed close to the antennas. In the event signal reception was not adequate, we could normally improve signal reception by improving the quality of connections and changing the angle of the antenna. Once individual antenna gains were tested in this manner, we wou Id repeatedly drift a transmitter through our intended areas of coverage to assess our ability to monitor these areas. Individual antennas were spaced 60-80m apart to reduce the amount of overlap in coverage between antennas (Figure 3).

To determine the efficiency of the fixed stations, we compared records collected by mobile tracking in the areas of fixed station coverage to data recorded by fixed stations. As part of our

Several comparisons were also made using water depth at fish location and distance from shore data for mobile contacts outside of the BRZ. Both variables were compared between reservoirs and among release sites and months (May-Nov.). To examine water depth and distance from shore across a 24-hour period, we defined 12 two-hour time intervals, and assigned each mobile contact to an interval. We then plotted mean water depth at fish location and mean distance to shore vs. time.

Results

Ninety-one percent (n=58) of the 64 northern squawfish released near TDA, and 94% (n=61) of the 65 northern squawfish released near JDA were contacted during mobile tracking in 1993. In addition, five of the six northern squawfish released near the Deschutes River were contacted while mobile tracking near the dam tailraces. Overall, 92% of the released fish were contacted by mobile tracking, with a mean of 12 contacts per fish (range: 1 to 39).

Nineteen northern squawfish moved across a dam, from one tailrace to another, covering about 39 river km. Of the northern squawfish released near TDA, 28% (n= 18) crossed above the darn and were later contacted in the JDA tailrace. Half of the fish that moved from the TDA tailrace to the JDA tailrace eventually returned to the TDA tailrace. Only one of the northern squawfish released near JDA moved to the TDA tailrace. Half of these movements, from one tailrace area to another, across a dam, occurred in June, 18'% in May, 18% in August, and the remaining 14% occurred in July. Mean travel time for the 19 fish that made 28 movements between tailraces was 5.9 days (range: 23 h to 26 days). These travel times, across approximately 39 river km between tailraces, translated into a mean rate of 13.4 km/day (range: 1.5 to 40.2 km/day).

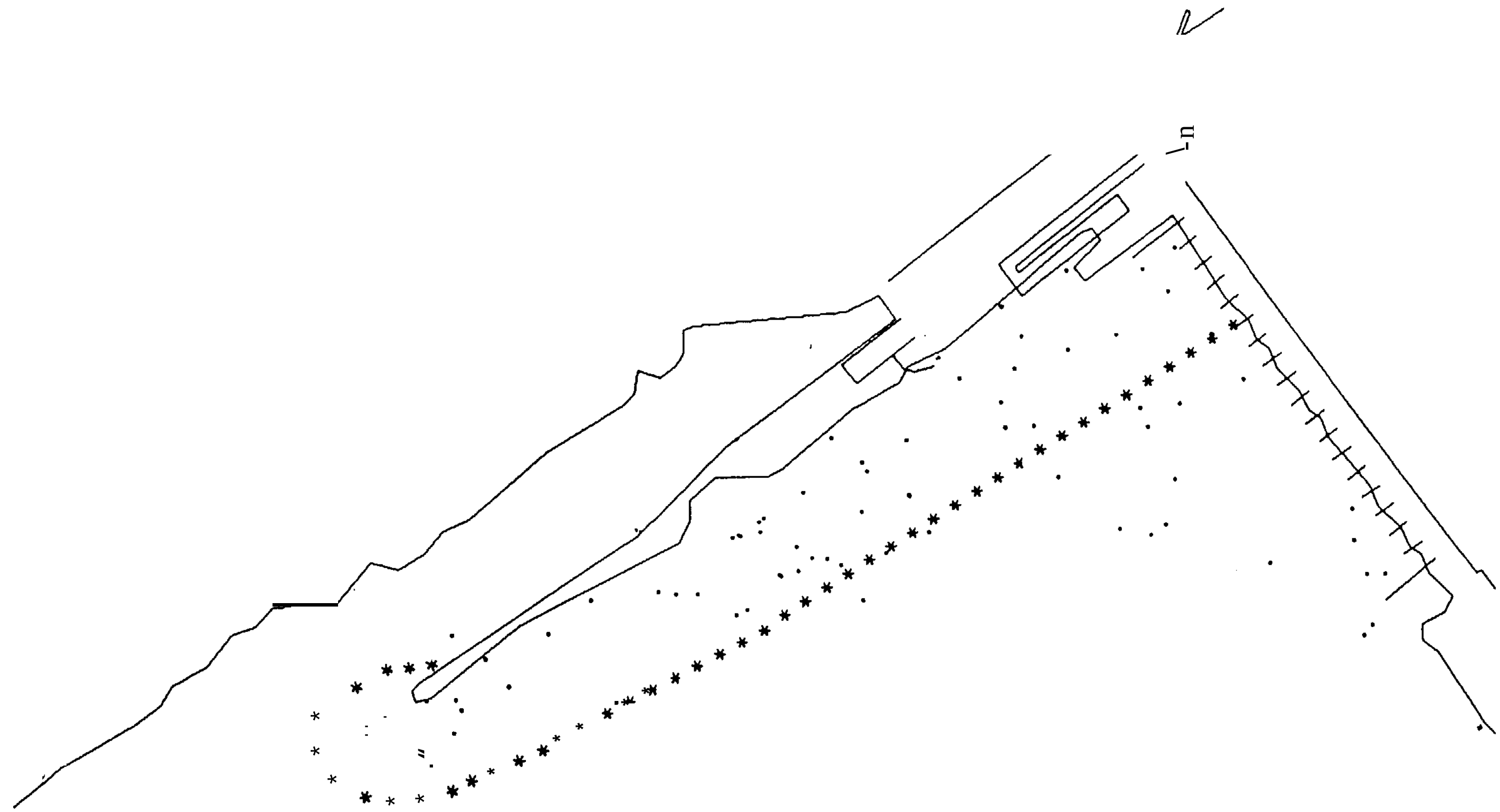


Figure 4. GIS display of mobile contacts near the navigation lock peninsula at John Day Dam. The plotted mobile points are those that were recorded by the fixed receiver (F bank) within 0-1 hour of the mobile contact. The distribution of the points around the navigational lock peninsula was used to estimate an actual zone of coverage to be used for efficiency estimates. The dashed line indicates the zone of coverage. This process was repeated for all receiver banks at each dam.

Northern squawfish that moved between dam tailraces had a mean fork length of431.8 mm, which did not differ significantly from the mean fork length of fish whose movements were confined to a single reservoir ($\bar{x}$=432.2 mm) (t=0.04 df=133 p=0.97).

Movement Distances and Rates

The mean maximum movement away from release site was 11.0 km; maximum movements ranged from 0.7 to 61.1 km (Figure 1). Northern squawfish contacted twice within 24 hours (i.e. short-term) had a mean movement rate of 460 m/h (n=222, range: 36 to 5,852 m/h). For northern squawfish whose sequential contacts were separated by more than 24 hours (i.e., long-term), the mean movement rate was 2.9 km/day (n= 163, range: 0.02 to 39 km/day). Combining all measured movements, movement distances between sequential contacts ranged between 0.1 and 45.0 km, with a mean of 5.1 km.

Mean movement distances were not significantly different among months (ANOVA F=l. 19 df=4 p=O.31) (Figure 2). Short-term movement rates differed significantly among months (ANOVA F=3 .55 df=4 p=0.0 1) with the greatest rates in September ($\bar{x}$=1, 175 m/h) (Figure 3A). Long-term movement rates showed no significant differences among months (ANOVA F=l .57 df=4 p=O. 17) (Figure 3B).

Northern squawfish that crossed a dam moved greater distances, and at faster rates than northern squawfish not crossing a dam over all months (May-Aug.; Figure 4). For movements where northern squawfish crossed a dam, neither the distance moved (ANOVA F=l .72 df=3 p=0. 19) nor the movement rate varied significantly with month (ANOVA F=O.83 df=3 p=O.49). For movements where northern squawfish did not cross a dam, movement distance varied significantly with month (ANOVA F=2.85 df=4 p=0.02); movement distances were greater in September as compared to May (Figure 4).

THE DALLES DAM

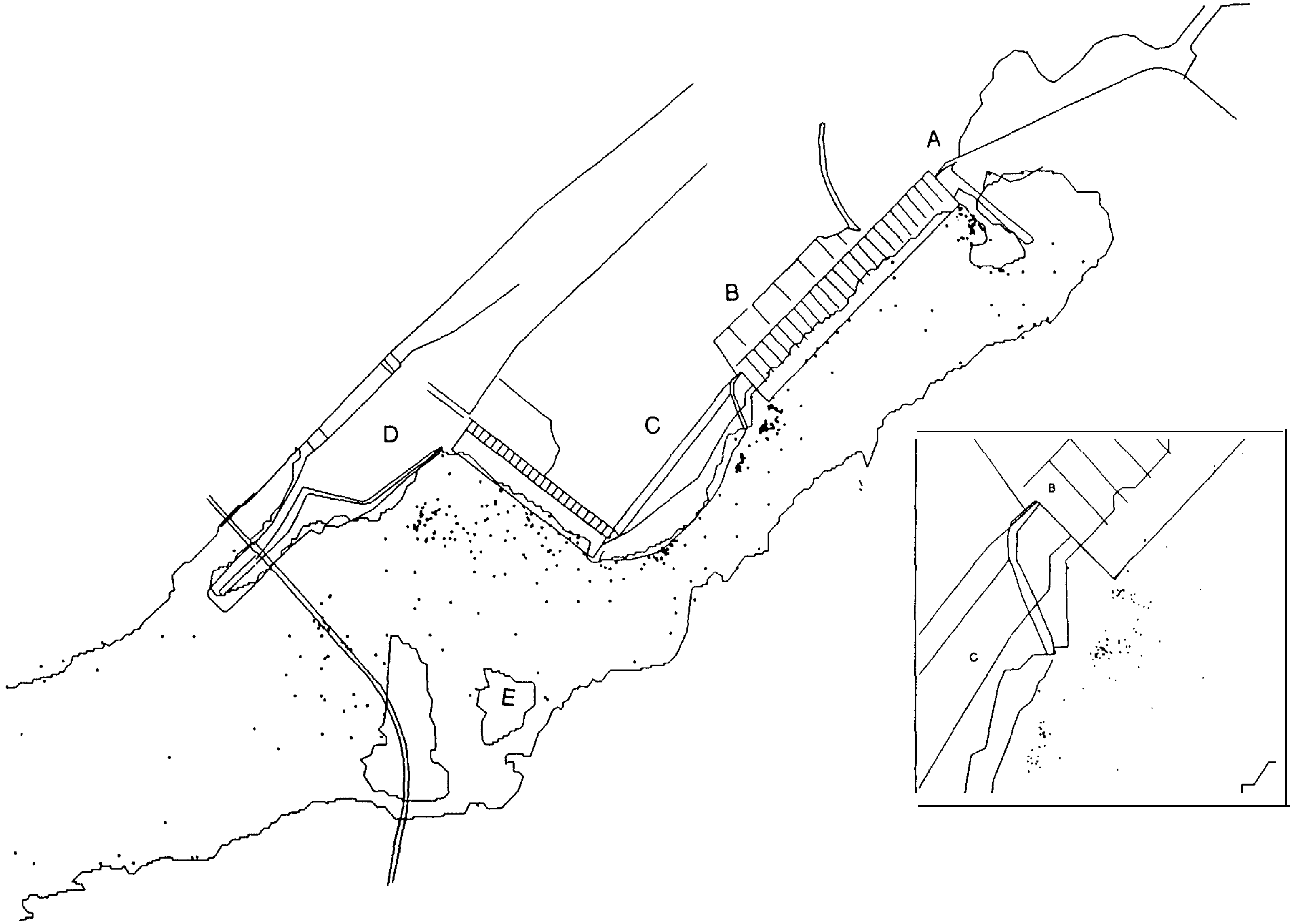


Figure 5. Location of mobile tracking contacts at The Dalles Dam (includes contacts with GPS positions and visual state plane positions, n = 717). Each single dot may may represent more than one fish contact; similar GPS fixes were taken at some locations around the dam, causing some fish locations to overlap on the GIS display (see inset, sluiceway area, n=223).

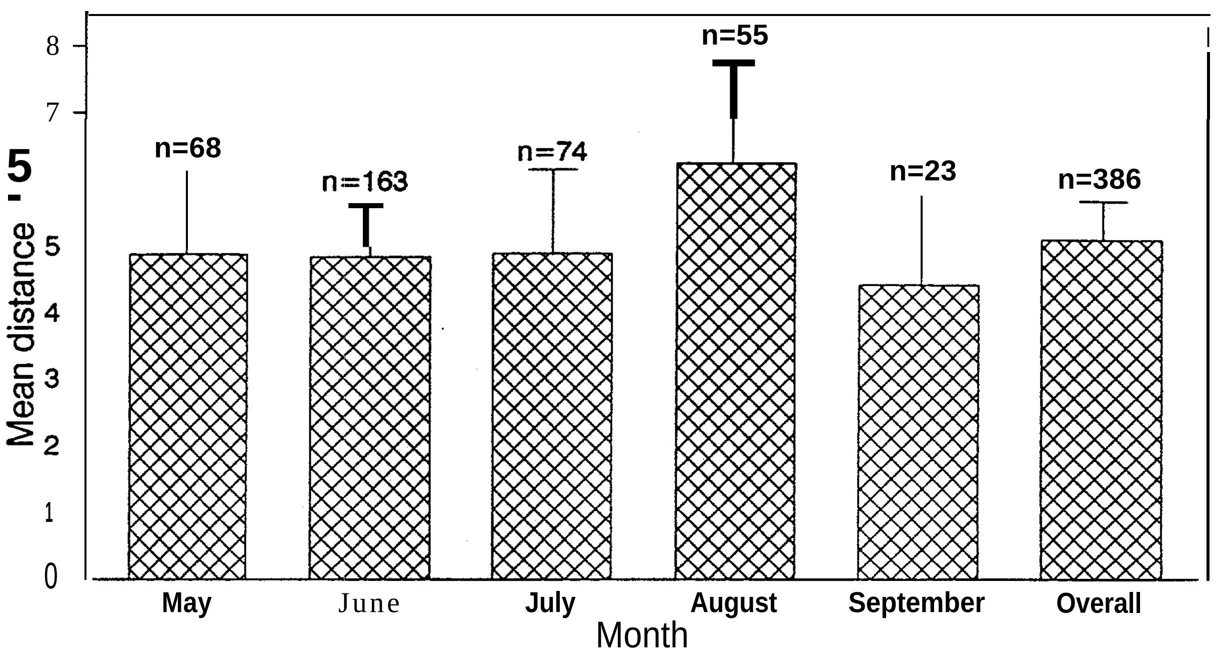


Figure 2.- Mean movement distances **by month, and over all months, for northern squawfish mobile tracked in 1993, Bars represent the standard error of the mean. n=sample size.**

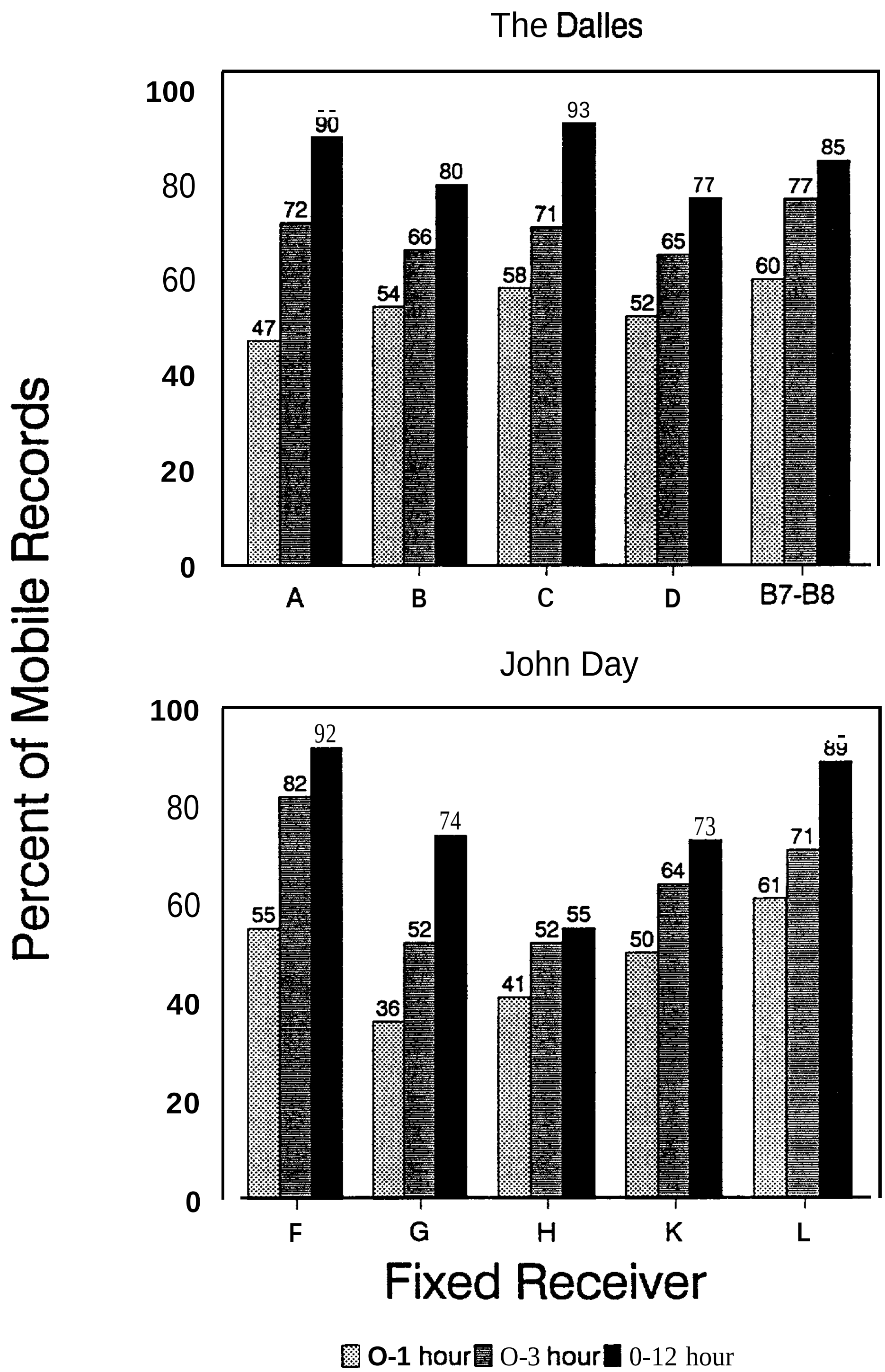
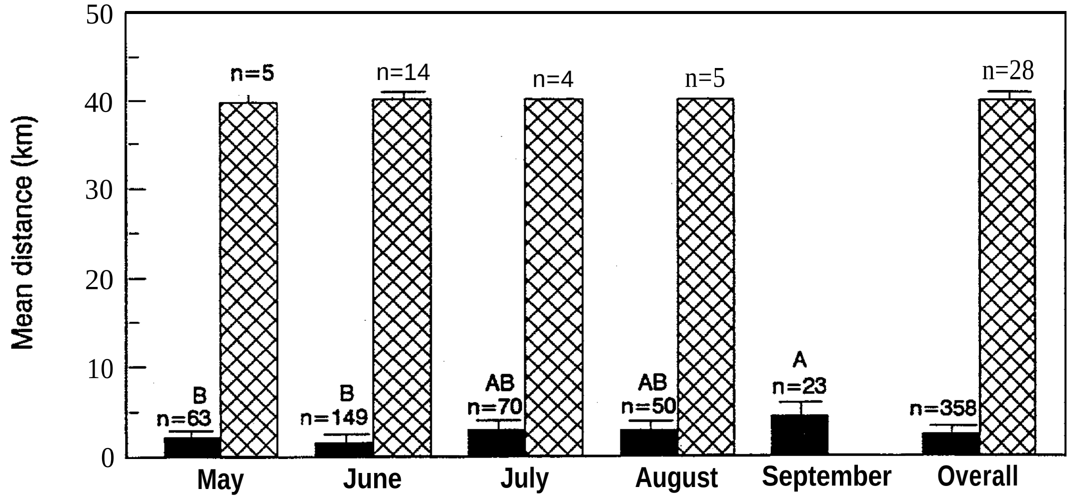


Figure 7. Fixed site receiver efficiency percentages, The Dalles and John Day Dams. Percents are based on the number of mobile records picked up by the appropriate fixed receiver site.

A



B

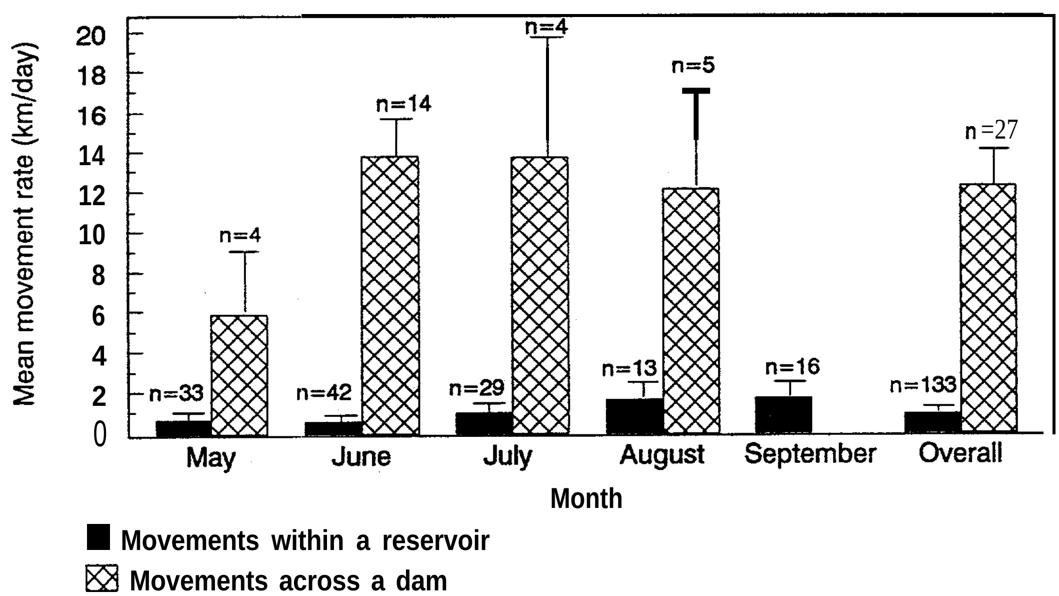


Figure 4.-Mean movement distance and rate by month for northern squawfish mobile tracked in 1993. Movements across a dam are separated from movements within a single reservoir. n =sample size, bars represent the standard error of the mean. A) Movement distance (km) by month. Values for months with the same letter are not significantly different according to parametric multiple comparison tests ($p= 0.02$). B) Movement rate (km/day) for long-term movements (sequential contacts separated by more than 24 h.). Monthly means were not significantly different for movements within a reservoir (ANOVA $p= 0.05$) or for movements across a dam (ANOVA $p= 0.49$).

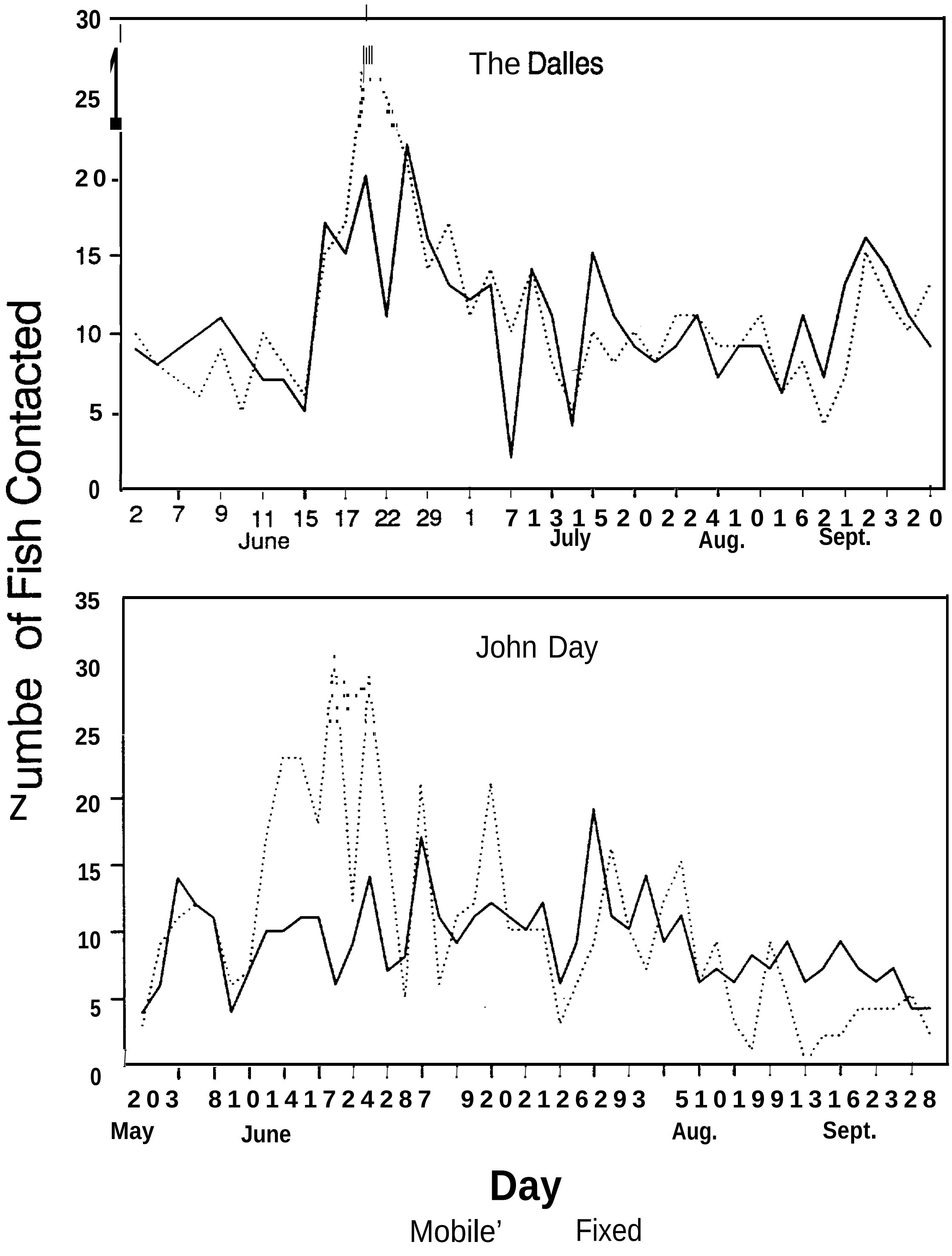


Figure 8. Number of fish contacted at the Dalles Dam and John Day Dam tailraces by mobile tracking and fixed receivers, May through September, 1993. There were no BRZ fish contacted (by mobile) at TDA for the month of May. The comparison only reflects those mobile contacts within the BRZ of both dams.

Table 1.- Mean, standard deviation (SD) and sample size (n) for movement distance, and short and long-term movement rates for the three sites where northern squawfish were released. Short-term movements are defined as having both contacts within a 24-hour period. Long-term movements have sequential contacts separated by more than 24 hours. Analysis of variance (ANOVA) results for comparisons for the different parameters are reported.

Parameter	Release Site									Comparison		
	The Dalles Dam			Deschutes River			John Day Dam			ANOVA		
	n	Mean	SD	n	Mean	SD	n	Mean	SD	F	df	p
Movement (km)	76	17.3	18.7	32	2.3	3.9	218	2.1	4.3	84.8	2	<0.01
Short-term rate (m/h)	11	215.1	178.6	25	688.5	1091.6	186	444.1	729.9	1.7	2	0.18
Long-term rate (km/day)	65	5.5	8.2	7	1.2	1.6	91	1.1	7.8	13.4	2	<0.01

Discussion

Fixed station efficiencies for the O- 1h time category were similar for most locations, with the exception of fixed receivers at John Day Dam powerhouse (receivers G and H). The lower efficiencies at receivers G and H may be explained by electromagnetic interference from turbines and overhead power lines and our inability to position antennas effective] y over the water's edge. We did not experience similar problems along the powerhouse at The Dalles Dam, which we attribute to our ability to position antennas under the powerhouse deck, partially shielding them from sources of electromagnetic interference. Other fixed stations were affected by electromagnetic interference to some degree, however, we believe our system configuration minimized the impacts of this interference (Hansel et al. this volume)

Our estimates of efficiency are most likely conservative (i.e. underestimates) because we considered observations for analysis that were outside our intended zone of coverage. Actual areas of coverage were larger than our intended areas for two reasons. First, due to attenuation of radio waves in water, the three dimensional area in which transmitters can be detected changes with respect to distance from the receiving antenna. Fish located near the surface of the water have a greater probability of being recorded by fixed stations than fish at the same distance from the antenna but deeper in the water column. Therefore, a fish close to the surface but outside the intended area of coverage could still be recorded. Second, since coverage boundaries were determined by mobile tracking observations, it is possible for fish to have been contacted by mobile tracking and subsequently move closer to fixed receivers and be recorded. Within the areas of intended coverage, receiver efficiency estimates will most likely be higher because fish will be closer to receiving antennas. Once our knowledge of GIS integration is expanded, estimates of efficiency will be determined by linear distance from the antennas rather than clustering of mobile tracking contacts.

Table 3.-Percent northern squawfish movements up vs. downriver by month. The direction of movement (up vs. downriver) was not independent of month (χ^2=12.8 df=4 p=0.001). n=sample size.

Month	n	Percent movements by direction	
		Upriver	Downriver
May	68	63.2%	36.8%
June	163	66.3%	33.7%
July	74	48.6%	51.4’%
August	55	38.2%	61.8%
September	23	39.1%	60.9%

areas. However, at other areas where northern squawfish were commonly located we are confident in our ability to determine location. For example, northern squawfish were commonly located by mobile tracking on the east side of the ice-trash sluiceway at The Dalles Dam. Fish recorded in this area were usually detected by receiver B, antenna seven, and 90% of these mobile tracking observations were within a 15-20m radius. In order to predict northern squawfish locations in other areas monitored by fixed stations, more fixed station and mobile contacts would have to be collected.

Our results demonstrate the need for both mobile tracking and fixed stations to monitor northern squawfish activity near hydroelectric dams. Fixed stations are capable of continuous monitoring within localized areas and contact similar numbers of individuals as mobile tracking. However, information on precise fish locations is limited and electromagnetic interference can limit coverage of certain areas. With mobile tracking we can obtain accurate estimates of fish location and avoid most of the effects of electromagnetic interference. Mobile tracking is limited in that relatively few data points are obtained per fish, and the spatial scale of the data collected is limited due to personnel constraints. We believe that a combination of mobile tracking and fixed stations provides the most accurate description of northern squawfish movements near hydroelectric darns on the Columbia River and we recommend the combination of fixed stations and mobile tracking when detailed behavioral data are desired for fish in localized areas.

Acknowledgements

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rough bell curve (Figure 5B). ‘The bell curve pattern held true for all months (May-Sept.) examined separately, except for May (n=30), where the 0-200 m/h and >1 000 m/h rate categories were equally represented (200/0). Long-term movements were most commonly (84.7°/0) in the O-5 km/day rate category (Figure 5C). Examination of each month separately revealed similar trends.

Depth and Distance from Shore at Fish Location

Mean water depth at fish location for mobile tracking contacts outside of the BRZS (n=279) was 4.4 m (range: 0.6 to 45.7 m), and mean distance from shore (n=271) was 24.8 m (range: 1.5 to 213.4 m). Comparison of mean water depth and distance from shore at fish location for mobile contacts of northern squawfish released near TDA, the Deschutes River, and JDA was not feasible due to a small sample size (n=3) for the Deschutes River. Although no statistical comparisons were made, means for these parameters were similar for mobile contacts of fish released near TDA and those released near JDA. Northern squawfish released near TDA had a mean water depth at fish location of 4.1 m, and a mean distance from shore of 26.9 m, while fish released near JDA had a mean water depth of 4.8 m and were, on average, 22.3 m from shore.

Mean water depth at fish location was significantly different among months; fish were associated with the deepest water in November and the shallowest water in September and May (ANOVA F=3.1O df=6 p=0.01) (Fig. 6A). Mean distance from shore did not vary significantly with month (ANOVA F= 1.26 df=6 p=0.27) (Fig. 6B), however, northern squawfish contacted in May were relatively further from shore than fish contacted in other months.

There is no evidence for significantly different mean water depths at fish location across a 24-hour period (ANOVA F=1 .64 df=10 p=O. 10). Although not statistically significant, northern squawfish tended to be associated with deeper water during daylight hours than periods of darkness

(Figure 7). Mean distance from shore did not vary significantly over a 24-hour period (ANOVA $F=1.48$ $df=10$ $p=0.15$).

Aerial Surveys

Aerial surveys were useful in contacting fish away from the dam tailrace areas and in tributaries. From May to early June aerial tracking contacts were concentrated in areas surrounding the three release sites. As the field season progressed, more northern squawfish were contacted at greater distances from the dams. Northern squawfish were contacted as far upriver as river km 365, approximately 18 rkm above JDA. The furthest contact downriver was at rkm 245, approximately 63 rkm below TDA. None of the aerial surveys contacted northern squawfish downriver of Bonneville Dam (Fig. 1).

Although tracking flights emphasized the Columbia River, northern squawfish were also contacted in two tributaries. Two northern squawfish were first contacted in the John Day River in mid-June, and a third arrived in mid-July. Of the three fish, two were released near JDA, and the third was released near TDA. Only one of these fish had multiple contacts within the tributary, being contacted roughly every two weeks for close to four months. Distances moved upstream ranged between 6 and 32 km. None of the northern squawfish contacted in the John Day River were later contacted in the Columbia River.

Five northern squawfish were first contacted in the Deschutes River in late July, and a sixth fish arrived in mid-August. Of the six fish, five were released near JDA, and the other was released near the mouth of the Deschutes River. Five of the six northern squawfish had multiple contacts within the Deschutes River, with a minimum stay in the river of 28 days and a maximum stay of about three months. Distances moved upstream ranged between 6 and 35 km. Four of the six northern squawfish contacted in the Deschutes River were later contacted in the Columbia River.

Northern squawfish *Ptychocheilus oregonensis* are the most significant predator of out-migrating juvenile salmonids in the Columbia River (Rieman et al. 1991). Consumption rates of northern squawfish are normally highest near hydroelectric facilities where juvenile salmonids are concentrated and are often injured or disoriented as a result of darn passage, making them more vulnerable to predation (Matthews et al. 1986; Maule et al. 1988; Mesa et al. 1994; Vigg et al. 1991). However, very little detailed information is available regarding northern squawfish movements, distribution and behavior near hydroelectric dams of the Columbia River. Such information would be useful in understanding the behavior and limitations of this predator in the areas where a disproportionately high number of losses of juvenile salmonids occur (Rieman et al. 1991).

We initiated a study at The Dalles Dam (TDA) in 1992 to determine the factors limiting northern squawfish predation near dam areas, specifically with respect to the placement of juvenile bypass outfalls (Shively et al. 1994). In 1993, we expanded the scope of the study to include John Day Dam (JDA), and we continued monitoring efforts at TDA. Within the boat resticted zones (BRZs) of each darn, we established a series of fixed station receivers that were configured to monitor northern squawfish general movements and distribution in these areas (see Shively et al. 1994). In addition, we regularly tracked northern squawfish by boat to obtain more accurate locations within the BRZs to verify and supplement data collected by fixed station receivers. In non-BRZ areas, boat tracking was conducted periodically, primarily to monitor northern squawfish movements within 5-10 km of the darns. In this section, we present results on the distribution, movement, and behavior of radio-tagged northern squawfish only in Bonneville and The Dalles non-BRZ reservoir areas, as determined by boat and aerial tracking.

inaccessible by boat. Therefore, it is difficult to determine if similar patterns of behavior are occurring at TDA. A fixed station receiver will be established in 1994 on islands downstream of TDA to help determine if similar short-term movements are occurring.

As compared to our short-term movement rates, Isaak (1994) reported lower rates for northern squawfish near Lower Granite Dam. His calculations were based on fish contacted within the immediate vicinity of the dam, whereas our calculations incorporated movements between BRZ and non-BRZ areas and omitted movements confined to the BRZ. Our higher short-term movement rates suggest that northern squawfish move more readily in areas slightly downstream of dams, perhaps due to more active foraging.

While most radio-tagged northern squawfish were not detected moving far away from the dams, some fish moved great distances. The majority of these longer movements were fish moving from the TDA tailrace to the JDA tailrace. About 30% of all tagged fish released at TDA moved above the dam and were contacted at JDA; 500/0 of these fish returned to the TDA tailrace. These data suggest that a substantial proportion of fish in the TDA area crossed the dam and moved into the JDA tailrace. In 1991, the University of Washington operated a Merwin trap in the TDA tailrace and tagged over 1,000 northern squawfish, some of which were recorded passing through the fish ladder (Mathews et al. 1993). Additionally, for the last several years, Washington Department of Fisheries personnel at TDA recorded between 60,000-80,000 northern squawfish passing through the east fish ladder (Rawding 1993). If our radio-tagged fish are indicative of the northern squawfish population in the TDA tailrace, then most of these fish would likely move to JDA.

Mathews et al. (1993) reported increased ladder use of tagged northern squawfish in mid- to late June. Our data show a similar trend, with 50% of movements involving ladder use at TDA occurring in June. Since spawning of northern squawfish in this area peaks in June (Vigg et al. 1991), We flew aerial surveys starting in May, with flights every two weeks until late January. Aerial surveys were used to monitor. general distribution of fish in The Dalles and Bonneville reservoirs and to locate fish that had dispersed away from the dams. Reference transmitters were periodically placed in the river along the flight path to ensure the aerial tracking equipment was functioning properly. Flights were conducted from Beacon Rock State Park (river km 228) below Bonneville Darn to Arlington (river km 391) upriver of JDA. A four-element yagi antenna was mounted to the landing strut of the airplane and surveys were flown at an altitude of 450 m (1500 ft). When a tagged fish was detected, the fish was assigned the closest landmark and river kilometer with a detailed map of the river. Flights periodically covered the lower reaches of the John Day and Deschutes rivers to determine if fish were traveling into these tributaries.

A data set of movement distances and rates was compiled through examination of the movements of all released northern squawfish. All movements of fish ranging outside of the BRZ were included in the data set presented and discussed in this report. Northern squawfish movements confined to the BRZ were considered only in the analysis of fixed receiver data (Hansel et al., this report). For calculation of movement distances and rates, several sources of fish locations were considered, including: mobile tracking contacts, ODF W mobile tracking contacts, and fixed site antenna contacts. Movement variables were calculated using straight line distance measurements and time intervals between successive contacts, resulting in minimal distance and rate estimates. In order to retain fine-scale movement rate information, we separated movements into two categories based on the time interval between successive contacts. Short-term movements are defined as movements with both contacts occurring within 24 hours, and have rates expressed as m/h. Long-term movements have sequential contacts separated by more than 24 hours and have rates expressed as km/day.

For each fish, we calculated a maximum distance moved from the release site and total number of mobile tracking contacts. Means were then calculated and reported for all released fish.

and fixed station receiver contacts during the fall, led us to believe that tagged northern squawfish were moving into deeper water for the winter.

In summary, mobile tracking of radio-tagged northern squawfish near TDA and JDA in 1993 was successful in begiming to describe the movements and distribution of this species. Our data showed that, in general, northern squawfish do not range widely from their point of release, and most of their movements are restricted to areas near the dams." Several fish made large movements, traveling between dam tailrace areas. Based on movement rates, it appears that crossing a dam does not provide a serious obstacle to the movements of these fish. Northern squawfish were found to be associated with shallow water during the spring and summer, and appear to move into deeper areas for the fall and winter. During the field season of 1994 we will be making modifications to both the fixed station receiver sites and the mobile tracking protocol in an effort to gain more detailed information on the movements of northern squawfish.

Several comparisons were also made using water depth at fish location and distance from shore data for mobile contacts outside of the BRZ. Both variables were compared between reservoirs and among release sites and months (May-Nov.). To examine water depth and distance from shore across a 24-hour period, we defined 12 two-hour time intervals, and assigned each mobile contact to an interval. We then plotted mean water depth at fish location and mean distance to shore vs. time.

Results

Ninety-one percent (n=58) of the 64 northern squawfish released near TDA, and 94% (n=61) of the 65 northern squawfish released near JDA were contacted during mobile tracking in 1993. In addition, five of the six northern squawfish released near the Deschutes River were contacted while mobile tracking near the dam tailraces. Overall, 92% of the released fish were contacted by mobile tracking, with a mean of 12 contacts per fish (range: 1 to 39).

Nineteen northern squawfish moved across a dam, from one tailrace to another, covering about 39 river km. Of the northern squawfish released near TDA, 28°/0 (n=1 8) crossed above the dam and were later contacted in the JDA tailrace. Half of the fish that moved from the TDA tailrace to the JDA tailrace eventually returned to the TDA tailrace. Only one of the northern squawfish released near JDA moved to the TDA tailrace. Half of these movements, from one tailrace area to another, across a dam, occurred in June, 18’% in May, 18% in August, and the remaining 14% occurred in July. Mean travel time for the 19 fish that made 28 movements between tailraces was 5.9 days (range: 23 h to 26 days). These travel times, across approximately 39 river km between tailraces, translated into a mean rate of 13.4 km/day (range: 1.5 to 40.2 Ian/day).

Part 5

1993 ANNUAL REPORT

MOVEMENT, DISTRIBUTION, AND BEHAVIOR OF JUVENILE SALMONIDS PASSING THROUGH COLUMBIA AND SNAKE RIVER DAMS

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Bonneville Power Administration

EXECUTIVE SUMMARY

- Rates of outmigration at The Dalles were slower for smelts released at the proposed upstream (0.5 -3.3 kmph) than at the proposed downstream (2.0 -6.0 kmph) bypass outfall sites. At John Day outmigration rates were 1.9 to 4.0 kmph, whether smelts were released at the outfall or through the bypass.

- Holding at The Dalles was four times more likely for chinook smelts released at the proposed upstream outfall site (60%) or from the sluiceway (31%) than at the downstream site (8%). Chinook smelts held in the areas of the bridge or basin islands; only fish released upstream held above the bridge. Two smolts held in the John Day Dam tailrace study area; both held 4.5 km from where they were released.

- The great majority of smelts released at John Day Dam migrated immediately.

- Several fish released at both dams held during the day, then resumed movement after dark.

- Stress appears to result in holding rather than rapid emigration, especially below The Dalles Dam.

- In The Dalles Dam tailrace study area smelts followed the main river fiow during outmigration. The Oregon shore, around the Basin Islands and Marina were areas where most smelts held.

- At John Day smelts followed the main flow from the powerhouse on the Oregon side until passing the island; thereafter they dispersed across the width of the river.

- We have no evidence of predation on radiotagged smelts for 1993.

- Smolts moved through the 39 km Dalles Pool at 3.2 kmph, and did not hold during the day.

- In The Dalles Dam forebay smelts moved toward the powerhouse, then along the powerhouse wall on the Oregon side. When the spillgates were closed and sluiceway open, four of five smelts moved through the sluiceway residing in the forebay only 50 min. When the spillgates opened for nighttime juvenile passage, all fish entering the forebay passed via the spillgates and resided in the forebay from one to 5.5 h. We suspect that a north spill pattern further delays smelts in the forebay. Movement of smolts in the tailrace study area after passing the dam naturally is equivalent to what we observed for fish released below.

INTRODUCTION

A significant problem facing outmigrating juvenile salmonids is the stress, injury, and mortality possible during passage through and just below dams. Designs of juvenile bypass systems (JBS) and dam operations have been and continue to be modified to help facilitate passage. Early modifications were based primarily on modeling and flow studies, hydroacoustic monitoring of juvenile fish at dam entrances, and examination of fish condition and counts at various points within the JBS. Very little testing has been done to evaluate the effectiveness of design and operation changes on the outcome and behavior of smelts immediately after passing through the dams.

The objectives of this second year of study were to: 1) utilize the techniques and the methodology developed in 1992 to radiotrack outmigrating spring chinook salmon (*Oncorhynchus tshawytscha*) smelts in the tailrace area of The Dalles Dam and to evaluate which of the two proposed juvenile bypass outfall sites best moves smelts downstream, 2) follow smelts released into the John Day Dam tailrace to evaluate how well an existing, state of the art, bypass system disperses juvenile salmon, and 3) develop the methodology and techniques for evaluating the effect of juvenile nighttime spill pattern on smelt passage through and below The Dalles Dam.

One of the problems we needed to overcome was to develop a radiotracking methodology to follow small fish in the tailrace area of a major dam in a large river system. Our studies on the Willamette River (1989-1993) demonstrated the effectiveness of stomach-implant radio transmitters in smelts larger than 16 mm fork length (Schreck, et al. 1992) Earlier radiotelemetry work on the Columbia River, primarily by the National Marine Fisheries Service (NMFS) in the mid 1980s, determined that radiotagged chinook smelts behaved similarly to other non-tagged smelts and that telemetry could "be used to assess spill efficiency and estimate where juveniles passed through the dams (Giorgi et al., 1983; Giorgi et al., 1985; Stuehrenberg et al., 1986; Giorgi et al., 1988). Very little of their work focused on the tailrace areas. Only Giorgi et al. (1988) and Stier and Kynard (1986) tracked in the tailrace areas, undertaking transect searches for fish after they passed through dams to determine if the fish were dead or alive. Giorgi et al. (1988) could not differentiate between dead or living smelts; Stier and Kynard (1986) were able to use radiotelemetry to determine whether Atlantic salmon (*Salmo* solar) smelts were alive.

Concern with the tailrace areas of dams and the behavior and condition of juvenile fish after passing through dams has increased with increasing numbers of fish (predatory on salmon) found in the Columbia River, especially in the vicinity of dams. Poe et al. (1991) and Viggs et al. (1991) discovered that large numbers of smelts were being consumed by predatory fish, primarily northern squawfish (*Ptychocheilus oregonensis*). Maule (1988) showed that passage through dams in general, and through the JBS in particular, is stressful to fish. Mesa (1992) found that chinook juveniles that when given an agitation stress treatment were more susceptible to predation by northern squawfish. Their work pointed to the importance of the area just below dams and the condition of smelts immediately after passage, and began to account for some of the unexplained losses of juvenile salmonids between dams.

The NMFS undertook the only extensive study on juvenile salmonid mortality and outmigration in any tailrace area, concentrating on Bonneville Dam (Ledgerwood et al., 1991). Their evaluation of direct mortality caused by the juvenile bypass system, along with their long term survival study of smelts released at various sites at Bonneville Dam and sampled at Jones Beach, illuminated the difficulties of trying to pinpoint the problems associated with a

JBS. Smelts released through the JBS had surprisingly low recapture rates at Jones Beach, and nearly the same as smelts released through the turbine units. However, direct mortality measurements at the JBS outfall were also very low . This suggests that most of the smelt mortality occurs downstream of the immediate outfall sites in the tailrace area.

Our work, as part of the National Biological Survey (NBS) study on the distribution and movement patterns of northern squawfish in The Dalles Dam tailrace using radiotelemetry, is a logical next step in determining the outcome of smelts after passing through dams. By following radiotagged smelts downstream of the proposed outfall sites in the tailrace we can examine their dispersal behavior, where they hold, how fast they outmigrate, their relationship to locations of known concentrations of predators, and how these variables change with differences in stress, river condition<, and darn operations. By better understanding these factors we may begin to determine which locations and operations will best pass smelts to minimize predator-related mortality as well as gather important information on general smelt outmigration biology.

MATERIALS AND METHODS

During the 1993 field season we evaluated the dispersal behavior of six releases of radio-tagged smolts in the tailrace area of The Dalles Dam and 10 releases at the John Day Dam tailrace area. The study areas consisted of the section of the Columbia River from The Dalles Dam downstream to river marker “66” and from John Day Dam to a disposal area, both approximately 5 km below the respective dams (Figures 1 and 2).

This year we obtained fish from the NMFS gatewell sampling station (Fish Handling Facility) on the erection deck of John Day Dam, rather than through the fish barging operation from Lower Granite Dam as in 1992. This allowed us larger

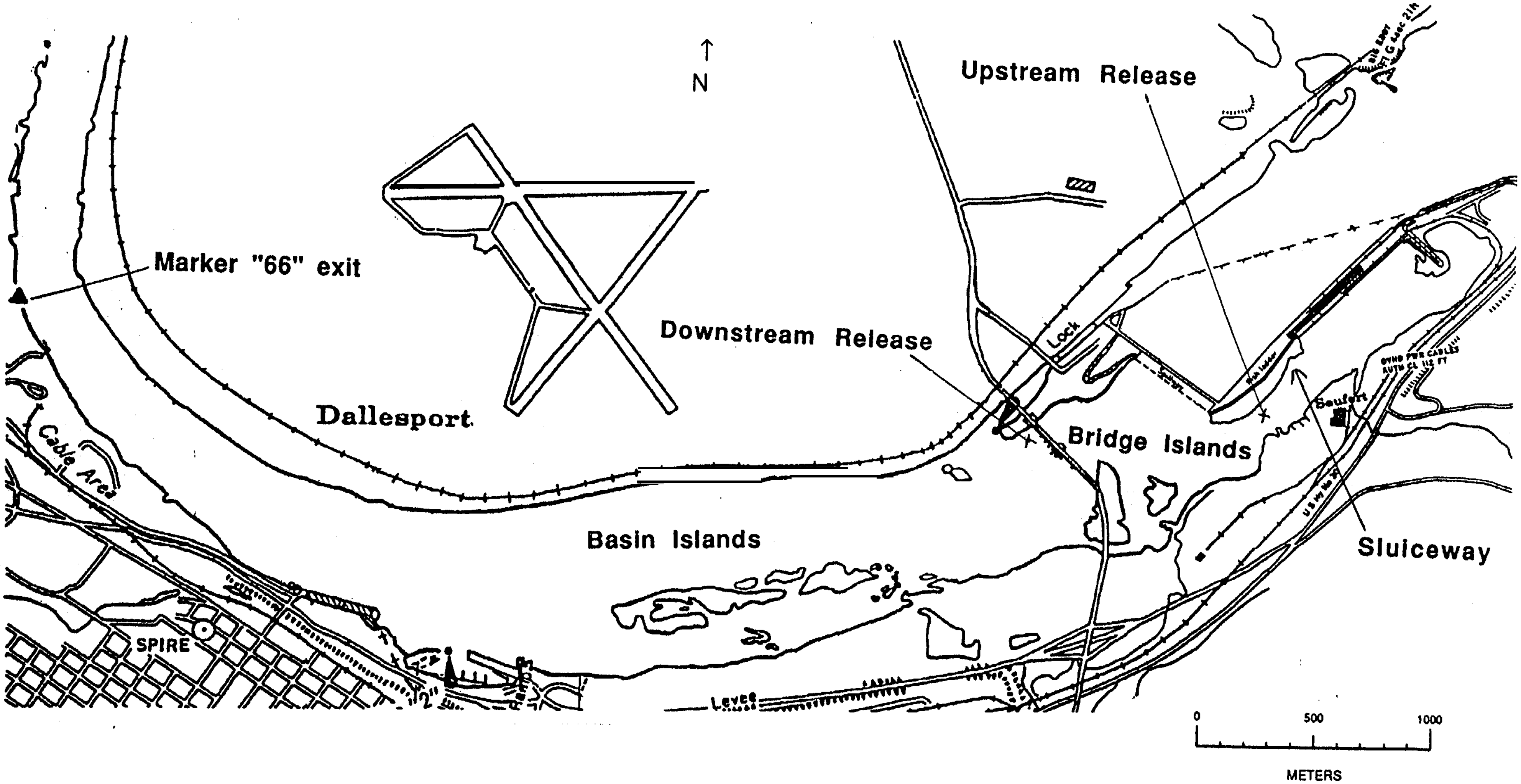


Figure 1. The Dalles Tailrace Study Area

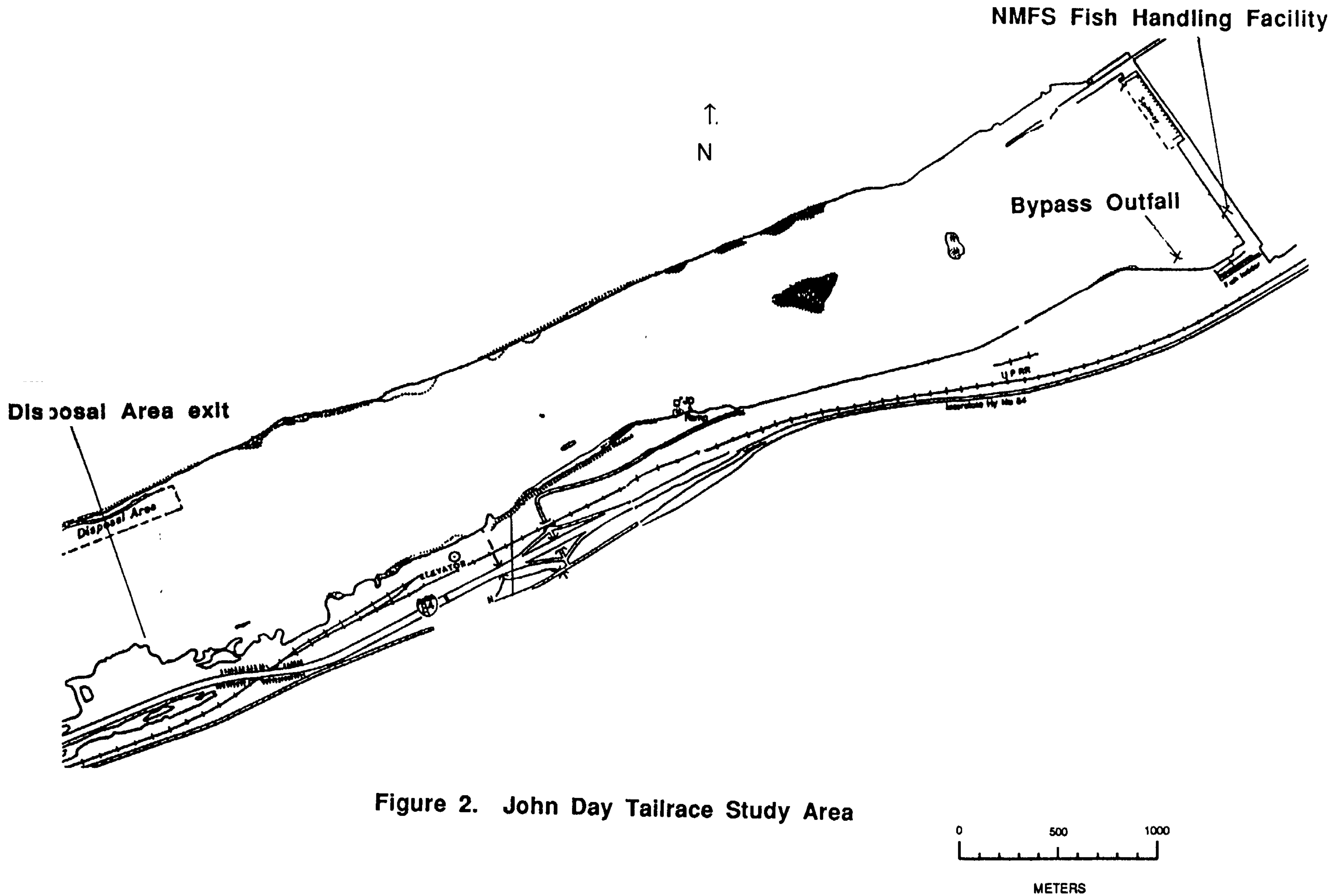


Figure 2. John Day Tailrace Study Area

fish, and fish which were not subjected to the stresses of barge ride transportation. Fish passage at John Day occurs chiefly during darkness; we obtained fish between 2100 and 2400 h. The NMFS facility samples for species composition, monitors brands, and examines fish for condition/descaling. Fish are pre-anaesthetized in a benzocaine/alcohol mixture (stock solution 151 benzocaine/ 1 alcohol; dosage 20 ml stock solution in 451 water) before they are raised from a holding tank and anaesthetized in MS 222 (Trichane methanesulfonate; stock solution 53 g trichane/ 1 water; dosage 15 ml stock solutionin601 water). We obtained hatchery reared spring chinook yearlings in the size range of 14-18 cm fork length from the NMFS fish handlers. We weighed and measured their fork lengths before implanting radio transmitters (weighing 1.3 g) in their stomachs, using a section of plastic pipette as a trochar; the length of antenna protruding from their mouth was bent to trail back. For releases at John Day, radio-tagged fish were sequestered in darkened 2001 holding tanks supplied with river water at a flow of about 10 1/ min and a density of less than 1 fish/ 201. The following day we checked the tanks for regurgitated tags, and reimplanted them if necessary (usually in previously untagged fish). For releases at The Dalles Dam fish were transported by truck immediately to The Dalles in a 2501 transport tank, and sequestered on the erection deck near turbine unit No. 22. Our holding tanks consisted of a perforated container inside an outer container with perforations only at the top. Once inside, the fish were not handled, and they were released without handling by de-watering the inner container for ease of lifting and pouring. Delayed mortality from either tagging or holding or both was always less than 5%.

At The Dalles Dam each release consisted of a group of about 10 fish liberated from a boat in the vicinity of one of the two proposed bypass outfall sites. The upstream outfall location is near mid-channel 100 meters downstream from the ice and trash sluiceway; two additional releases here were modified because spill conditions prevented the operation of our boat upstream during high flows; COE project operators reduced flow in the ice and trash sluiceway (from about 5 to 1.5 kcfs), and we released fish there about 50 m upflow from its outfall into the tailrace. The remaining three releases occurred in the vicinity of the most likely bypass outfall site on the south side of the navlock peninsula approximately 50 meters downstream from The Dalles bridge (Figure 1), hereafter referred to as the "downstream" outfall location.

Except for the two groups released directly into the ice and trash sluiceway, half of each release group underwent an additional stress treatment, seven minutes of being poured from one 201 bucket to another; our agitation-stress treatment was similar to that used by Petersen et al. (1990) except that a flexible, plastic sleeving was attached to both buckets to prevent smelts from jumping or falling from the system during pouring. The other half of each release group was untreated and used as controls for differences in smelt dispersal behavior related to differences in the stress they experience before release.

At John Day Dam five releases of about 10 fish each were made directly into the bypass channel by way of the NMFS fish handling facility release tank; half of these fish received treatment simulating the vehicle and boat ride (described below); their tank was dewatered to about 1001 and agitated once a minute for 20 min. An additional five releases were made by trucking fish from their holding area on the erection deck to a rocky beach in the tailrace. They were then transferred to a boat, motored to the outfall site, and released. Half of these fish underwent the additional stress treatment described above. The other half was not additionally stressed and used as controls for differences in smelt dispersal behavior related to differences in the amount of stress they experience before release.

A total of 139 fish were released and tracked at the two dams with release times between 0700 and 0800 h; details on fish for which we obtained location estimates and exit times are, found in Tables 1 and 2. Intensive radiotracking occurred during the 12 h immediately following release. Two tracking boats were outfitted with 4-element yagi antennae and swivel masts connected to LOTEK (Ontario, Canada) or ATS (Isanti, MN) receivers. Each boat was assigned half of the fish released that morning. With the large number of rapidly moving fish, location estimates were made quickly by carefully listening to the receivers. Accurate directions were obtained, but in order to obtain the most information, and not frighten the fish, no time was expended to pin point exact locations; the location estimates for each fish were roughly circular in shape with a diameter varying from 20 to 150 meters. These points were plotted, along with the corresponding times on maps of the area. As fish dispersed, researchers exchanged information using VHF marine radios, and crews adjusted the frequencies they were tracking, with one boat monitoring the exit of the fish from the study section and the other locating stragglers or holding fish. At both projects the boats were the primary means of establishing exit times for each fish. At The Dalles an exit monitor (an event recorder with reseacher monitoring its performance was situated on the Oregon shoreline next to river marker "66" {see Fig. 1) with a six element Yagi antenna directed straight across a narrow section of the river 4.8 km downstream of The Dalles bridge. Signal strengths were recorded every 2 min. or less for each radio-tagged fish as they passed by. The time at which the maximum signal strength occurred was considered the time the fish exited the study area; whenever possible both the boat and bank monitors confirmed the time of exit. Passage times were determined by the difference in time between when the fish were released and when they exited the study area. Passage times for the upstream released fish were adjusted for the additional 0.8 km they traveled to allow velocity comparisons between all releases. A similar exit site was established at a narrow

Table 1. The time to exit in minutes for spring chinook smelts released at The Dalles Dam in 1993

DATE/NOTES	TOTAL DISCHARGE (KCFS)	UPSTREAM LOCATION: NO ADDITIONAL STRESS	UPSTREAM LOCATION: ADDITONAL STRESS	DOWNSTREAM LOCATION: NO ADDITIONAL STRESS	DOWNSTREAM LOCATION: ADDITONAL STRESS	EFFECT ADDITIO
28-Apr	174			99	92	
				95	111	
				91	267	
				105	102	
				MEAN = 97.5	MEAN = 143	neu
30-Apr	189	274	1200			
Proposed		175	186			
Outfall		129	181			
		105	838			
			960			
		MEAN = 170.8	MEAN = 673			neutral/
17-May	396			48	46	
				44	58	
				56	57	
				45	48	
				MEAN = 48.3	MEAN = 52.3	neu
2 1-May	393	233				
Ice and Trash		21s				
Sluiceway		160				
		75				
		80				
		74				
		68				
		205				
		MEAN = 138.8				
2 5-May	355			48	58	
				48	56	
				4s	64	
				48	55	
				MEAN = 47.3	MFAN = 58,3	pos
28-May	329	11/				
Ice and Trash		97				
Sluiceway		77				
		154				
		74				
		87				
		MEAN = 101				

(1) two tailed t tests performed and ,025 arbitrarily selected as "significance level

Table 2. The time to exit in minutes for spring chinook smelts released at John Day Dam in 1993

DATE/NOTES	TOTAL DISCHARGE (KCFS)	RELEASED AT BYPASS: NO ADDITIONAL STRESS	RELEASED AT BYPASS: ADDITIONAL STRESS TO SIMULATE TRANSPORT	RELEASED AT OUTFALL: NO ADDITIONAL STRESS	RELEASED AT OUTFALL: ADDITIONAL STRESS	EFFECT OF BYPASS (1)
21-Apr-93	160			138 77 96 MEAN = 103.1		
23-Apr-93	174	94 73 70 84 MEAN = 80.3	87 88 81 97 MEAN = 88.3			neutral/positive
4-May-93	210			61 70 59 MEAN = 63.3	60 62 63 70 74 MEAN = 65.8	
6-May-93	222	69 67 63 MEAN = 66.8 68	89 na			no comparison
12-May-93	282			64 59 57 78 62 MEAN = 64	5s 80 63 MEAN = 66	
14-May-93	326	45 51 50 45 49 48 MEAN = 48	47 49 93 74 67 77 MEAN = 67.6			neutral

1-Jun-93	272			47	52	
				57	75	
				54	52	
				53	54	
					54	
					74	
				MEAN = 52.8	MEAN = 60.2	
3-Jun-93	266	52	49			neutral
		51	50			
		53	54			
		49	62			
		77				
		MEAN = 56.4	53.8			
7-Jun-93	232			66	60	
				147	68	
				101	55	
				59	55	
				MEAN -- 93.3	MEAN = 59.5	
9-Jun-93	293	53	62			neutral/positive
		56	53			
		56	53			
		49	53			
		MEAN = 53.5	MEAN= 55.3			

(1) bypass release with simulated transport stress compared with outfall release and no additional stress by two tailed t test on days with paired flow conditions, and .025 arbitrarily selected as “significance” level

point 5.2 km below the John Day Dam where the Washington shore is labeled "Disposal Area" (Fig. 2). . _.

At the start of the field season we tested the array of antemae interfaced with Lotek datalogging receivers employed in 1992 within the boat restricted zone in the tailrace above The Dalles bridge (Hwy 197). Reception zones were mapped prior to any releases of fish. Between fish variation in the exact size and shape of the reception zone occurred based on differential strength of the transmitted radio signal, the depth of the fish equipped with the transmitter, and the amount of interference present. Owing to extreme interference and the imprecision of the system, we decided that use of a second boat was important. Whenever possible when data loggers were employed, an observer monitored and validated their performance. By interpreting the strength of reception at each antenna a general location area with a diameter of 100-150 meters could sometimes be determined. As the season progressed we relied upon the antenna array less and less. At John Day Dam we also experimented with a mini-array on the island, and various single antenna sites on shore. These also proved less reliable than units overseen by observers and with boats. At both dams we backed up the boat exit monitor with bank monitor described above at the exit sites. And if fish remained in the study areas longer than we could, we set up data loggers for remote monitoring; these were successful in exiting fish only about half of the time, owing to low signal strength.

One of the major problems that outmigrating smelts face is that many of the slackwater areas in which they would rest and reorient themselves are also areas where predatory fish are abundant. How quickly smelts that are disoriented and stressed by passage through a dam reach these “holding areas”, and in what numbers, may greatly influence the number of smelts lost to predation.

For this study, "holding" by a fish was defined as that fish remaining within a 400 meter or less diameter area for a minimum of 30 min. Nettles and Gloss (1987) used similar criteria with radiotagged Atlantic salmon to decide when a fish was holding or if it had moved. In their study fish had to change their location by at least 0.5 km before they were considered to have moved.

All sites where we located fish were plotted on a map, along with the time, and used to determine movement patterns and distribution, holding areas and times, and dispersal rates. Comparisons were then made between different river conditions and release dates, fish sizes, release sites, species, and treatments by combining maps of different releases (Figures 3-11; Appendix A)

Distances traveled at 15, 30, 45, and 60 min were determined by measuring the distance between the location estimate for a fish at that time and the release site for that fish. If we were unable to locate a smelt at those exact times, an estimate was made by interpolating between the locations obtained at the closest times on either side of the target time. We assumed a constant rate of travel between these two adjacent locations.

River conditions (river flow, turbine output, and river temperature) were obtained from hourly checks made by COE personnel in the control room of each darn and averaged for the first 4 h after release (Tables 3 and 4).

Although spill testing scheduled for 1993 was canceled, we followed fish released from John Day Darn, and tracked their movements by boat around and through The Dalles Dam. A shore tracking station established the time of arrival as fish neared The Dalles forebay. Then we employed personnel on foot up and down the erection and spillway decks to establish when and where fish passed. Additionally our two boats were stationed below in the tailrace, and could thereby follow these fish in our downstream tailrace study area after they passed naturally through the project.

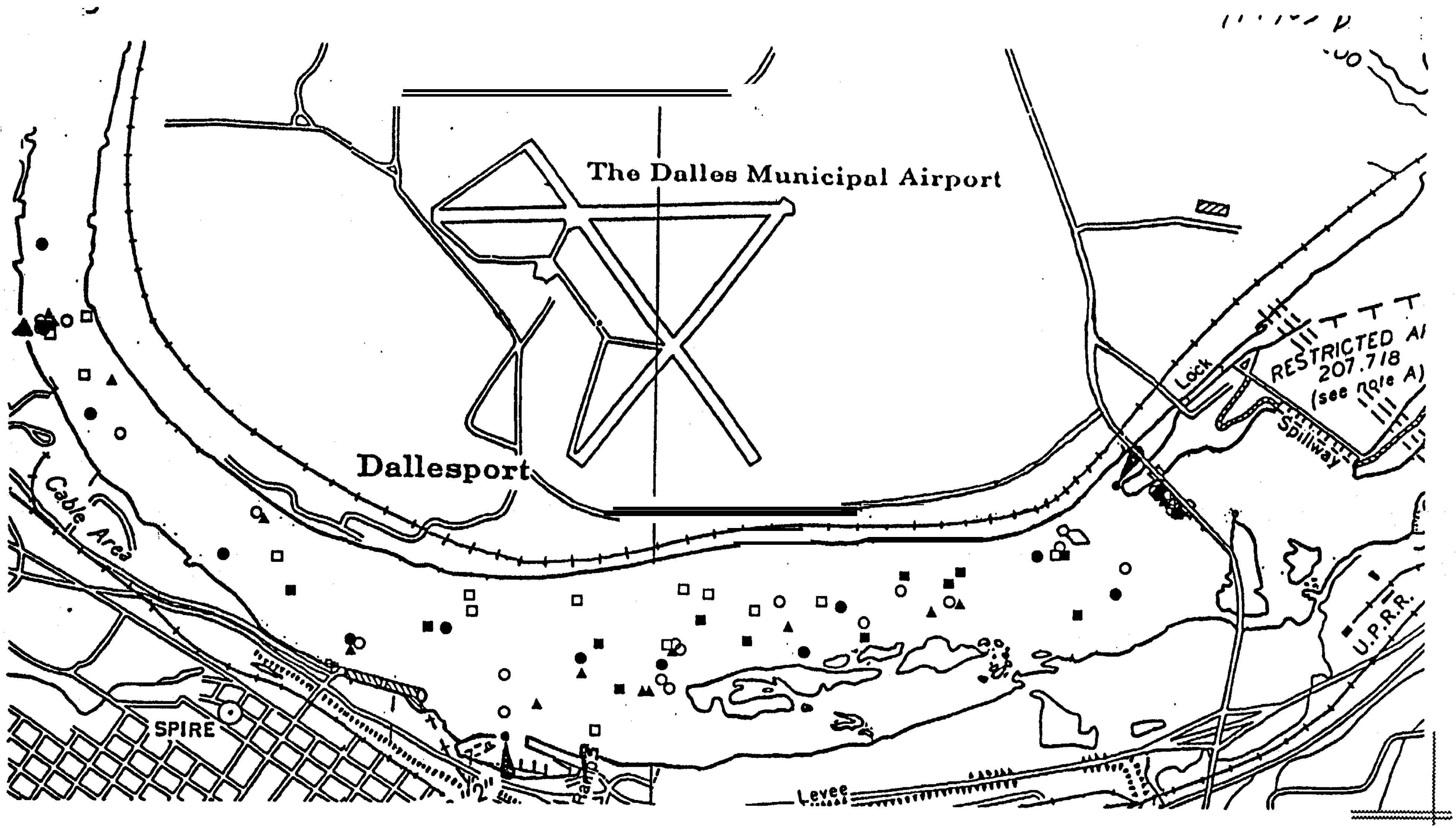


Figure 3. The Dalles Dam 1993 downstream releases 28 Apr, 17 May, 25 May non-agitated

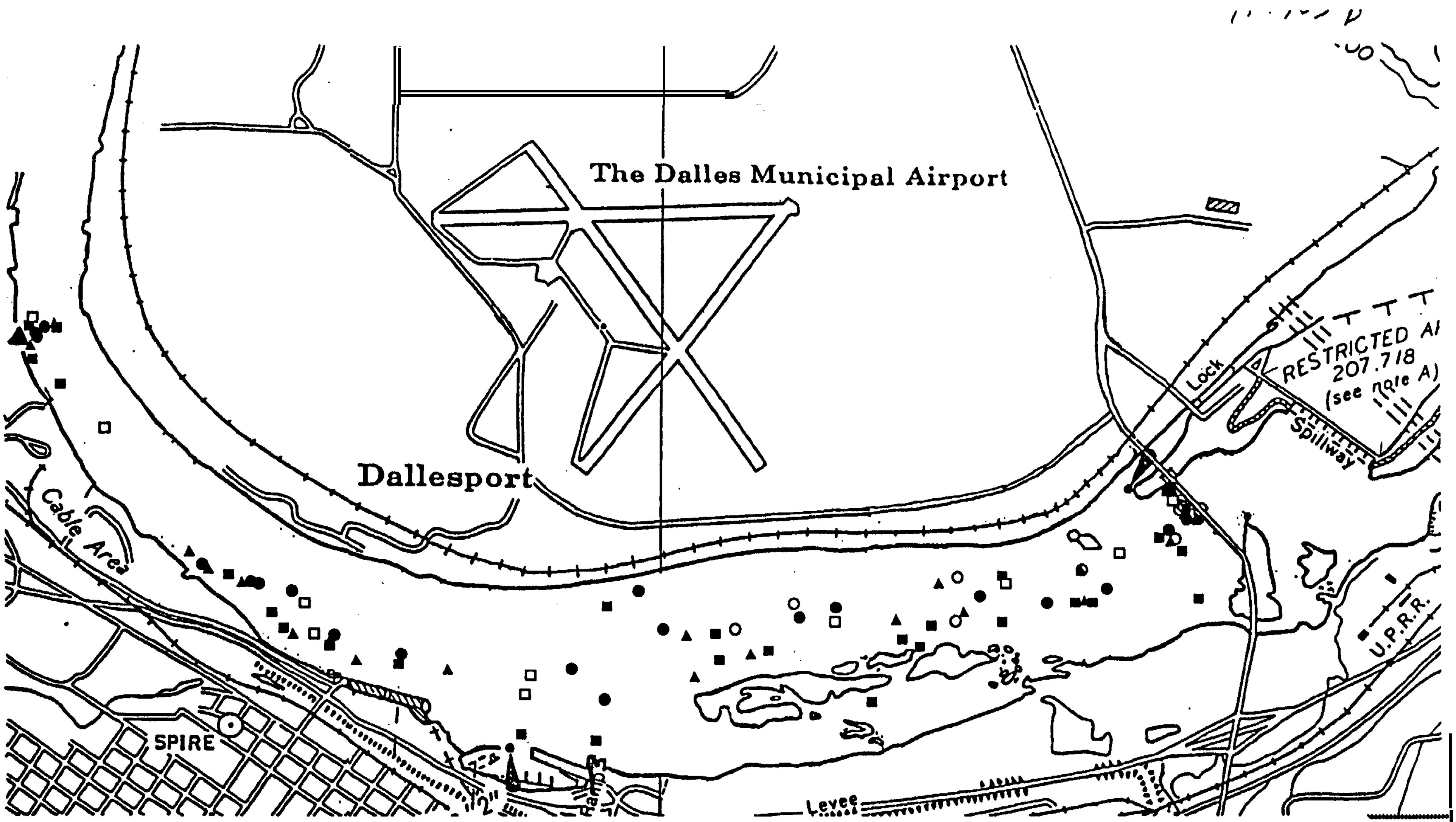


Figure 4. The Dalles Dam 1993 downstream releases 28 Apr, 17 May, 25 May agitated

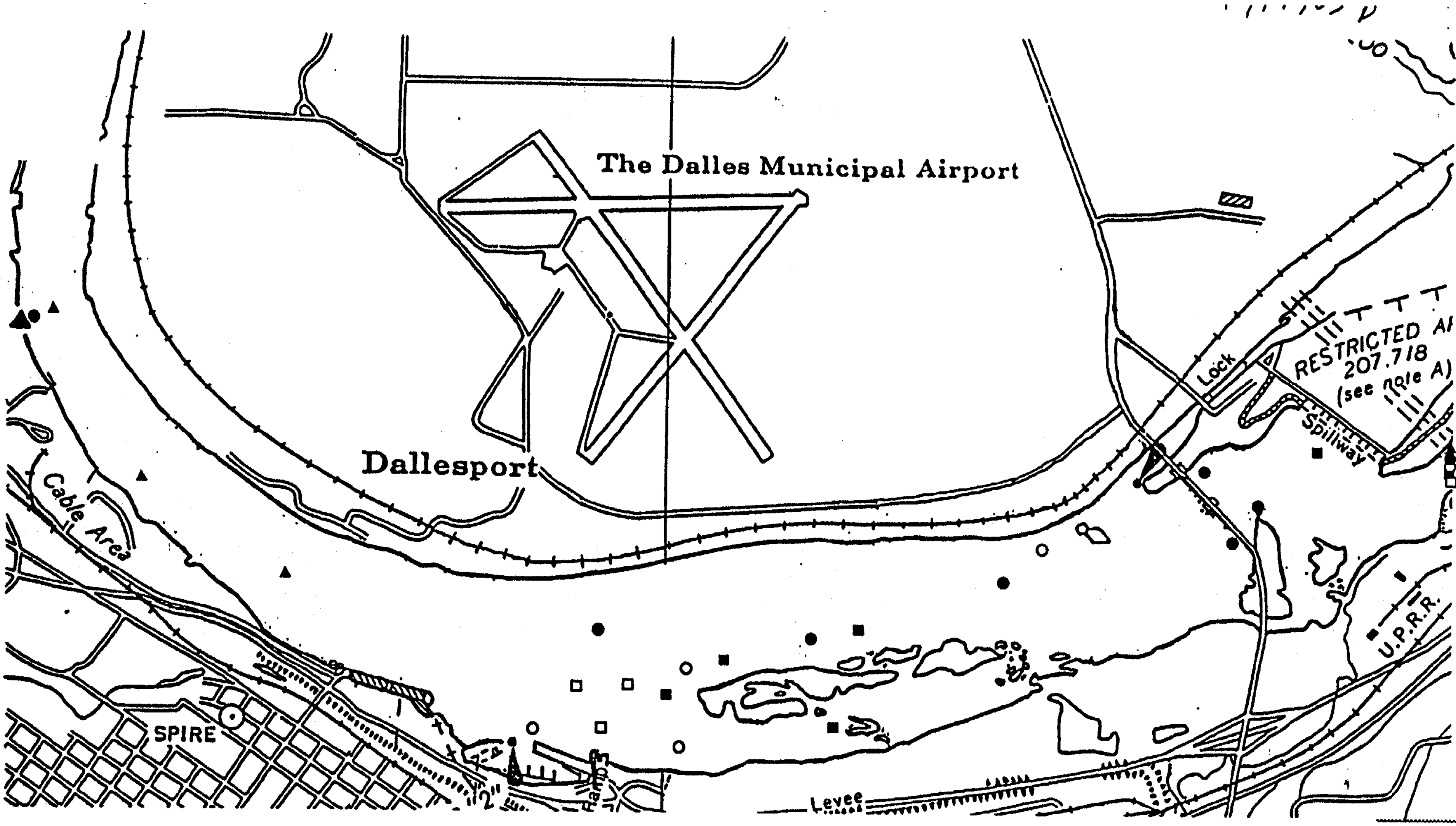


Figure 5. TDD Release 30 April 1993
upstream release at 0758
agitated

● 8.922
○ 8.353
• 8.982
□ 8.952
▲ 8.892

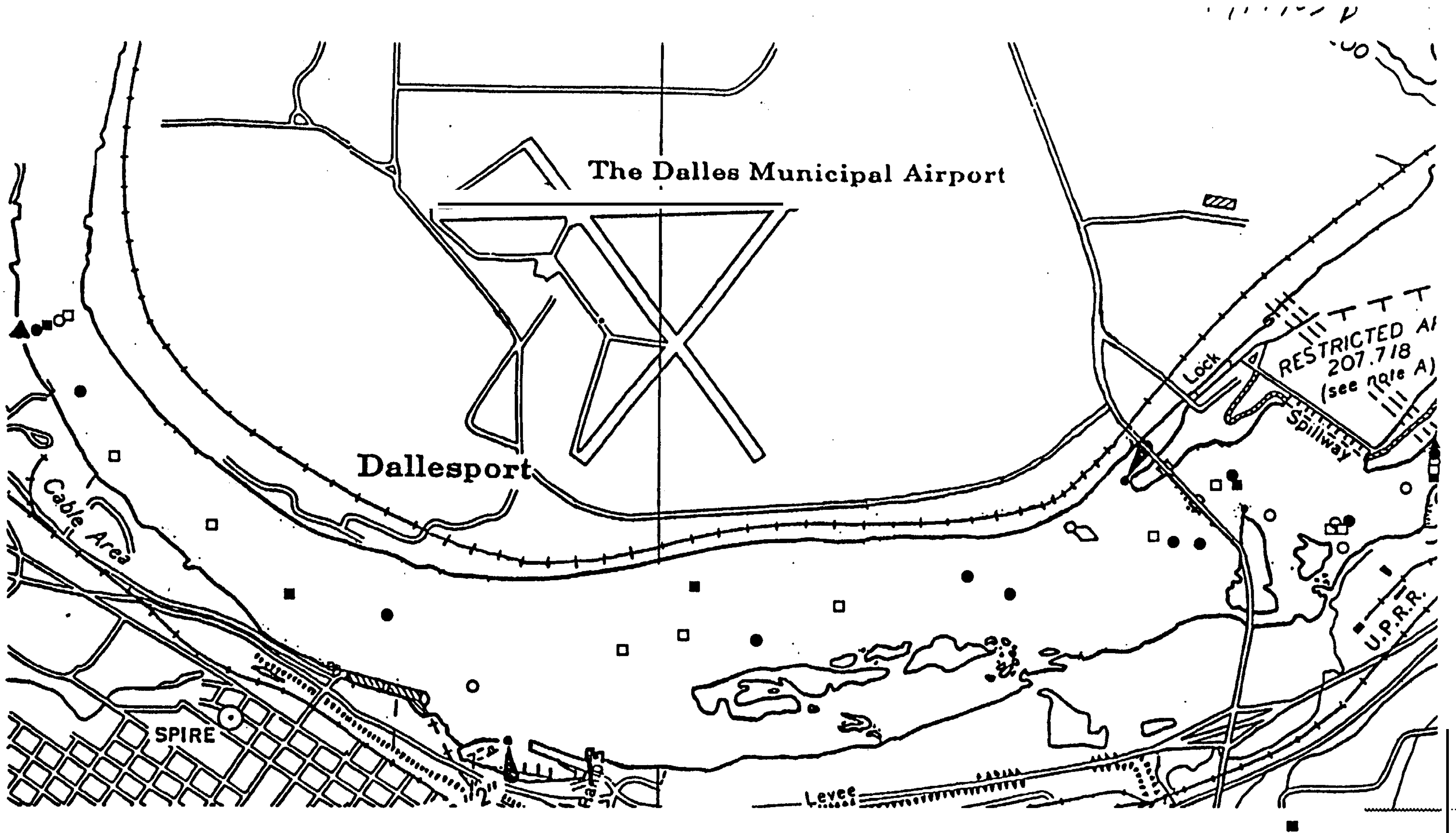


Figure 6. TDD Release 30 April 1993
upstream release at 0758
non-agitated

● 8.444
○ 8.022
■ 8.532
□ 8.652

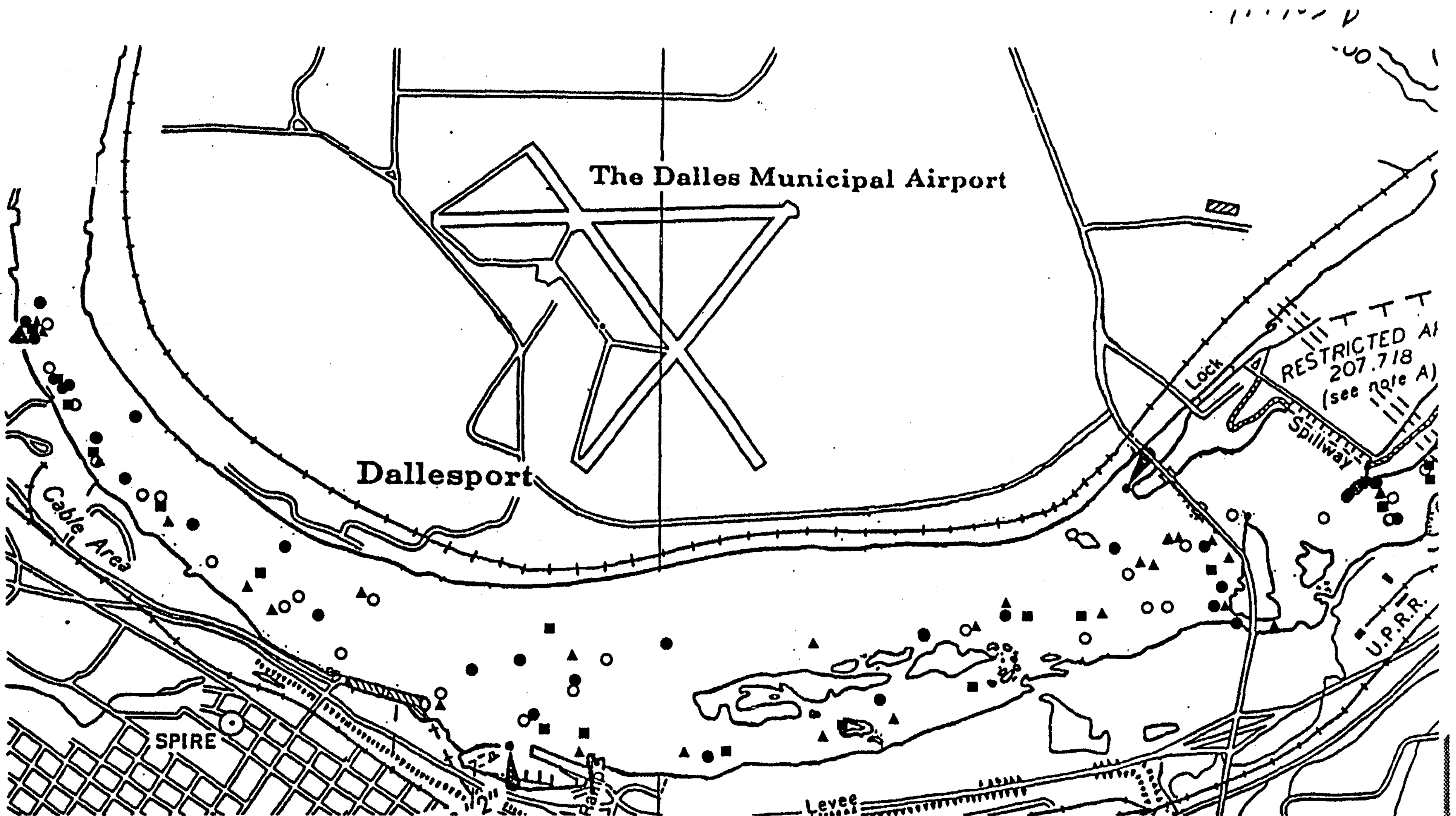


Figure 7. The Dalles Dam sluiceway releases 21 May, 28 May

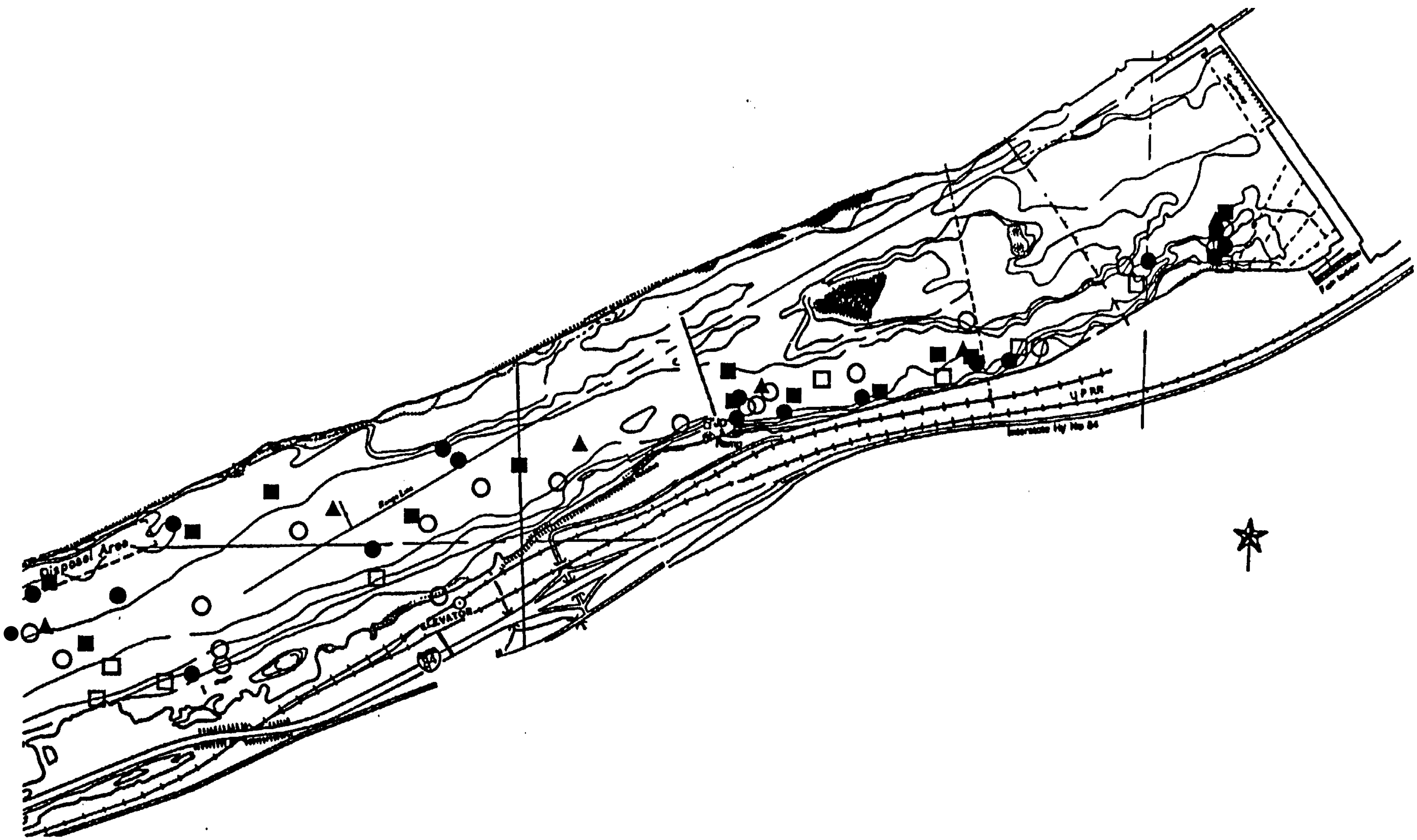


Figure 8. JDD Bypass Releases 1993
23 April, 14 May 7 June, 9 June
agitated

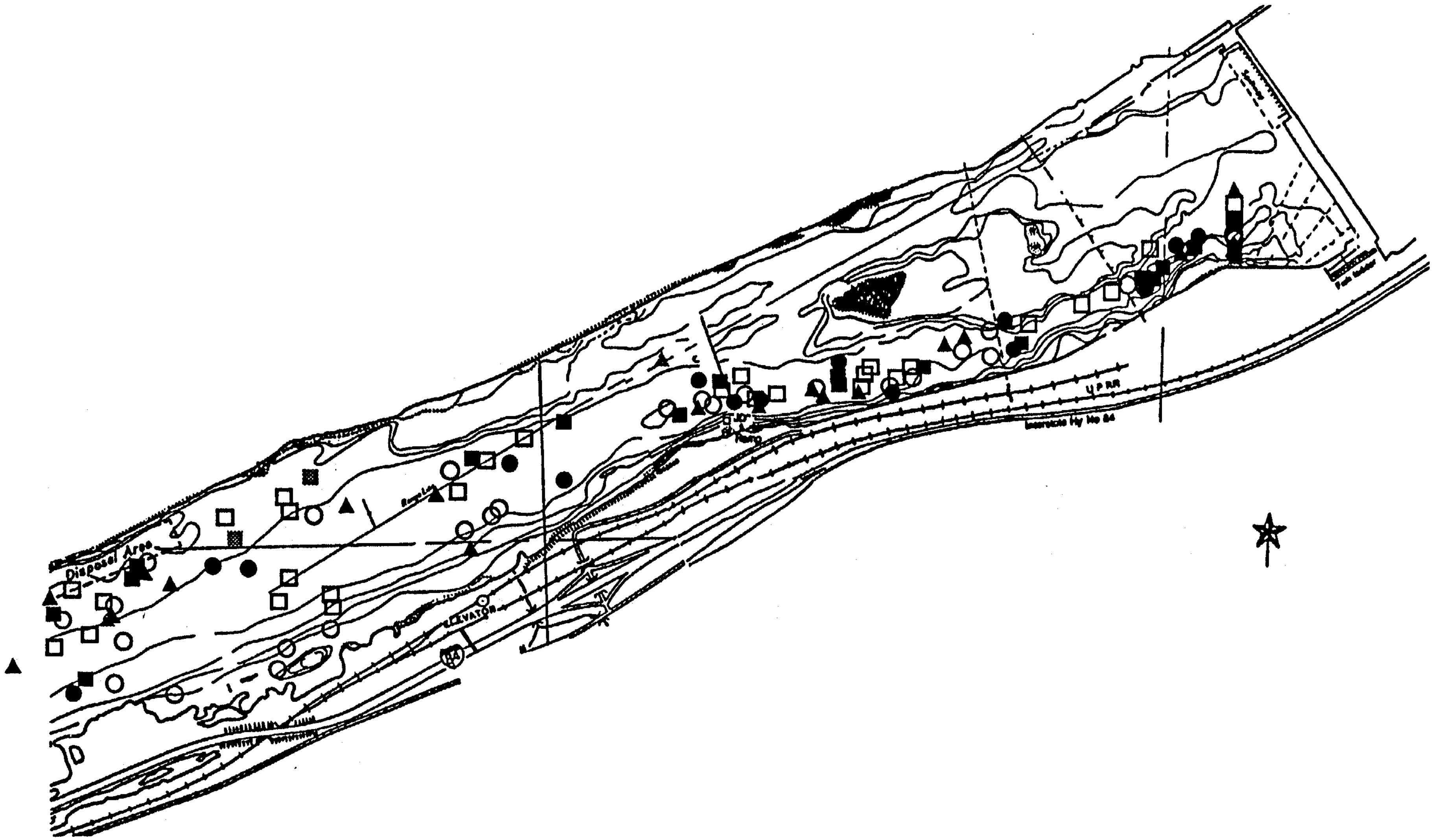


Figure 9. JDD Bypass Releases 1993
23 April, 14 May, 7 June, 9 June
non-agitated

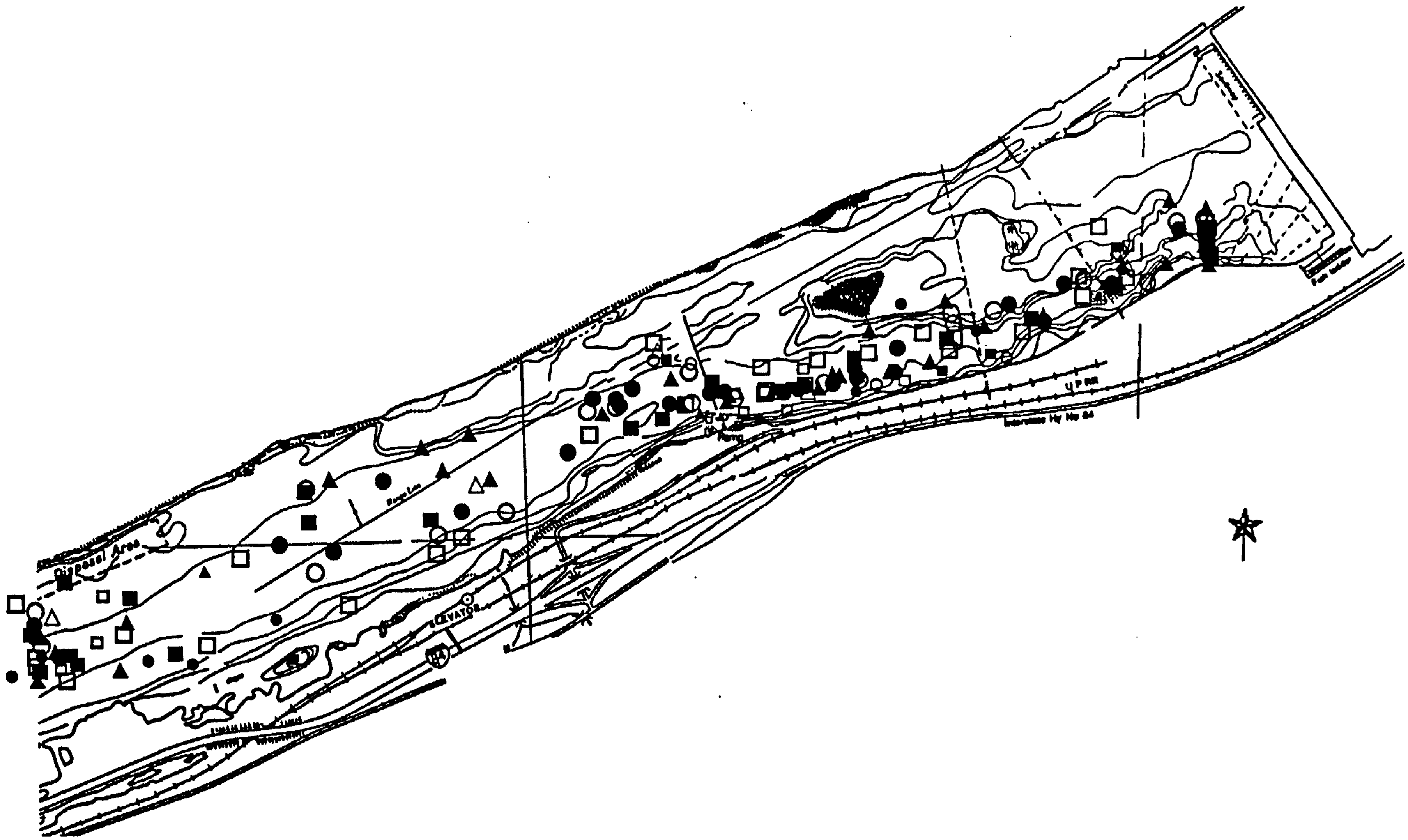


Figure 10. JDD Outfall Releases 1993
21 April, 4 May, 6 May, 12 May, 1 June, 3 June
non-agitated

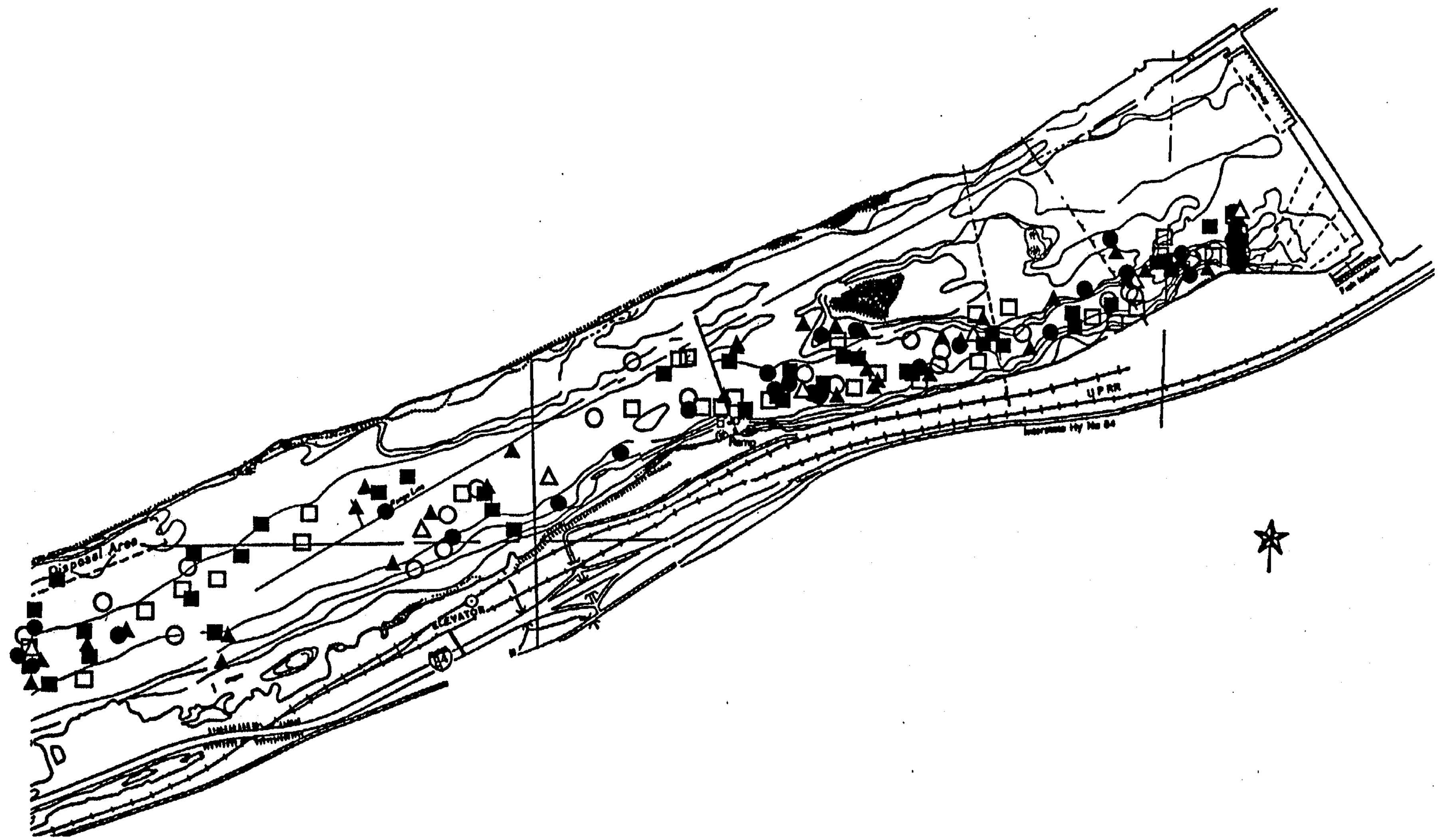


Figure 11. JDD Outfall Releases 1993
4 May, 6 May, 12 May, 1 June, 3 June
agitated

Table 3. Conditions at The Dalles Dam, g over the four hours after release of chinook salmon smolts.

DATE/LOCATION OF RELEASE	TOTAL DISCHARGE (KCFS)	TURBINE DISCHARGE (KCFS)	SPILL DISCHARGE (KCFS)	WATER TEMPERATURE (o C)
28-Apr-93 downstream	174	· 69	0	· 1
30-Apr-93 upstream	89	183	0	· 2
17-May-93 downstream	396	8[illegible]	203	13
21-May-93 sluiceway	393	2· 8	170	· 4
25-May-93 downstream	355	94	155	14
28-May-93 sluiceway	329	· 7≤	148	14

Table 4. Conditions at John Day Dam, averaged over the four hours after release of chinook salmon smelts, data provided by Corps of Engineers.

DATE/LOCATION OF RELEASE	TOTAL DISCHARGE (KCFS)	TURBINE DISCHARGE (KCFS)	SPILL DISCHARGE (KCFS)	WATER TEMPERATURE (o c)
21 APR 93/O/N	160	158	o	12
23 APR 93/B/A	174	172	0	
04 MAY 93/O/A	210	208	0	11
06 MAY 93/B/N	222	220	0	11
12 MAY 93/O/N	282	179	102	13
14 MAY 93/B/N	326	224	101	11
01 JUNE 93/o/A	272	270	0	13
03 JUNE 93/B/N	266	264	0	16
07 JUNE 93/O/N	232	236	0	16
09 JUNE 93/B/N	293	291	0	16

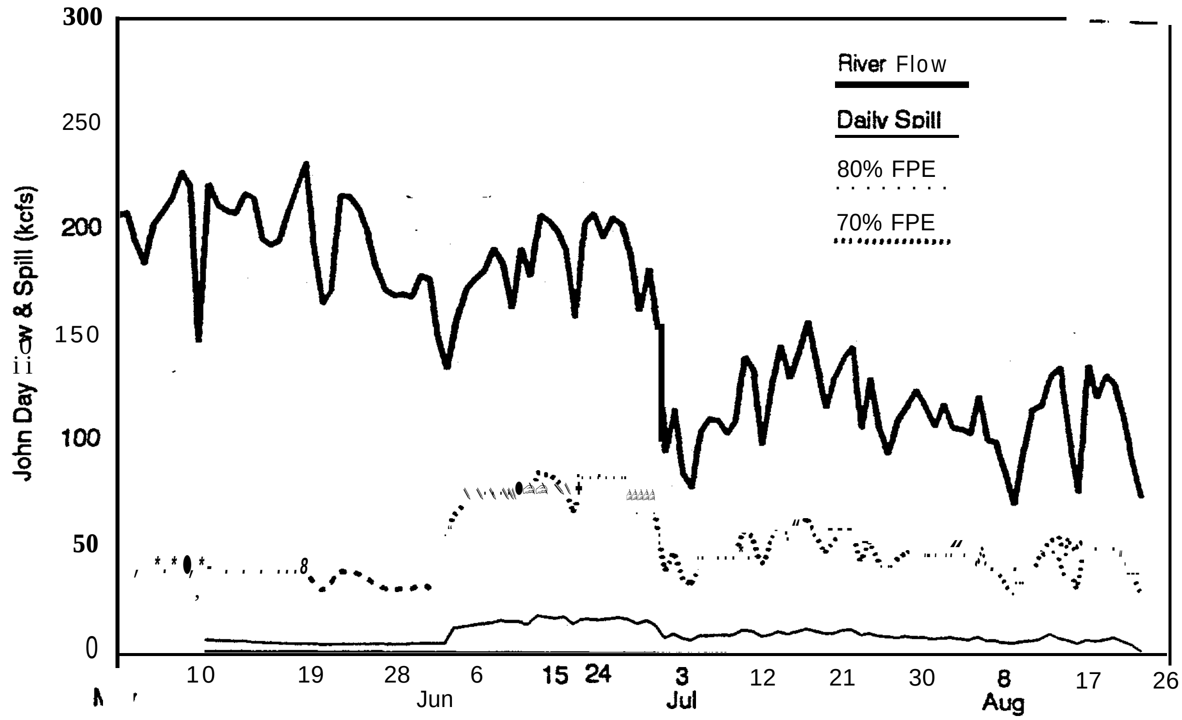
RESULTS AND DISCUSSION

Columbia River Flow at John Day and The Dalles Dams

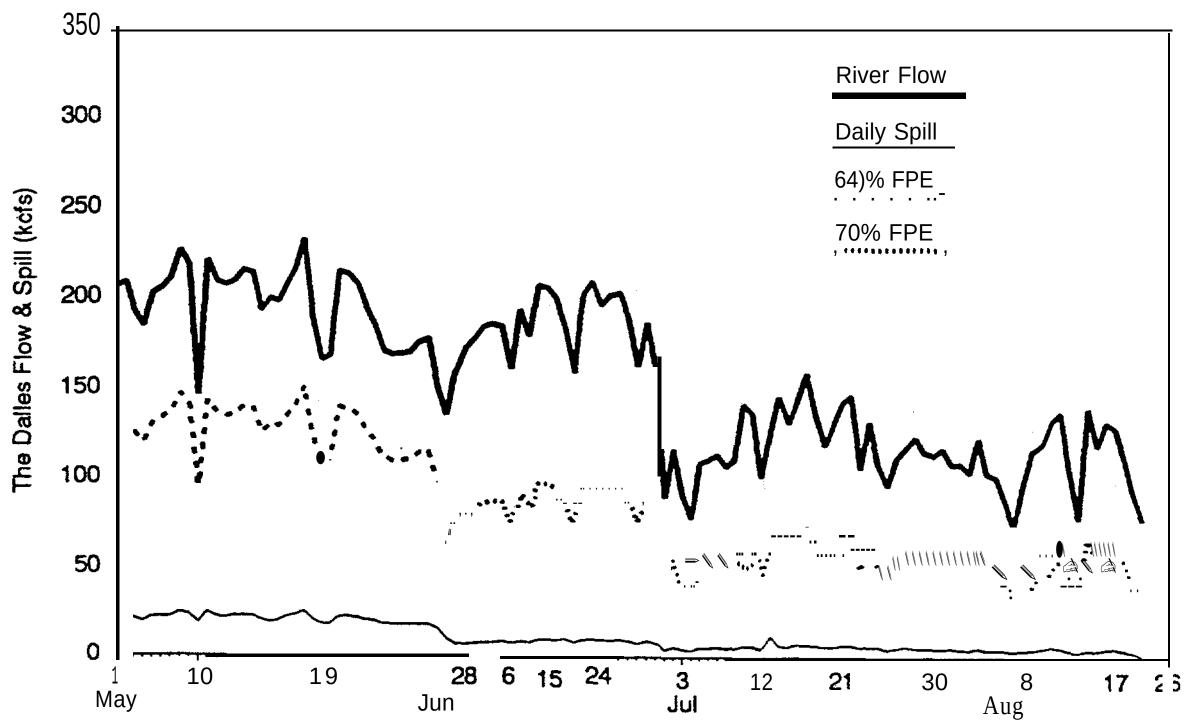
During the spring of 1993 the Lower-Columbia experienced wide variations in water flow, and with markedly greater flows than in 1992 (Tables 3 and 4, and Figures 12 and 13). Through the first week of May flows were less than 200 kcfs during our releases, but thereafter in excess of 200 kcfs; flows approached 400 kcfs during our releases in mid-May. These environmental changes provided some interesting comparisons with flow and smelt behavior with 1992, when flows rarely exceeded 200 kcfs.

Description of the Smelts Studied

A total of 352 location estimates for 50 spring chinook smelts were obtained at The Dalles Dam tailrace study area; there were 65 locations for 9 fish released upstream, 112 estimates for 16 fish released in the sluiceway, and 175 estimates for 25 fish released downstream. At the John Day study area we obtained 651 location estimates for 89 fish; there were 331 locations for 43 smelts released at the outfall and 320 locations for 46 smelts released through the bypass. The number of location estimates per fish varied from 1 to 14 at The Dalles Dam and 2 to 16 at John Day Dam depending on how rapidly the fish moved through the study area, and the weather and tracking conditions. We encountered more than 95% of the fish released; depth, transmitter failure, extreme noise interference (our study areas are electronically noisy in the upper 149 MHz range), and mortality or spitting would account for those few fish we never heard from.

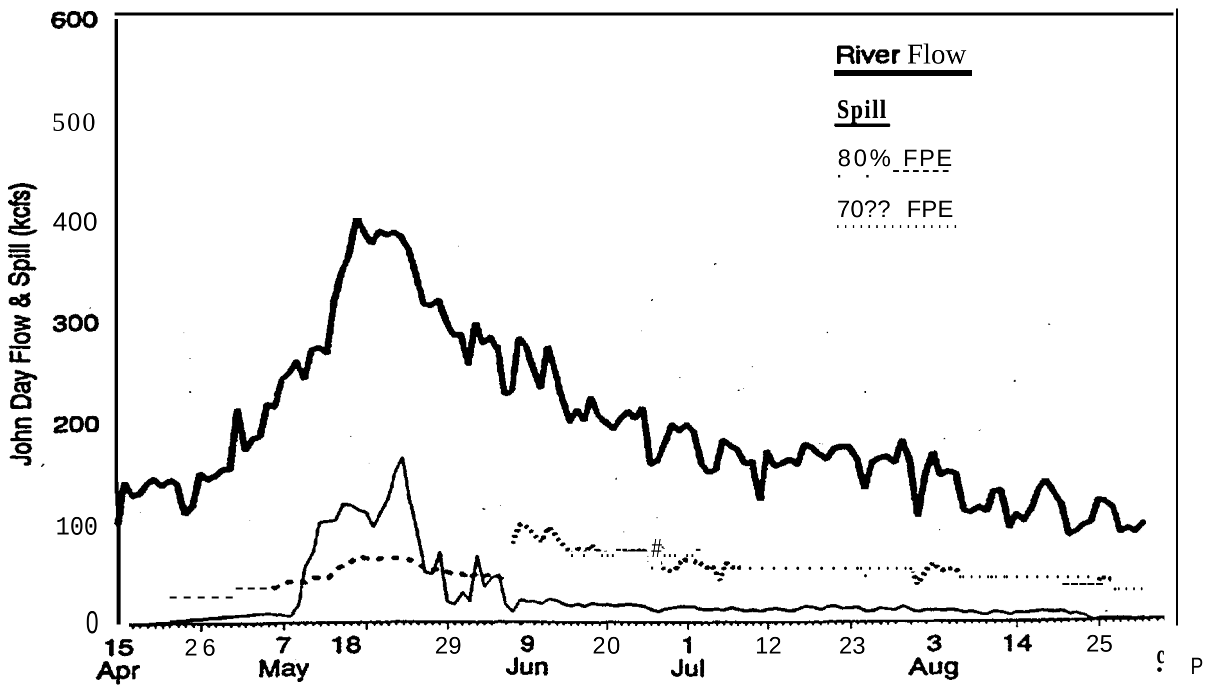


Average daily flow and spill at John Day Dam compared to the levels needed to achieve the S0/70 Fish Passage Efficiency (FPE) request.

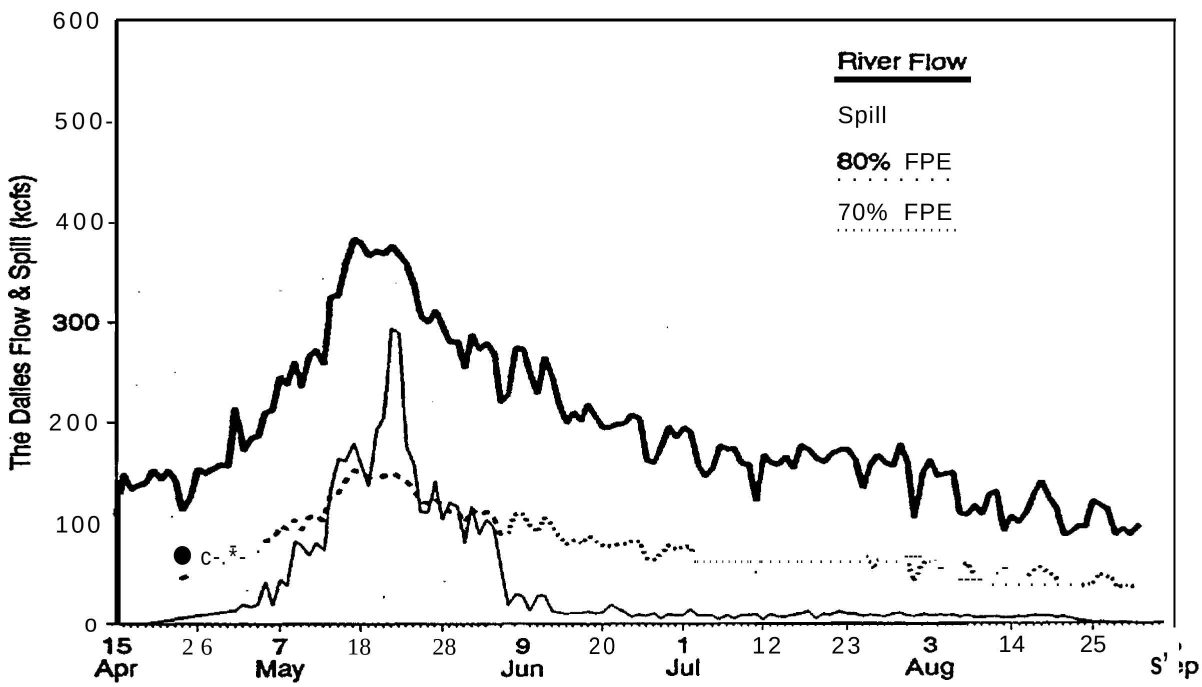


Average daily flow and spill at The Dalles Dam (10% - spring and 5% - summer) compared to the levels needed to achieve the 80/70 Fish Passage Efficiency (FPE) request.

Figure 12. Columbia River flow at The Dalles and John Day Dams for 1992. From the Annual Report of the Fish Passage Center, Portland, OR.



Average daily flow and spill at John Day Dam in 1993, compared to the levels needed to achieve the 80/70 Fish Passage Efficiency (FPE) request.



Average daily flow and spill at The Dalles Dam in 1993, compared to the levels needed to achieve the 80/70 Fish Passage Efficiency (FPE) request.

Figure 13. Columbia River flow at The Dalles and John Day Dams for 1993. From the Annual Report of the Fish Passage Center, Portland, OR.

The fork lenghts and weights of fish tagged during our studies are found in Table 5. Because of variable flows this year, we chose not to analyze the relationship between flow and fish size and passage time, dispersal rates or hoMing Likelihood. Any differences may be obscured by changes in flow, especially with our relatively small sample size for each release.

Behavior of Smelts at The Dalles Dam

Comparisons between each release showed differences for passage times depending on release site and the application of additional stresssors prior to release (Table 2). Owing to several high flow events when we were unable to release at the upstream site, releases were not replicated at the upstream location. There were differences in the number of fish holding, however. This may not be considered unusual given the differences in flow and temperature during our releases (Table 3).

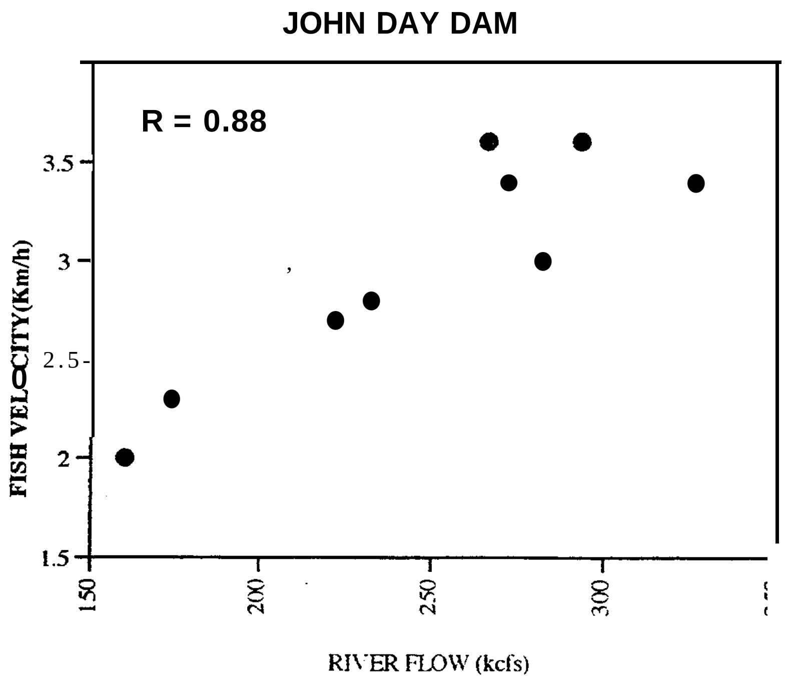
Mean passage times for individual releases of chinook smelts varied from 48 to 143 min for downstream releases, and from 101 to 673 min for upstream releases (Table 1); it is important to note that upstream releases involved an increased distance of 0.8 km, however, fish released at the downstream location traveled at from 2.0 to 6.0 kmph in the first 4.8 km after release, and fish released upstream traveled at from 0.5 to 3.3 kmph in the first 5.6 km. These rates of travel are faster than we reported for steelhead trout (*Oncorhynchus mykiss)* smelts in 1992 and those reported by Schreck et al. (1992).

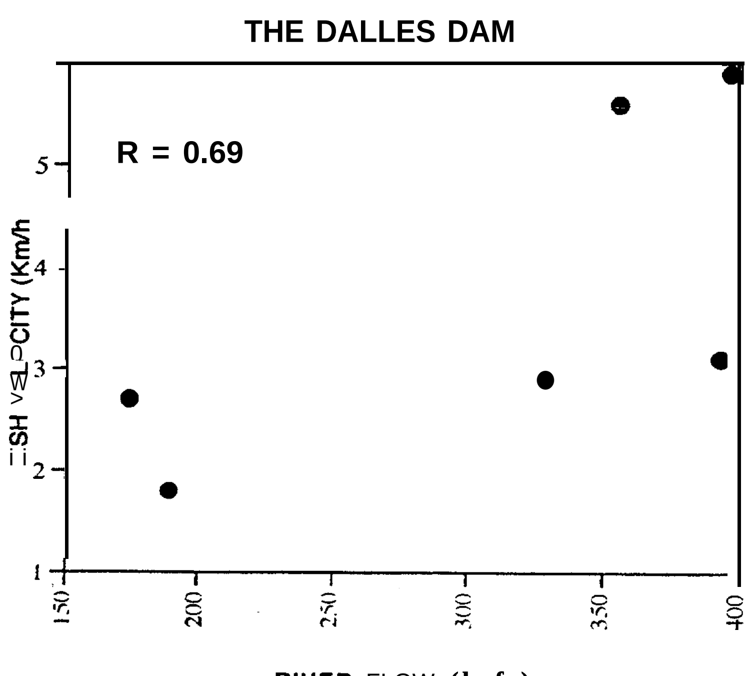
As we have reported with spring chinook migrating below Bonneville Dam (Schreck et al. 1992) there is a strong correlation (R=0.69) between migration velocity of smelts and flow below The Dalles Dam (Figure 14).

Additional stress significantly influenced holding (remaining in a 0.4 km area longer than 30 rein) in smelts released either upstream or downstream; the only

Table 5. Size and weight of yearling spring chinook smelts implanted with radio transmitters in 1993

	FORK LENGTH (cm)	WEIGHT **(g)**	NUMBER TAGGED
THE **DALLES DAM**			
UPSTREAM RELEASE			
ADDITIONAL STRESS	17,0	50.0	5
NOT STRESSED	17.2	51,6	4
DOWNSTREAM RELEASE			
ADDITIONAL STRESS	15.0	31.4	13
NOT STRESSED	16.2	42.9	12
LOWER SLUICEWAY RELEASE	15,0	33,0	17
JOHN DAY DAM			
OUTFALL RELEASE			
ADDITIONAL STRESS	16,3	42.7	20
NOT STRESSED	16.2	44.8	25
BYPASS RELEASE			
ADDITIONAL STRESS	15,7	37,6	26
NOT STRESSED	15.5	38.2	25


JOHN DAY DAM
R = 0.88
FISH VELOCITY(Km/h)
3.5
3
2.5
2
1.5
150
200
250
300
RIVER FLOW (kcfs)


THE DALLES DAM
R = 0.69
5
4
3
2
1
150
200
250
300
350
400

fish which held had received additional stress; 1 of 13 (8%) for three downstream releases and 3 of 5 (60%) for one upstream release. Five of 16 (31%) smelts from two releases into the sluiceway held (Table 6). Holding times varied between 0.5 h (3 fish) and 9-10 h (6 fish). Smelts released upstream were four times more likely to hold than those released downstream. Apparently the majority of fish which held did so for several hours, suggesting a major change in downstream movement. In 1992 we observed a similar tendency of additionally stressed steelhead smelts to hold. The tendency of steelhead to hold was just as likely whether released upstream or downstream; this difference with chinook in 1993 may be the result of increased flows, especially from the spillway.

As in 1992 for steelhead, holding areas for chinook in 1993 were confined to the area above the Bridge Islands in a large counterclockwise eddy, and the downstream half of the Basin Islands within the Marina area (Figure 1). Fish released downstream were physically unable to hold in the Bridge Island area because water currents forced them to move downstream. The maps showing the distribution of all the locations where we found chinook smelts (Figures 3- 7; 16 and 17) indicate these two island groups as heavy use areas.

The single smelt which held from a downstream release did so after moving for 30 min. Three fish holding after upstream release did so after a mean travel time of 40 min. All fish holding after sluiceway releases did so after only 7 min of travel. Similar differences were found to be significant with steelhead smelts in 1992.

Data from only one release of smelts released upstream, and two sluiceway release groups show significantly slower dispersal than fish from three releases at the downstream site in the first 15, 30, 45 and 60 minutes after release (Figure 15). Overall, the fish tended to spread out over time following release. In 1992, while

Table 6. Spring Chinook Smelts Holding (less than 400 m area greather than 30 min.) at The Dalles Dam, 1993

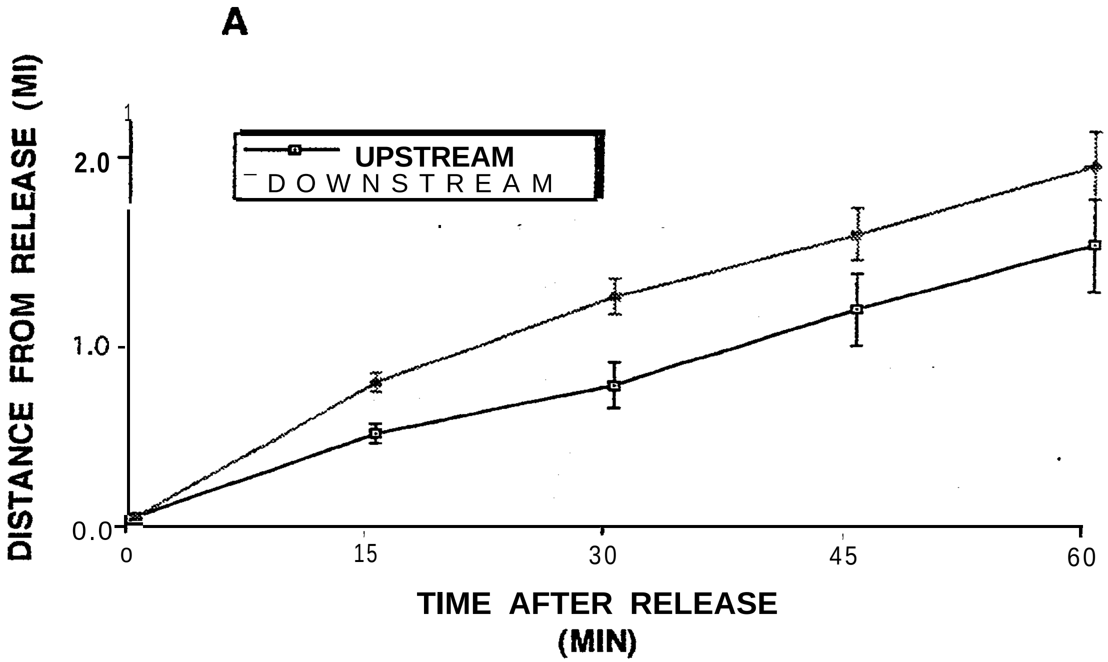
Smelts **released below the dam during daylight**

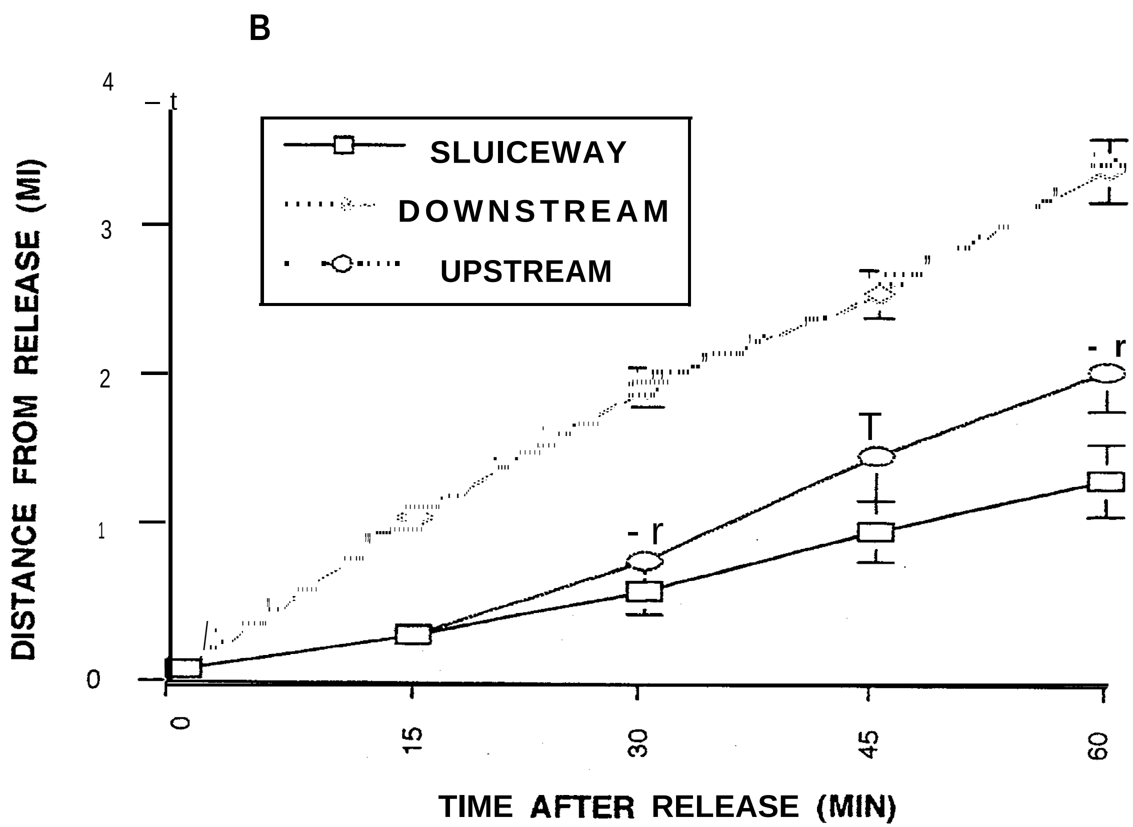
	additional stress	no additional stress	Time to First Hold (rein)	Holding Duration (hours)
Downstream Release	1/13 = 8%	0/12	30	10
Upstream Release	3/5 = 60%	0/4	40	10 ,
Sluiceway Release (lower 100 m)	5/16 = 31%	na	7	4

smelts held in area of **Bridge or Basin Islands**
all smelts holding above bridge were released at the upstream or sluiceway sluiceway locations

Smelts released at John Day Dam and followed through **The Dalles Dam in the evening as run-of-river fish**

passed through ice and trash sluiceway	passed through spillgates
2/5 = 40%	2/9 = 22%
1 ea held above and below Bridge	1 held at Basin, 1 at exit under COE fish barge!


A
UPSTREAM
DOWNSTREAM
DISTANCE FROM RELEASE (MI)
2.0
1.0
0.0
0
15
30
45
60
TIME AFTER RELEASE
(MIN)


B
SLUICEWAY
DOWNSTREAM
UPSTREAM
DISTANCE FROM RELEASE (MI)
4
3
2
1
0
0
15
30
45
60
TIME AFTER RELEASE (MIN)

the same trend was evident for steelhead smelts, only differences at 15 and 30 min. were significant.

Once at a similar point in the river, the outmigration routes used by the chinook smelts do not show differences between treatment groups with respect to release site, or the application of additional stress (Figures 3- 7; Appendix A). Fish generally traveled in the deep river channel at from 3 to 10 m deep; but we located some fish distributed across the width of the channel. Fish released from the sluiceway, of which 31% held, seemed to concentrate their movement near the Oregon shore (in the Basin Islands), however (Figures 17 and 18).

Unlike in 1992 with steelhead, we have no evidence of chinook being predated; no chinook moved upstream against the current. Only three of the fish which held did not subsequently exit the study area; these may have been missed by the data logger at the exit site, for depth and distance were major factors in the reliability of this system capturing fish which passed. Two fish released from the lower sluiceway on one release date held in a pool above the Bridge Islands, and we never detected their exit. A careful search of the area in subsequent days did not detect these transmitters, so we assume the smelts did indeed exit or their tags drifted too deep to be detected.

Our data show that a third of all the chinook smelts we released upstream, but only 4% of those that we released downstream, searched out a place to hold following release. If this behavior is typical then during high flow conditions at The Dalles Dam smelts released at the proposed downstream outfall site should be relatively immune to predation in holding areas immediately below the dam. On

sluiceway are

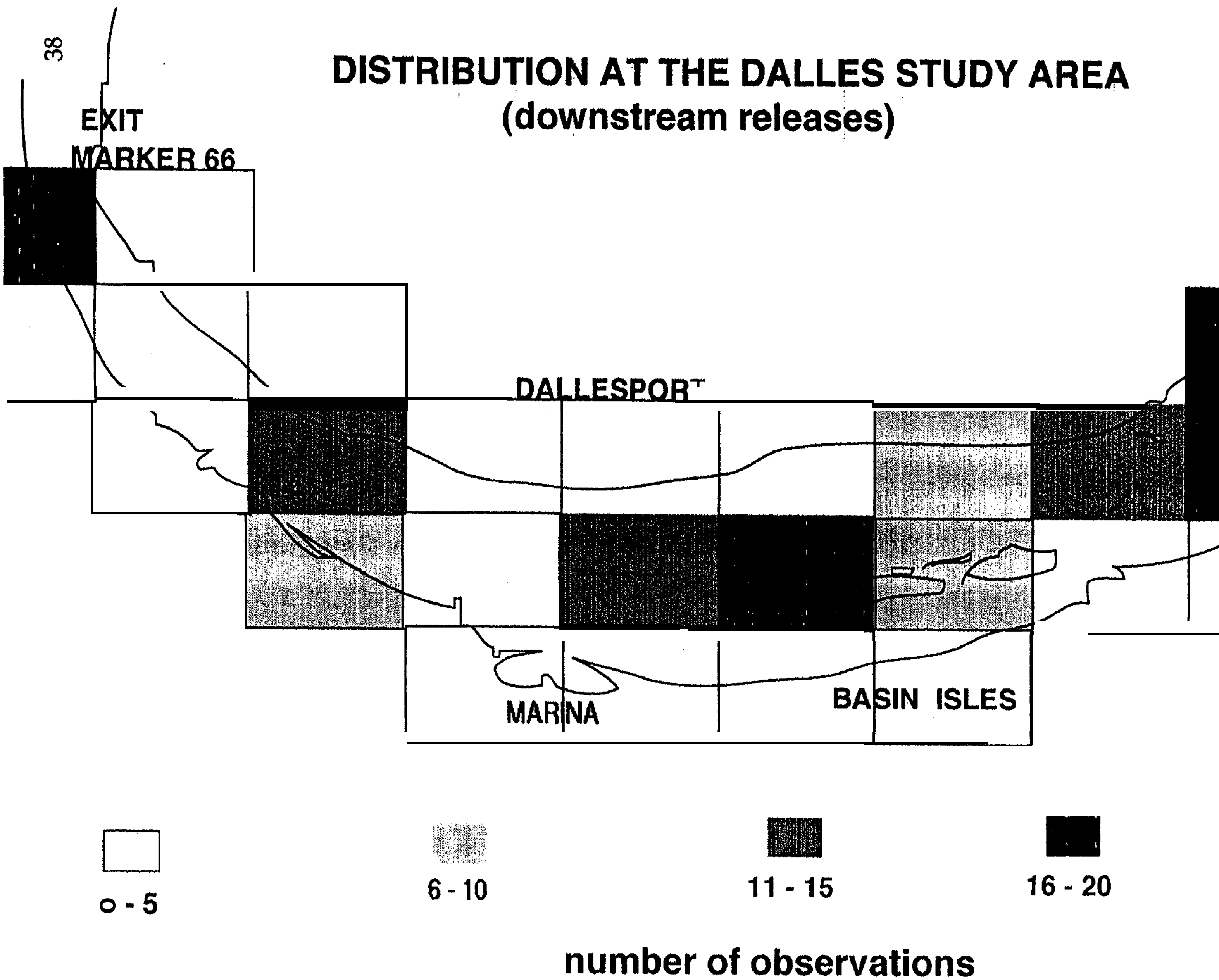


Figure 17. The distribution of observations of radio-tagged spring chinook smo
Dalles Dam tailrace study area based on a 400 X 600 m grid overlay.

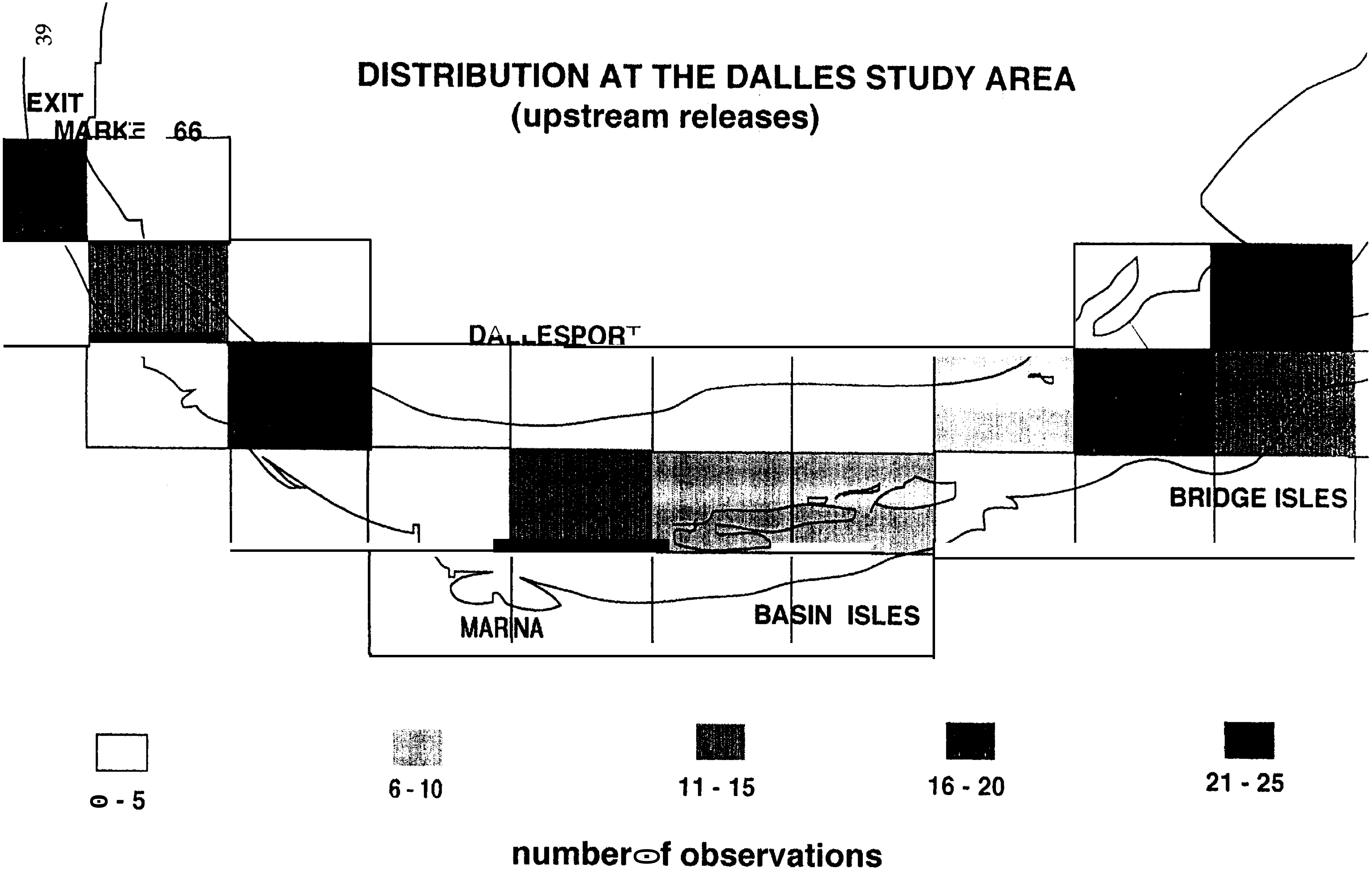


Figure 18. The distribution of observations of radio-tagged spring chinook smolts in The Dalles Dam tailrace study area based on a 400 X 600 m grid overlay.

The location of bypass outfalls, or any other location where fish pass through dams, and the influence of dam operations on river flows maybe critical to the effects of predation on outmigrating salmonids. In our study, chinook smelts released at the upstream site had half as far to travel and less than one-third the time before reaching their first holding area. The surface currents in that area rapidly moved into a series of turns, which potentially could move many of the smelts into an area of rocks and abundant pockets of relatively still water, especially if they are searching for a place to hold. Stress may compound this problem, since only fish receiving an additional stress held.

Similar holding tendencies and predation problems may exist in any area below a major stressor, such as waterfalls and irrigation diversions.

Behavior of Smelts Released below John Day Dam

The times to exit (mean passage times) varied between 48 and 103 min for chinook smelts released below John Day Dam (Table 2). Thus fish released in the John Day tailrace outmigrate over the 5.2 km study area at from 1.9 to 4.0 kmph. This is equivalent to that of fish released downstream at The Dalles and is probably characteristic of fish moving in a relatively straight, uncomplicated section of the Lower-Columbia River.

As we have reported with spring chinook migrating below Bonneville Dam (Schreck et al. 1992) there is also a strong correlation (R=0.88) between migration velocity of smelts and flow below John Day Dam (Figure 14).

Again because of increasing total discharge (river flow) during our releases, and the known importance of flow on fish outmigration velocity, we have chosen not to pool the data. Mean passage times for fish released through the bypass were from 48 to 89 min.; fish in each release which received additional stress simulating vehicular transportation around the project required more time to exit than their replicates. Mean passage times for fish released at the outfall were from 63 to 101 min.; again fish which received additional stress took slightly longer to exit. There were no apparent differences in the distance traveled (at 15 min. intervals during the first hour) between smelts released at the outfall or through the bypass (Figure 19).

A significant objective in our studies at John Day is to evaluate the performance of a "state of the art" bypass system. Fish released through the bypass system after receiving simulated transport stress were compared with fish transported and released at the outfall to isolate the effect of the bypass alone (Table 2). While these differences are not significant (*t* test), owing to small sample size, they suggest that fish released through the bypass move out of the tailrace area more rapidly than those released at the outfall, especially during flows less than 200 kcfs. Defining these differences more clearly will be a high priority for the 1994 field season.

Only two of 89 fish (2%) held in the John Day tailrace study area; both were released at the outfall and without additional stress; and both held in an area 4.5 km below the dam in a pool 7 m deep where we recorded fish of varying size on the depth finder, and where commercial fishing guides concentrate their efforts. One held during high flow (after traveling for 109 rein), and one held at low flow (traveling 128 min before holding). As we observed with fish holding in the Marina area at the Dalles, fish often held during the day, then moved downstream just after dark.

Our data strongly suggest that chinook smelts do not stop to rest or recuperate in the first 4 km below John Day, and therefore may not be vulnerable to ambush

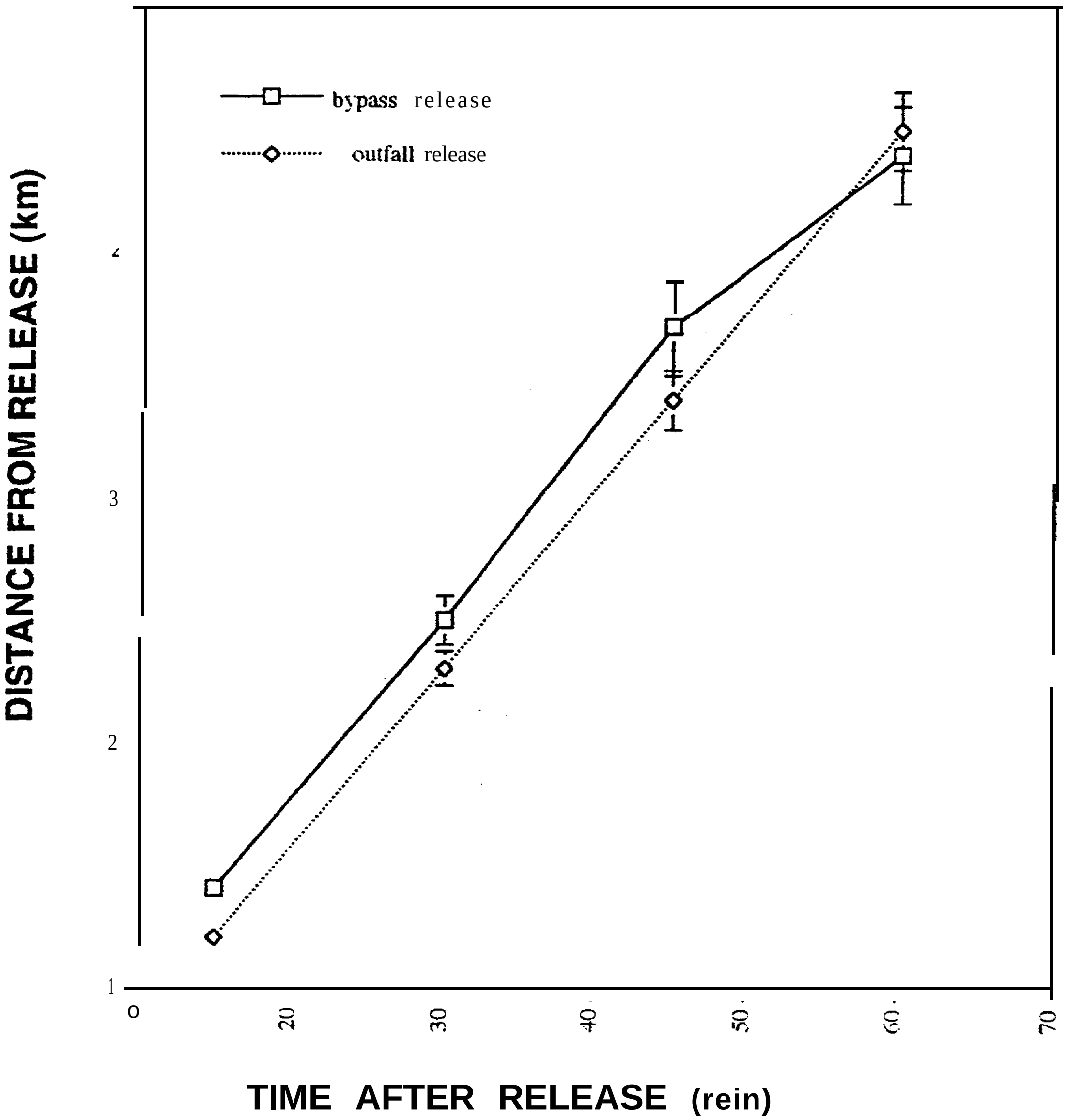


Figure 19. The distance traveled in kilometers (mean and standard error) **for spring chinook smolts released through the bypass and at the outfall in the John Day Dam tailrace study area, 1993.**

predators there. We believe that the linear nature of the John Day tailrace area is a chief factor in affecting fish behavior there.

The dispersal patterns of chinook smelts released below John Day are similar and unrelated to release method or the application of additional stress. Smelts followed the main flow from the powerhouse in the Oregon half of the river until they reached the downstream end of the island. Thereafter they spread out across the river, with perhaps the majority of fish in the Washington half at the exit site (Figures 8- 11; Appendix A). The tendency of fish to spread out at the exit area which we saw at The Dalles in 1992 and 1993, was even more evident at John Day.

We have no evidence of radiotagged smelts being predated in the John Day tailrace study area. Owing to the lack holding behavior we were able to concentrate effort on those two fish which did. Both exited the area in a manner consistent with normal outmigration.

Movement of Smelts through The Dalles Pool, around The Dalles Dam, and in the tailrace area below

Growing concern over the effectiveness of passing outmigrating juvenile salmonids using the current spill pattern at The Dalles Dam was heightened by the results of preliminary tests we conducted in 1993. Historically and based on studies of smelt density, The Dalles Dam spilled during the nighttime hours and at the south end of the spillway for juvenile passage. Recently, with concern about predation of smelts in the tailrace area, this spill pattern was re-evaluated by NMFS and the Fish Passage Advisory Committee (FPAC). Although spilling from the south end of the spillway is effective at quickly moving fish from the forebay to the tailrace, modeling at the Corps of Engineers (COE) Vicksberg, MS laboratory showed that at low flows the predominate current may push smelts into the Bridge Island area at the south end of The Dalles Bridge where they might be more susceptible to predation. Consequently, the present nighttime spill pattern for juvenile passage is from north spill gates. The effectiveness of using spill from the north gates to collect smelts from the forebay and quickly pass them downstream through the main flow channel needs to be more carefully investigated.

In 1993 we were able to establish the feasibility of following radio-tagged chinook salmon smelts from John Day Dam through the 39 km Dalles (Celilo) Pool and then tracking them through The Dalles Dam project. From a sample of about 50 fish, we established that smelts covered this river reach at speeds of about 3.2 kmph and usually did not stop before arriving at The Dalles. We critically examined the behavior of 14 fish for which we have complete data; viz. exact time of arrival at The Dalles forebay, and time and route of passage through the project. Four smelts which reached the forebay before 2000 h, prior to nighttime spill for juveniles, resided there for 50 min. on average, and all exited through the ice and trash sluiceway (Table 7, Figure 21). Whereas 10 smelts which arrived later than 2000 h remained in the forebay for 101 min. (average), and all but one exited through spillway gates 9-12 (middle to south). Several other fish, for which we did not obtain complete entry and exit data, resided a minimum of 1 to 5.5 hours in the forebay before exiting. Movement tracks of representative fish (Figure ~~15~~ 21), show that all fish are attracted to the main flow through the turbines. Those exiting via the ice and trash sluiceway make a left turn directly. During the present north spill pattern" fish which exited by spillway were initially attracted to the south end, wandered across the face of the spillway, and eventually exited through the middle gates. The present north spill pattern may have delayed fish passage.

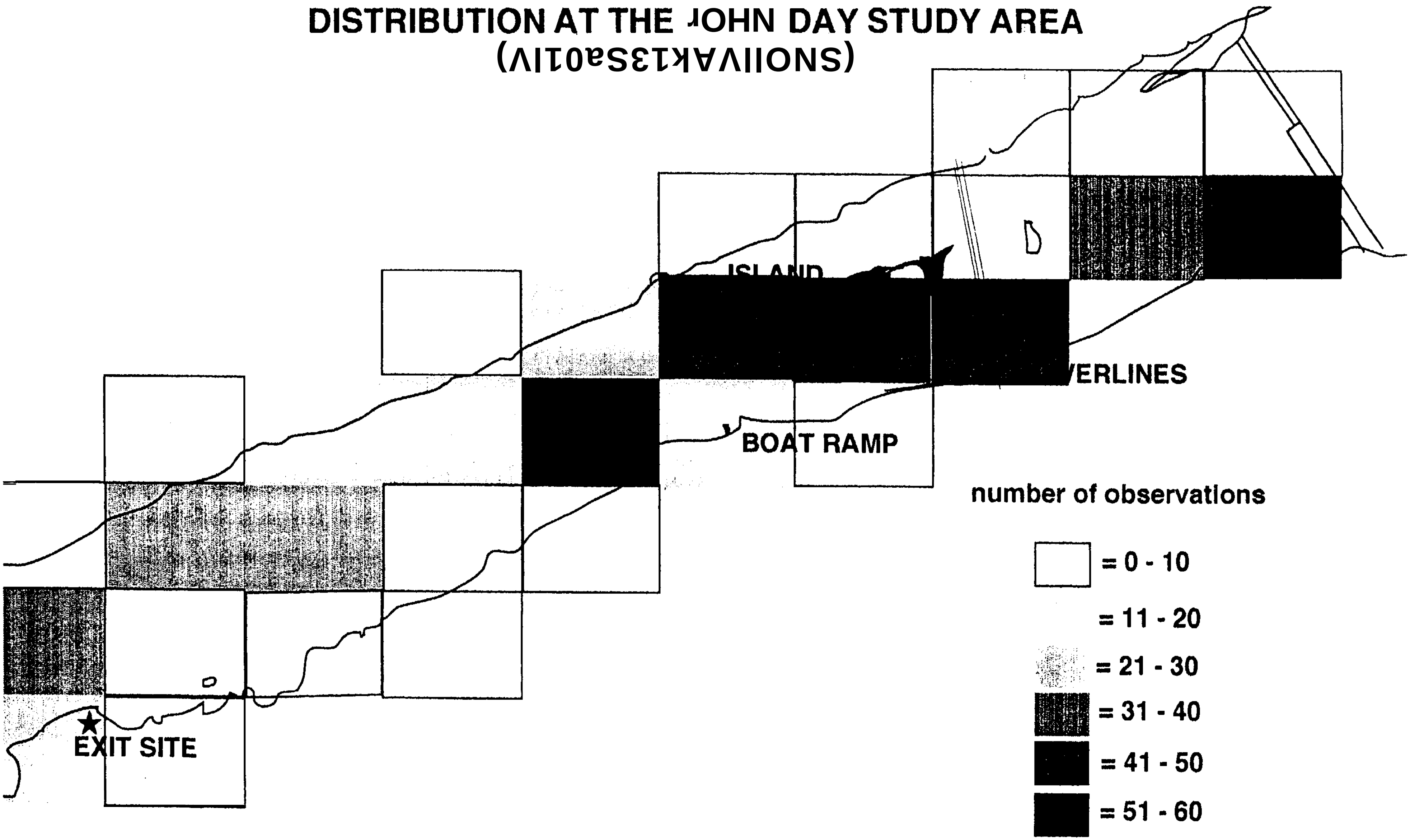


Figure 20. The distribution of observations of radio-tagged spring chinook smolts in The Dalles Dam tailrace study area based on a 400 X 600 m grid overlay.

Table 7. **BEHAVIOR OF SPRING CHINOOK SMOLTS IN THE DALLES DAM FOREBAY**

Passage Point	Passage Time		Mean Residence Time
	before 2000 h (number of fish)	after 2000 h (number of fish)	
Ice and Trash Sluiceway	4	1	50 min. (n=5)
Spillway Gates 9-12	0	9	101 min. (n=9)

---

fish which did not pass during our observations resided from 1 to 5,5 hours in the forebay

Figure 21. Generalized movement tracks of chinook salmon smelts as they arrive at The Dalles Dam and pass through the project. Smelts were radiotagged at John Day Dam and traveled 38 km before reaching The Dalles. Number 1 shows fish which passed through the ice and trash sluiceway. Number 2 are fish which passed through the spillway. And number 3 represents fish which did not pass through the project during our observations.

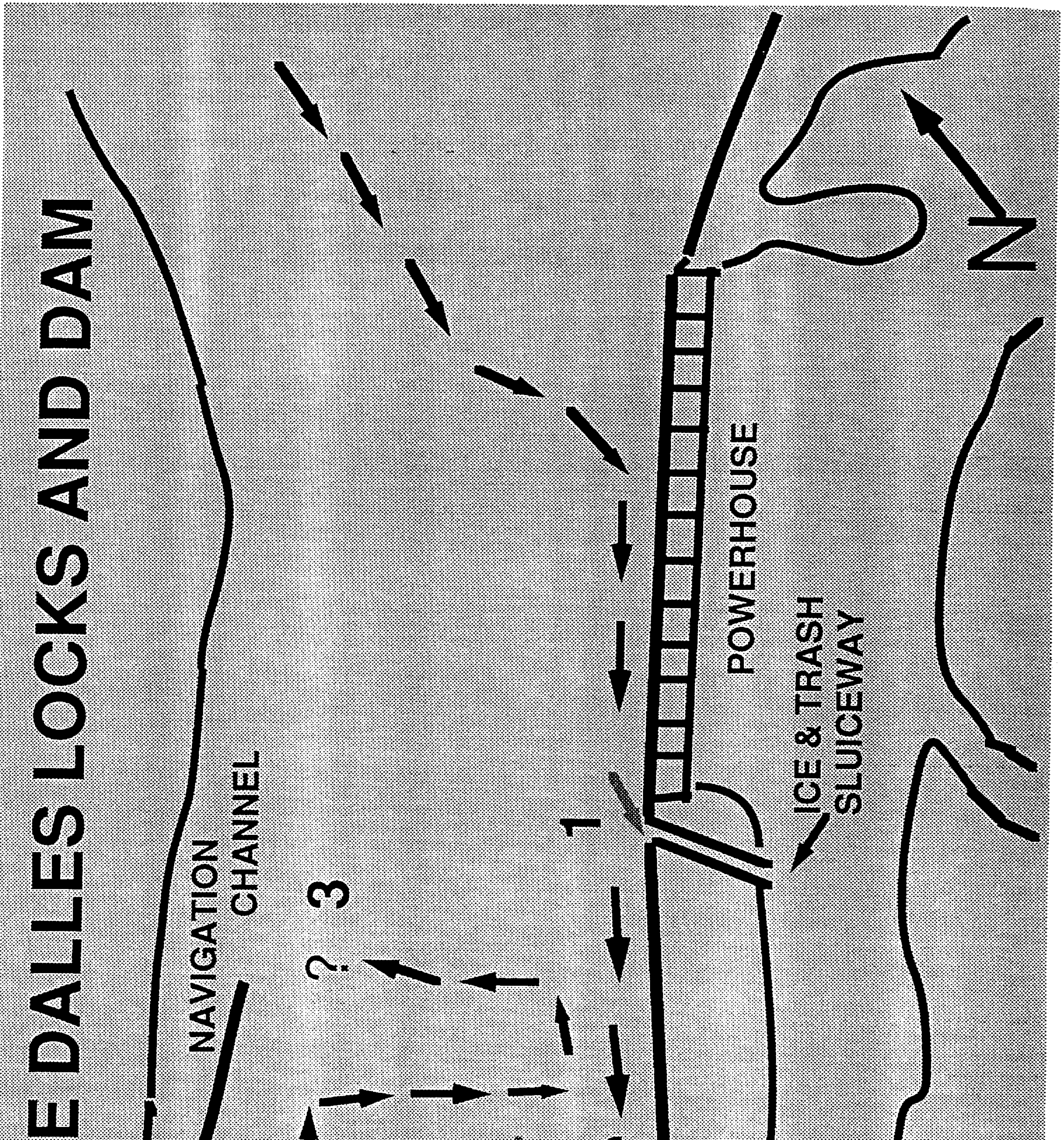

E DALLES LOCKS AND DAM
NAVIGATION CHANNEL
POWERHOUSE
ICE & TRASH SLUICEWAY
1
3
?
N

Table 7. MEAN OUTMIGRATION SPEED (KMPH) OF SPRING CHINOOK SALMON SMOLTS OVER 3 MILE STUDY AREA BELOW THE DALLES DAM TAILRACE (fish size 14-18 cm fork length)

Smelts Released Below The Dam

Agitated*	Not Agitated	Sluiceway Release	Upstream (includes sluiceway)	Downstream
3.4 (n=17)	4.5 (n=16)	3.4 (n=14)	2.7(n=23)	4.7 (n=24)
p >0.1			p<<< .001	

(Comparison of Fish passing Through The Dam After Migrating 24 mi. From Release At John Day Dam with those released at Downstream site)

Ice-Trash Sluiceway Passage	Spillway I'assage	Downstream Release (above)
3.4 (n=3)	3.7(n=8)	4.7(n=24)
	p >0.1	
p >0.5		

* agitated fish were transferred (poured) between two 401 buckets for seven minutes

We were successful in following eleven smolts on exit through the dam and through the 4.8 km tailrace study area below. The mean outmigration speed of smolts passing through the spillway at night (3.7 kmph) was less than that of a larger sample of fish we released 200 m below the spillway during the day (4.7 kmph, $p>0.1$, Table 7). Our sample of three fish passing via the ice and trash sluiceway migrated at 3.4 kmph in the tailrace below. Four of 14 (29%) fish we followed through the project held after passage, i.e. remained in a 400 m area for 30 min or longer (Figure 5). Eight percent of fish we released just below the spillbay (downstream release) held compared with 22% of the fish passed naturally, suggesting the stressful nature of spillway passage, or perhaps differences in holding tendencies at night when the majority the fish passed through the spillway. Five of 16 (31%) of fish we released into the lower sluiceway held, compared with 2 of 5 (40%) of fish which passed naturally; these results are similar, although the natural sluiceway passage must be far more rigorous.

Although our data are few, we believe that at 1993 flows (average river flow at The Dalles was 320 kcfs during the period of our tests), smolts which pass through the north/middle spillway gates are only slightly more likely to hold (and experience predation) than those released just below the spillbay. We plan to expand these tests in 1994.

Laboratory tests to determine effect of stomach-implant radio transmitters on small chinook smolts

During- the final weeks of the 1993 field season we implanted several smolts with single battery (1.5 v) transmitters weighing about 1 g each. Our tests indicated these transmitters provided data of comparable reliability to the larger 3 v (1.4 g) tags. We conducted rigorous laboratory tests on the acceptance of these tags by 10 to

13 cm fish during the winter of 1993/94, evaluating their effect on growth and swimming performance. While the results are not fully analyzed the abstract of our draft report follows:

Pre-smolt hatchery spring chinook salmon (*Oncorhynchus tshawytcha*) were used in laboratory tests to study the effects of stomach-implant radio transmitters on weight gain, swimming performance, feeding behavior, and gross pathological changes. Two replicates of 50 small fish (95-114 mm forklength) and similar replicates of large fish (115-125 mm) were acclimated in 5 ft circular tanks, and fed five times per day at 4% of their body weight per day. Swimming tests were conducted in modified Blaska respirometer-stamina chambers. Half of the fish in each tank received 1g stomach-implant radio transmitters. Over a 23 d period tagged fish gained an average of 5.0% compared with 27.9% for controls. All but a few fish fed actively. There were no gross pathological changes in the gastrointestinal tracts of fish at necropsy. Tagged fish continued to cough during the study, and several tags were regurgitated. Length of radio tag implantation did not significantly effect the critical swimming speeds of tagged fish (1.5 d implantation 2.81 BL/sec and 28 d implantation 2.62 BL/sec) (Snelling J.C., C. B. Schreck, S. K. Guttenberger, and D. A. Kelsey. Stomach-implant radio transmitters: growth and swimming performance in chinook salmon pre-smolts. A draft report submitted to Dennis Rondorf, SBS, Cook, WA)

REFERENCES

Giorgi, A.E. and L.C. Stuehrenberg. 1983. Smolt passage behavior and flow-net relationships in the forebay of John Day Dam, 1984, Annual Report, (Contract DE-A179-83BP39644) Bonneville Power Administration, Portland, OR.

Giorgi, A.E., L.C. Stuehrenberg, D.R. Miller, and C.W. Sims. 1985. Smolt passage behavior and flow-net relationships in the forebay of John Day Dam, 1985, Annual Report, (Contract DE-A179-83BP39644) Bonneville Power Administration, Portland, OR.

Giorgi, A.E., L. Steuhrenberg, and J. Wilson. 1988. Juvenile radio-tag study: Lower Granite dam, 1985-86, Final Report, (Contract DE-A179- 85BP21237) Bonneville Power Administration, Portland, OR.

Ledger-wood, R.D., E.M. Dawley, L.G. Gilbreath, P. J. Bentley, B.P. Sanford, and M. H. Schiewe. 1991. Relative survival of subyearling chinook salmon that have passed through the turbines or bypass system of Bonneville Dam Second Powerhouse, 1990. Report to U.S. Army Corps of Engineers, Contract E86900104.

Mesa, M.G. 1992. Effects of multiple acute disturbances on the predator avoidance, physiology, and behavior of juvenile chinook salmon. Report 4. in Poe, T.P. (ed.), Significance of selective predation and development of prey protection measures for juvenile salmonids in Columbia and Snake River reservoirs, 1991, Annual Report, (Contract DEAI79-88BP91964) Bonneville Power Administration, Portland, OR.

Petersen, J. H., M. G. Mesa, J. Ha&Griswold, W. C. Schrader, G. W. Short, and T. P. Poe. 1990. Magnitude and dynamics of predation on juvenile salmonids in Columbia and Snake river reservoirs. Annual Report. (Contract DE-AI79-88BP91964) Bonneville Power Authority, Portland, OR.

Poe, T.P., H. C. Hansel, S. Viggs, D. E. Palmer, and L.A. Prendergast. 1991. Feeding of predaceous fishes on out-migrating juvenile salmonids in John Day reservoir, Columbia River. Trans. Am. Fish. Soc. 120: 405- 420.

Schreck, C.B. and J.C. Snelling. 1992. Migratory characteristics of spring chinook salmon in the Willamette River. Annual Report to Bonneville Power Administration, 75 pp.

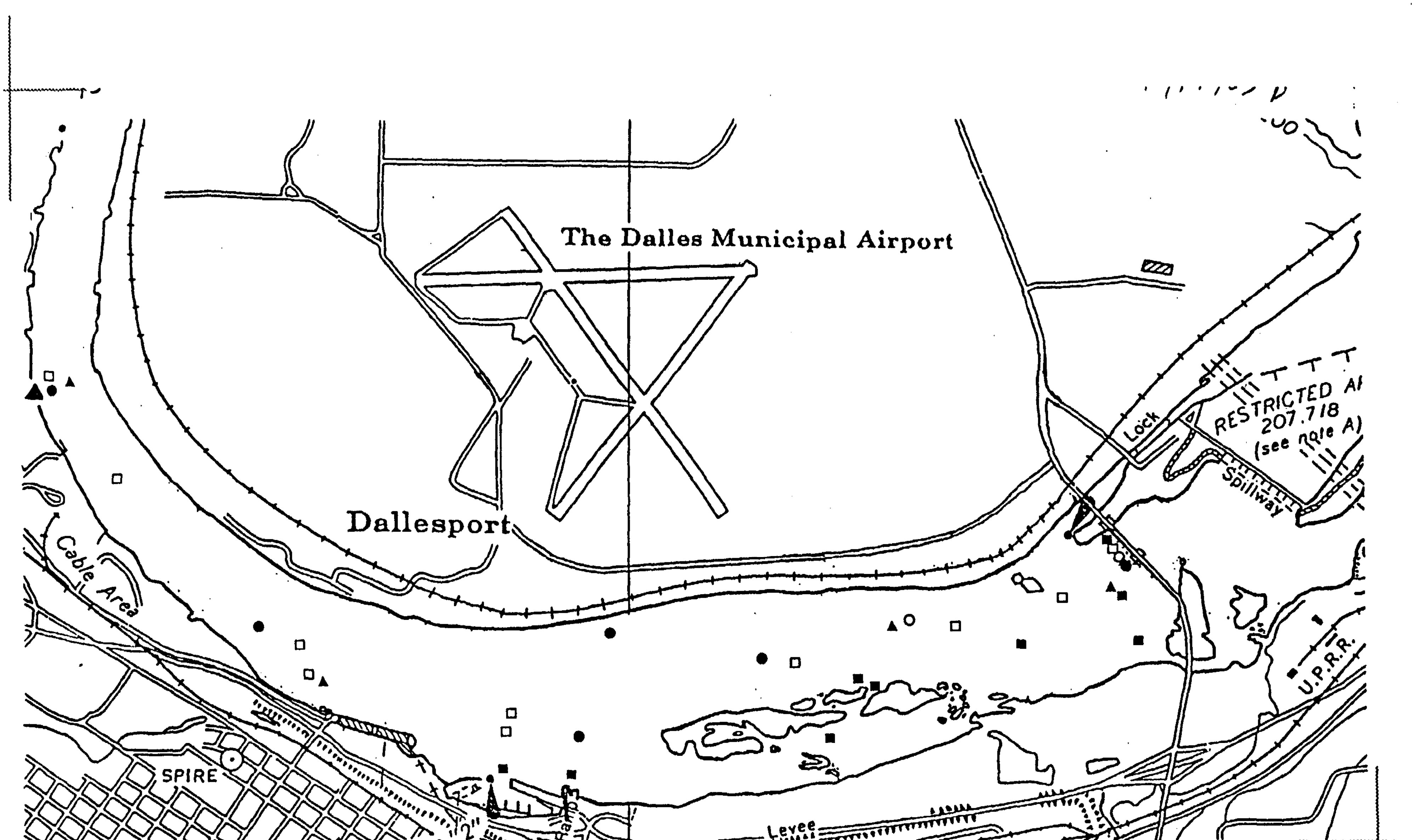
Schreck, C. B., S. Kattari, J.L. Congleton, and L. E. Davis. 1992. Evaluation of facilities for collection, bypass, and transportation of outmigrating chinook salmon. Draft Annual Report to U.S. Army Corps of Engineers , Walla Walla District, Research Element JFT-92-XX-3.

Stier, D.J. and B. Kynard. 1986. Use of radio telemetry to determine the mortality of Atlantic salmon smolts passed through a 17-MW Kaplan turbine at a low-head hydroelectric dam. Tran. Am. Fish. Soc. 115:771- 775.

Stuehrenberg, L.C., A.E. Giorgi, C.W. Sims, J Ramonda-Powell, and J. Wilson. 1986. Juvenile radio-tag study: Lower Granite dam, 1985, Annual Report, (Contract DE-A179-85BP21237) Bonneville Power Administration, Portland, OR.

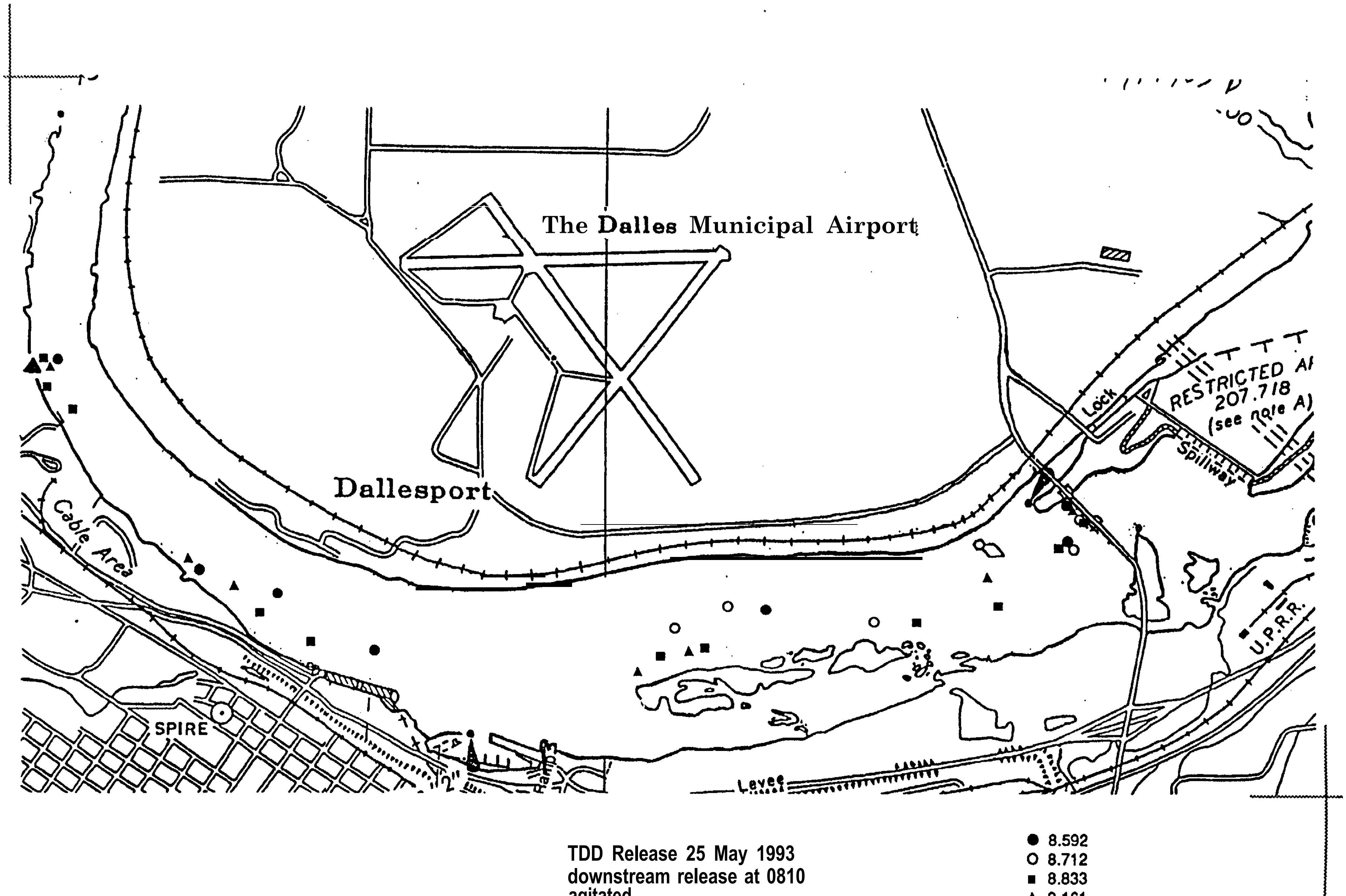
Viggs, S., T.P. Poe, L.A. Prendergast, and H.C. Hansel. 1991. Rates of consumption of juvenile salmonids and alternative prey fish by northern squawfish, walleyes, smallmouth bass, and channel catfish in John Day reservoir, Columbia River. Trans. Am. Fish. Soc. 120: 421-438.

Appendix A. Maps of location plots for each release of chinook smolts at The Dalles and John Day Dams



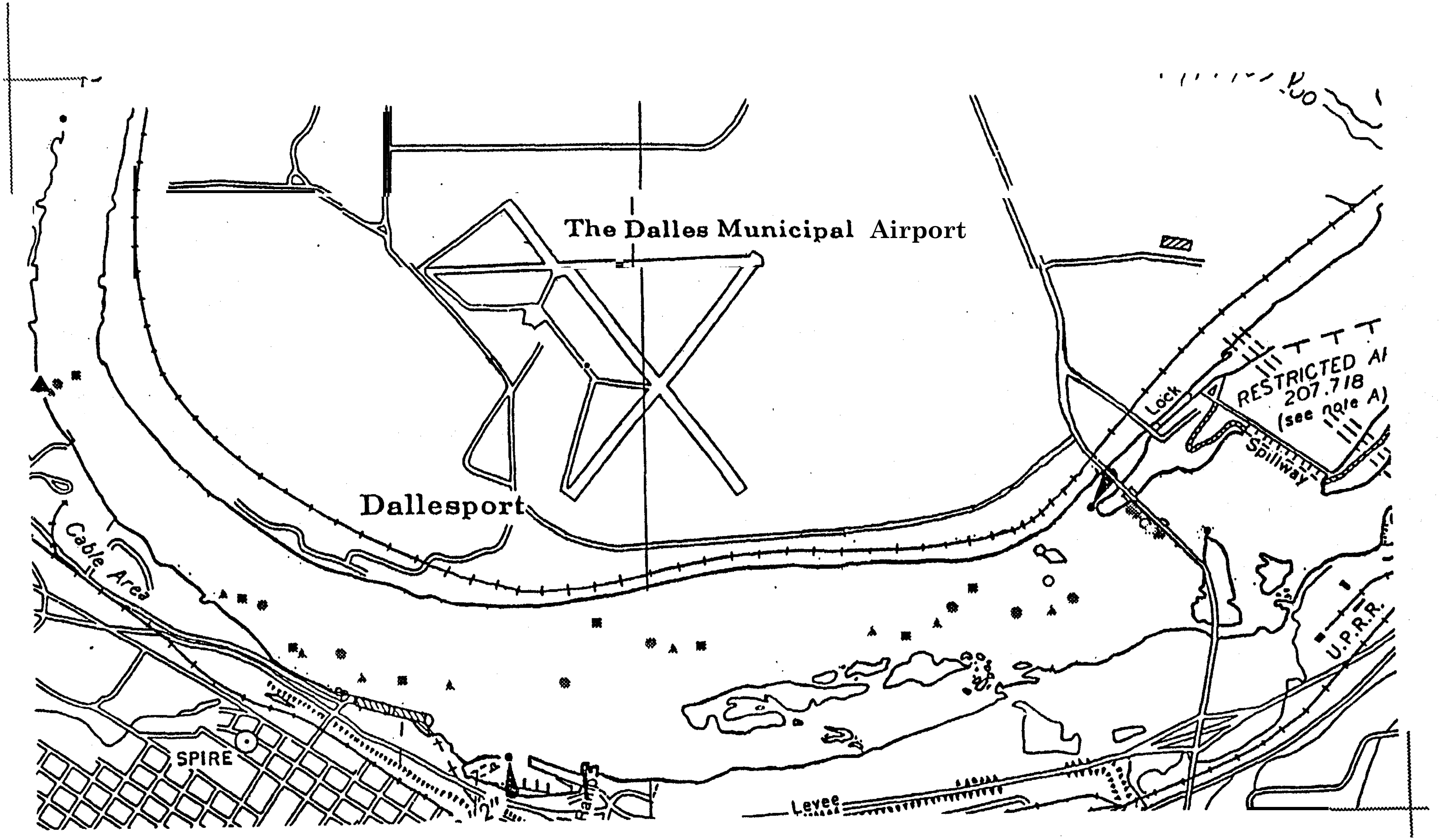
TDD Release 28 April 1993
downstream release at 0813
agitated

● 9.203
○ 9.234
• [illegible]
□ 9.154
▲ 9.243



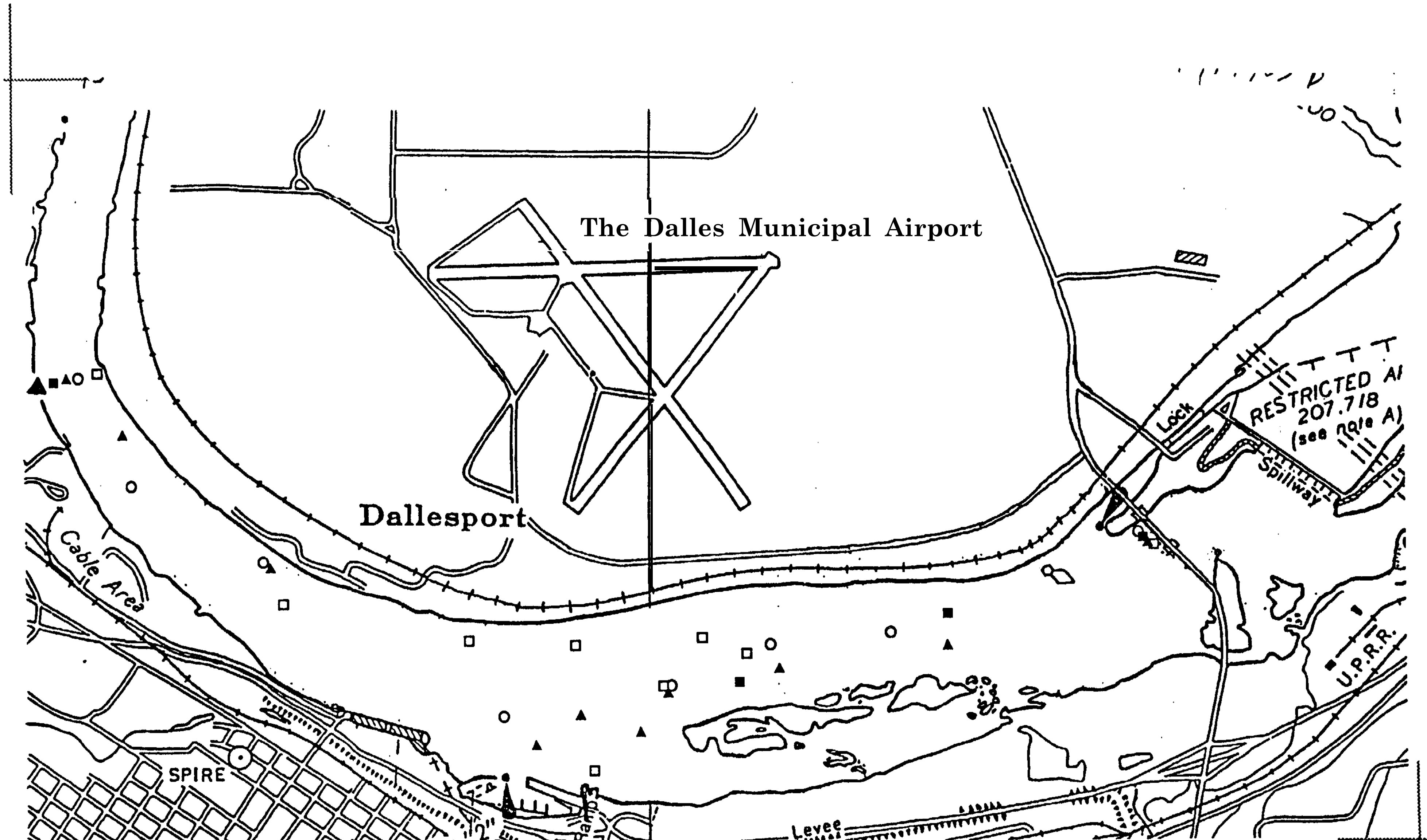
TDD Release 25 May 1993
downstream release at 0810
agitated

● 8.592
○ 8.712
■ 8.833
▲ 9.161



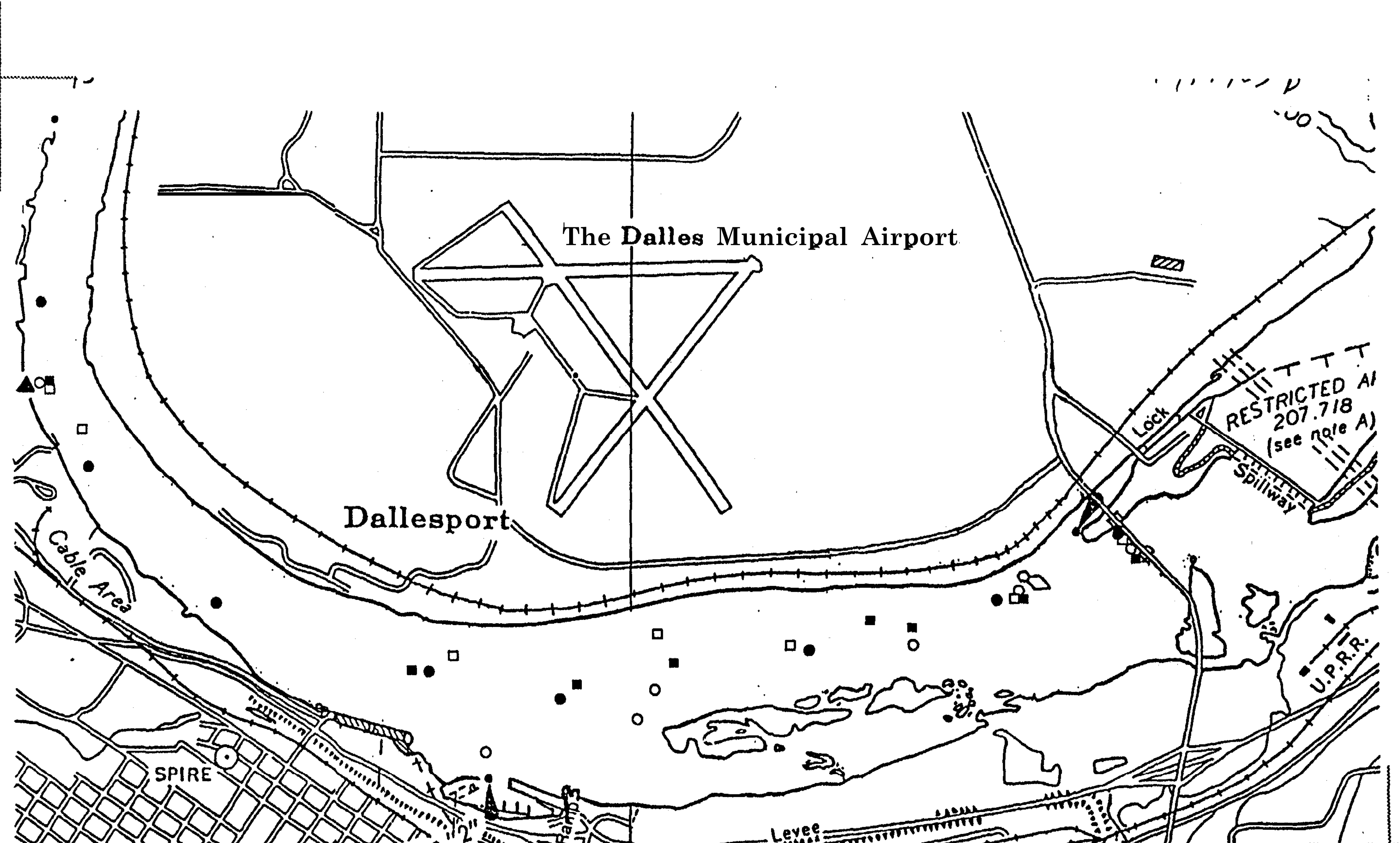
TDD Release 17 May 1993
downstream release at 0814
agitated

○ 9.354
■ 8.053
▲ 8.323



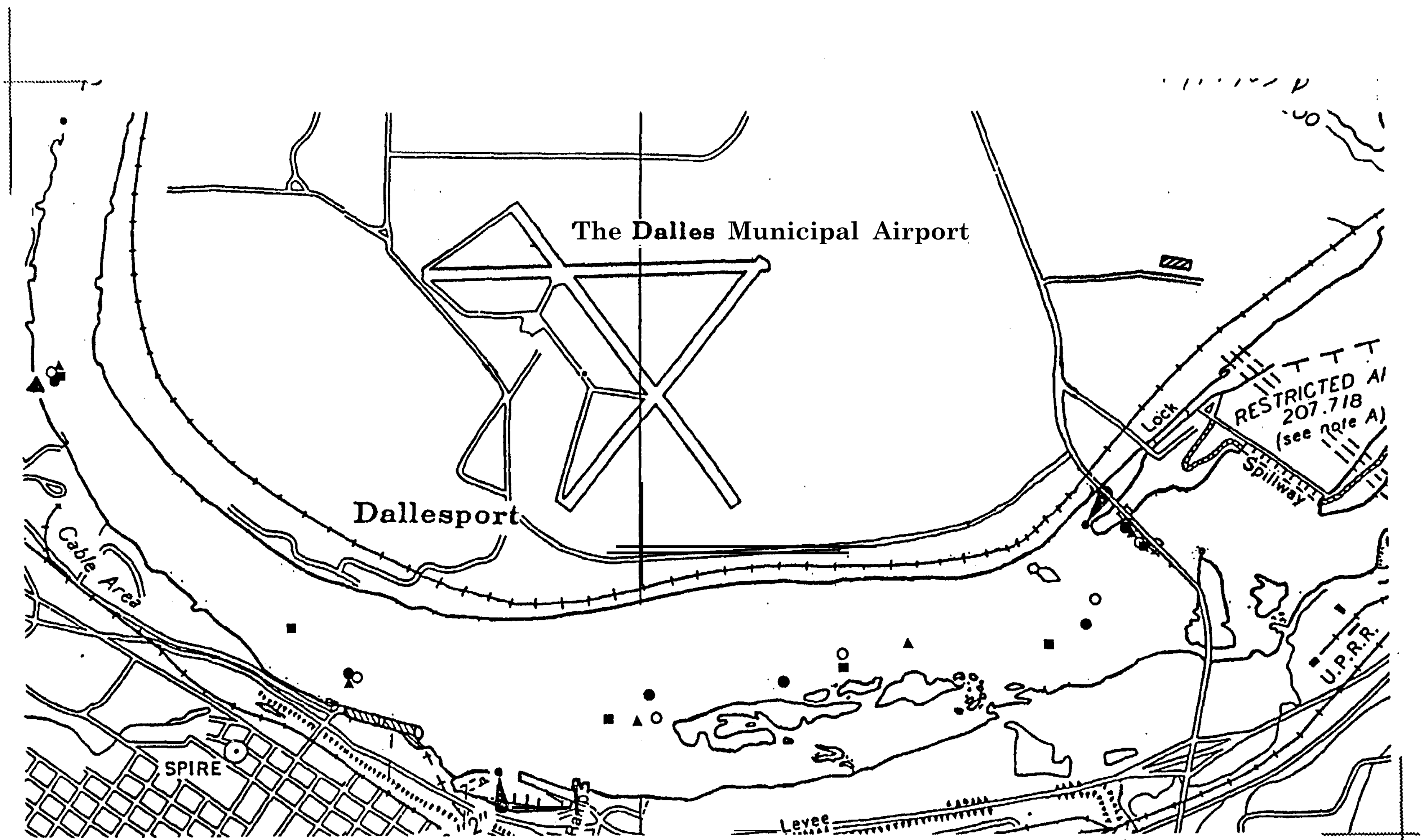
TDD Release 28 April 1993
downstream release at 0813
non-agitated

□ 9.146



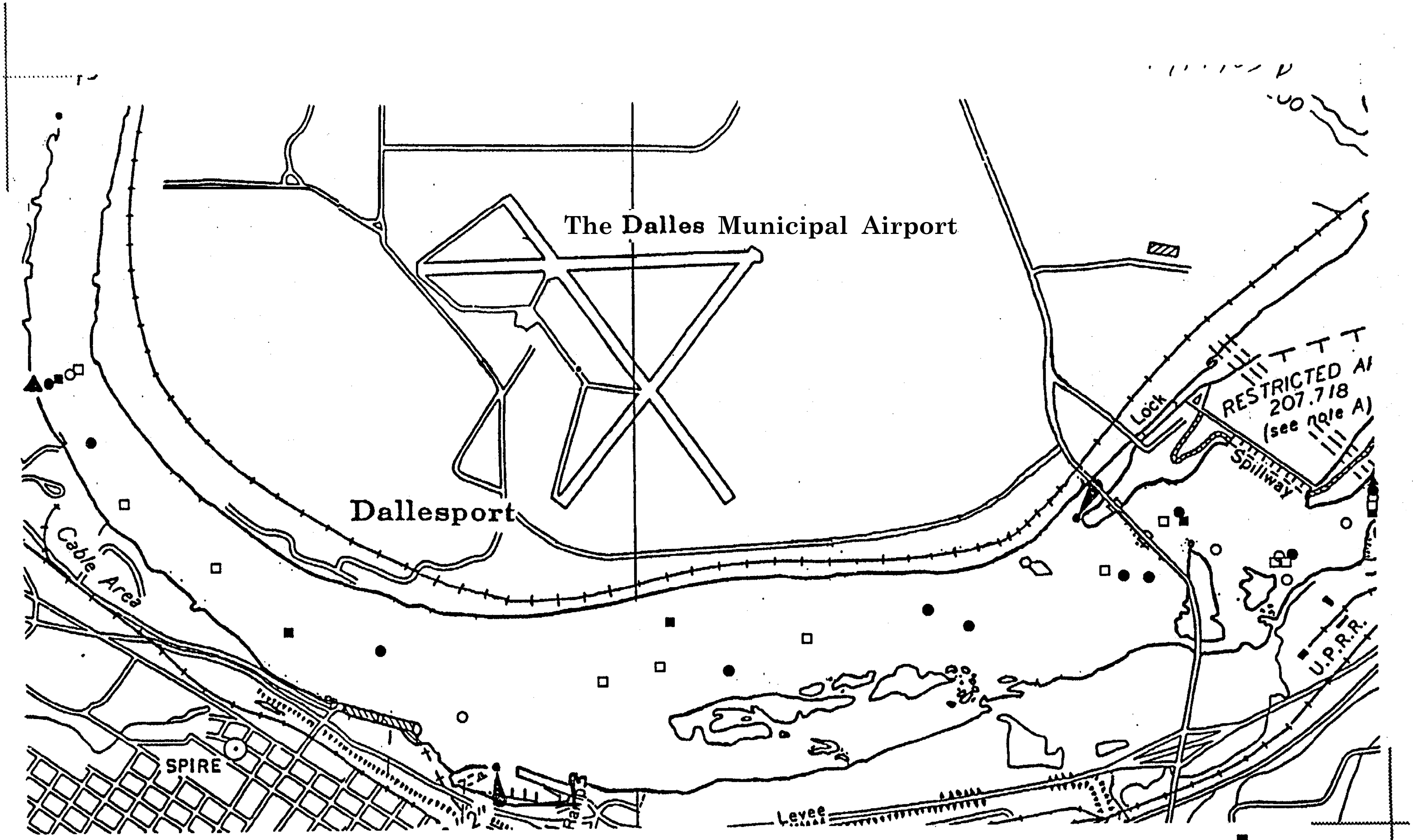
TDD Release 17 May 1993
downstream release at 0814
non-agitated

● 9.724
○ 9.713
■ [illegible]
□ 9.264



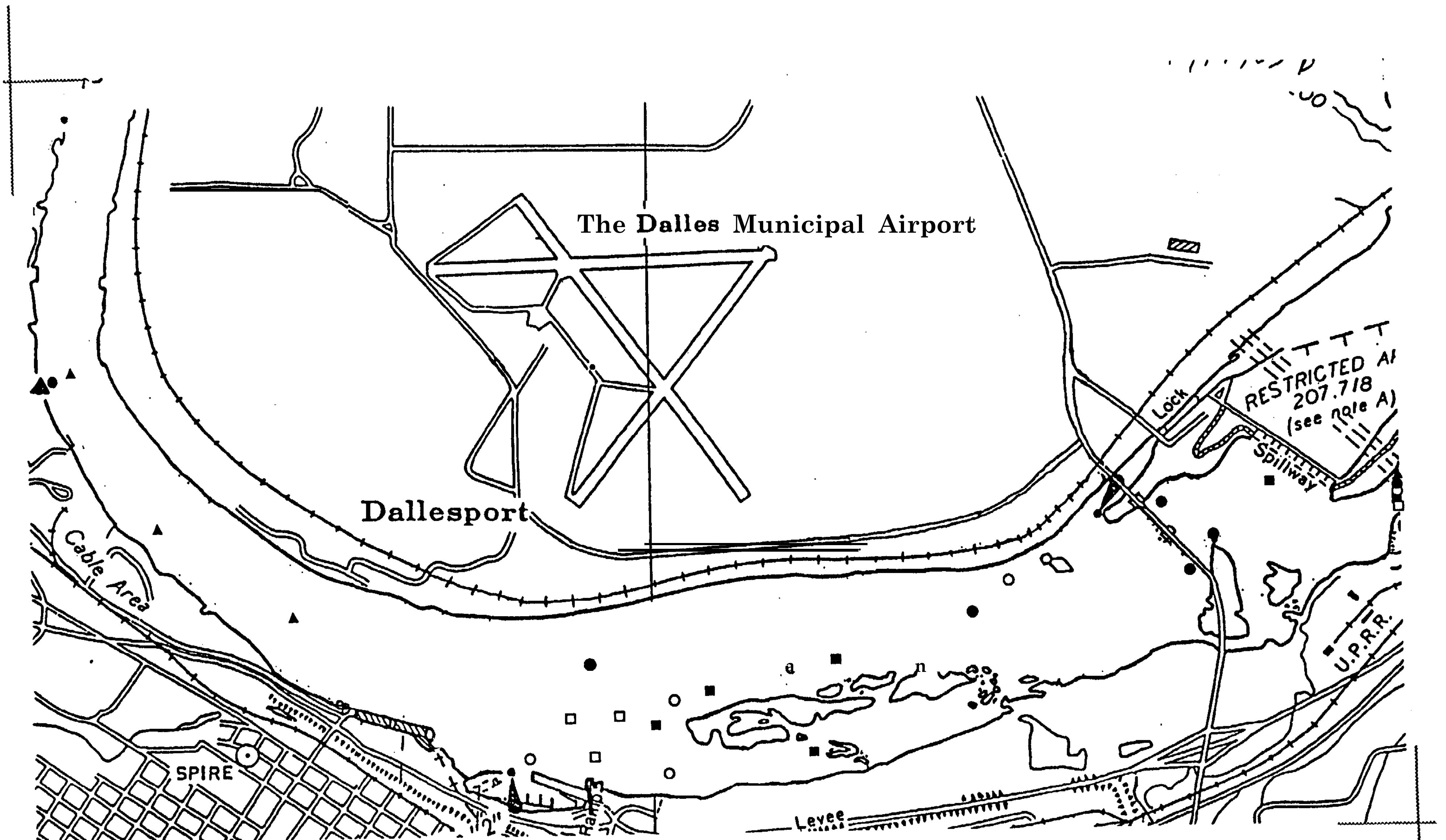
TDD Release 25 May 1993
downstream release at 0810
non-agitated

● 9.425
○ 9.462
■ [illegible]
▲ 9.384



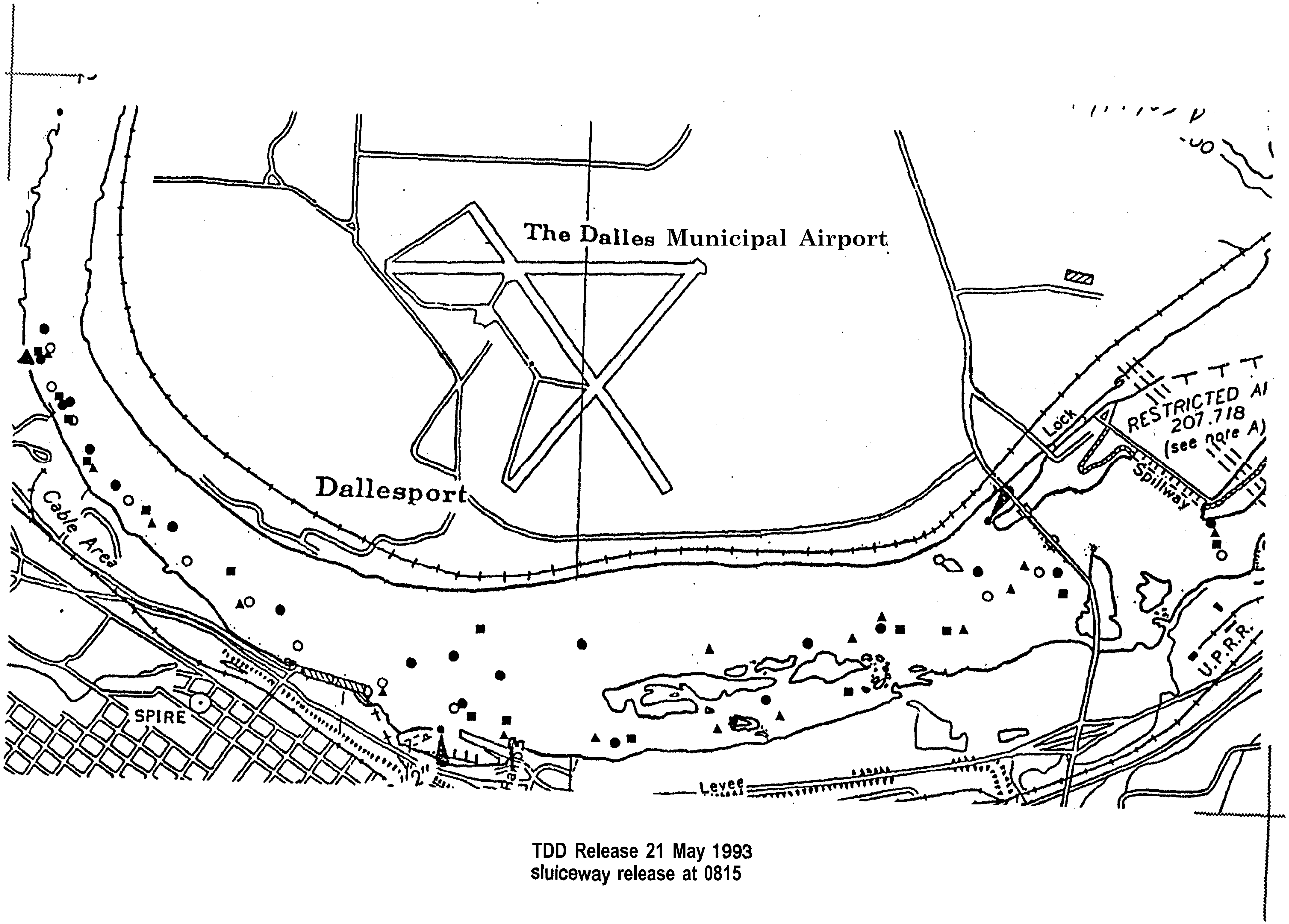
TDD Release 30 April 1993
upstream release at 0758
non-agitated

● 8.444
0 8.022
■ 8.532
□ 8.652

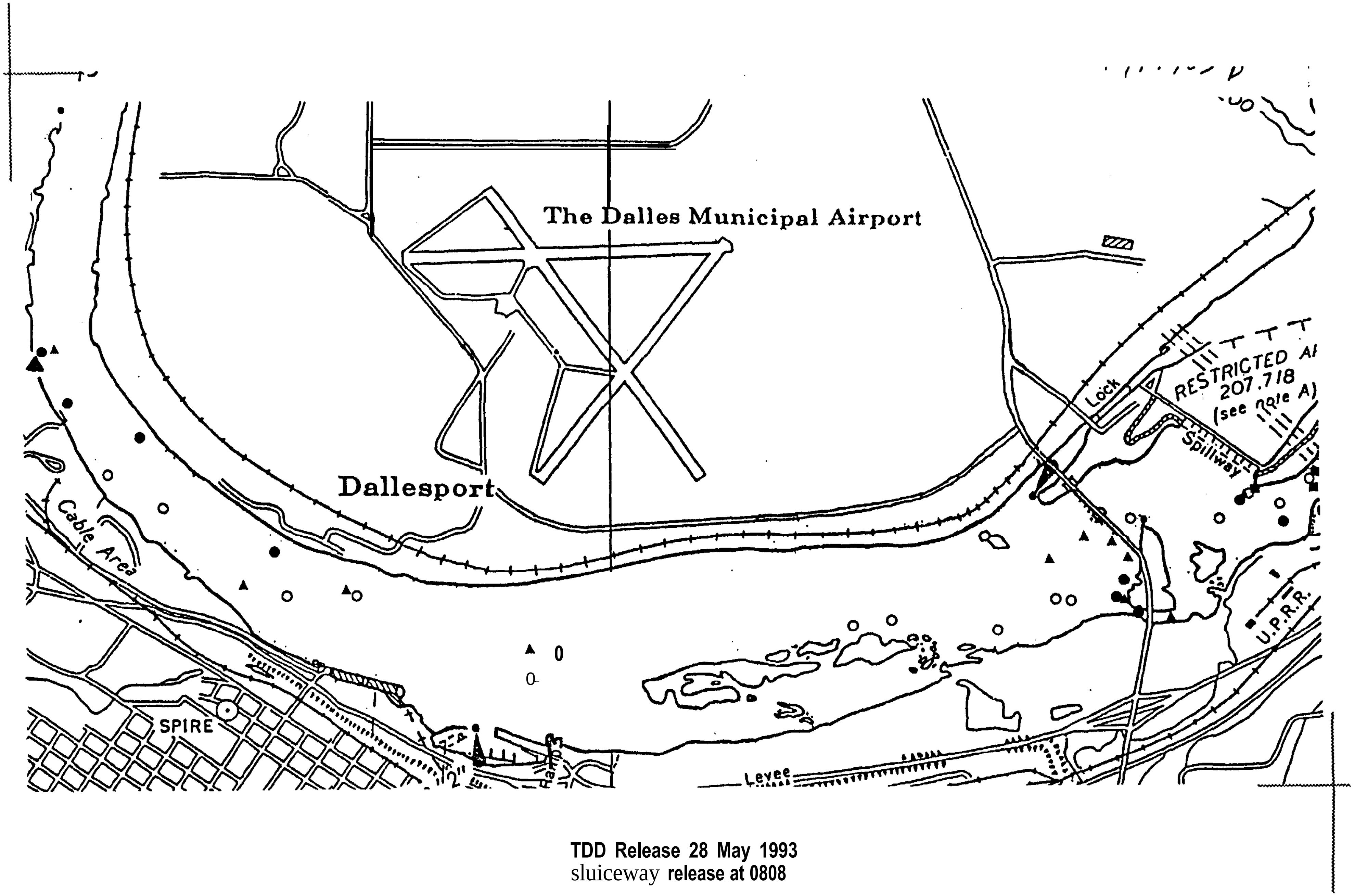


TDD Release 30 April 1993
upstream release at 0758
agitated

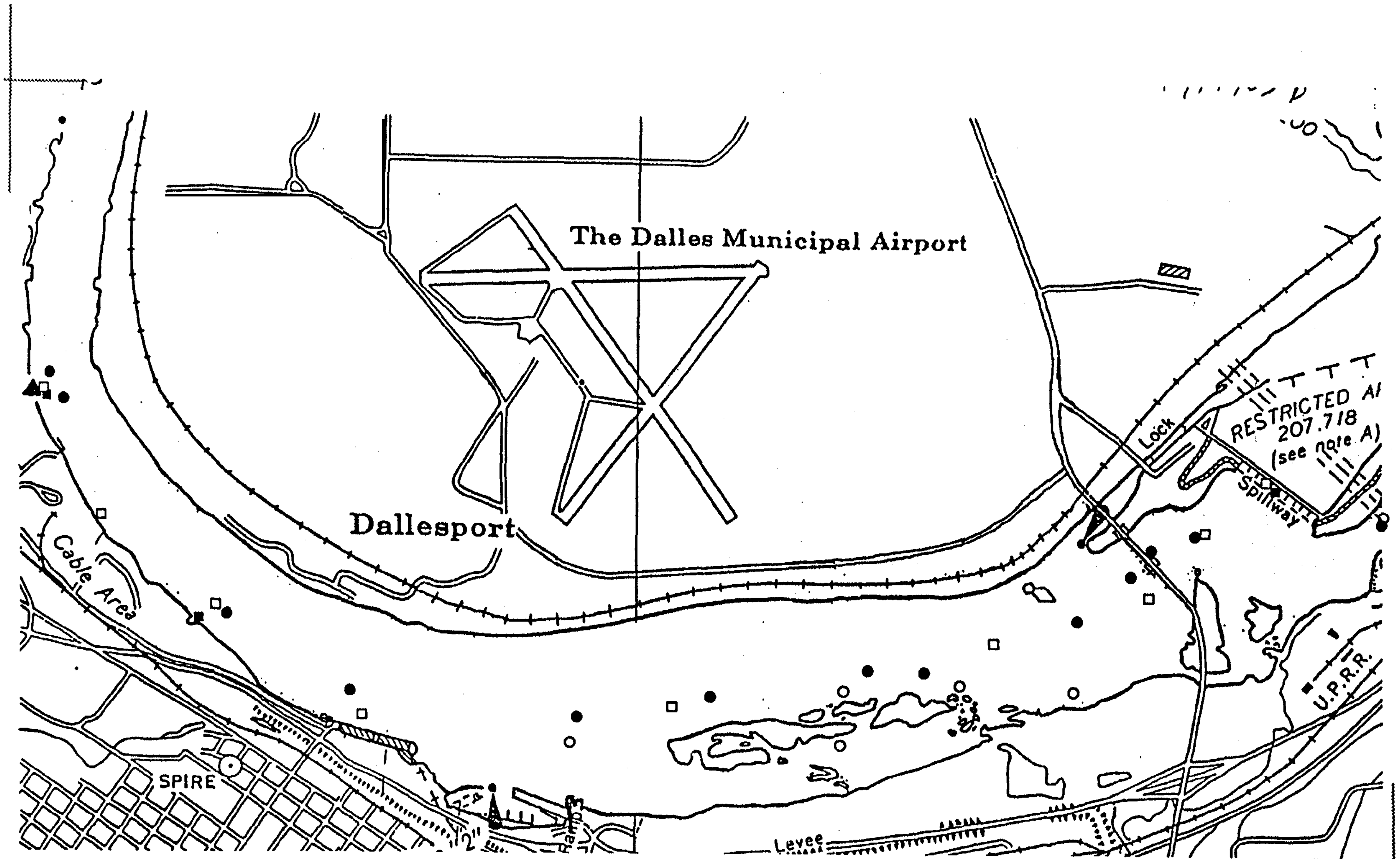
● 8.922
○ 8.353



TDD Release 21 May 1993
sluiceway release at 0815

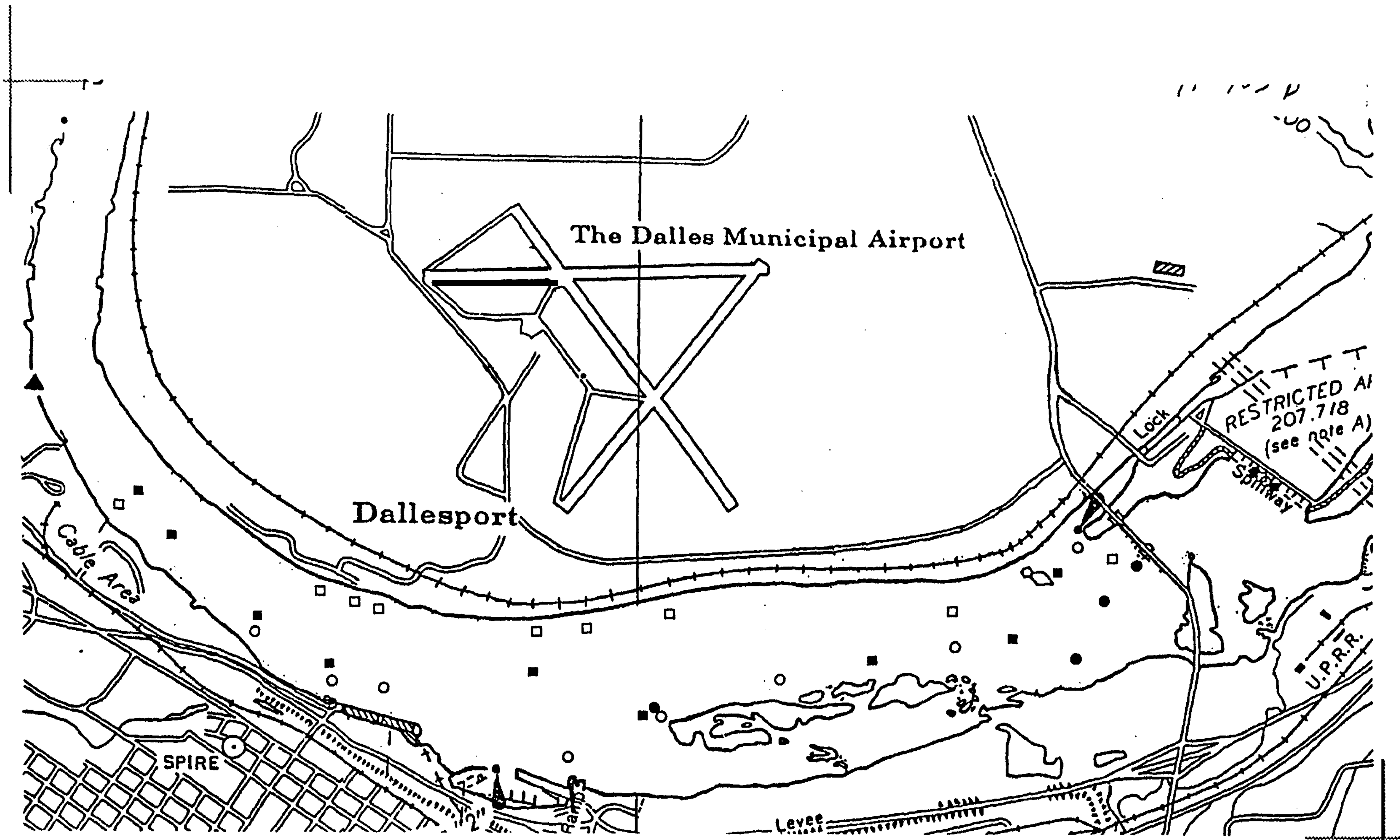


TDD Release 28 May 1993
sluiceway **release at 0808**



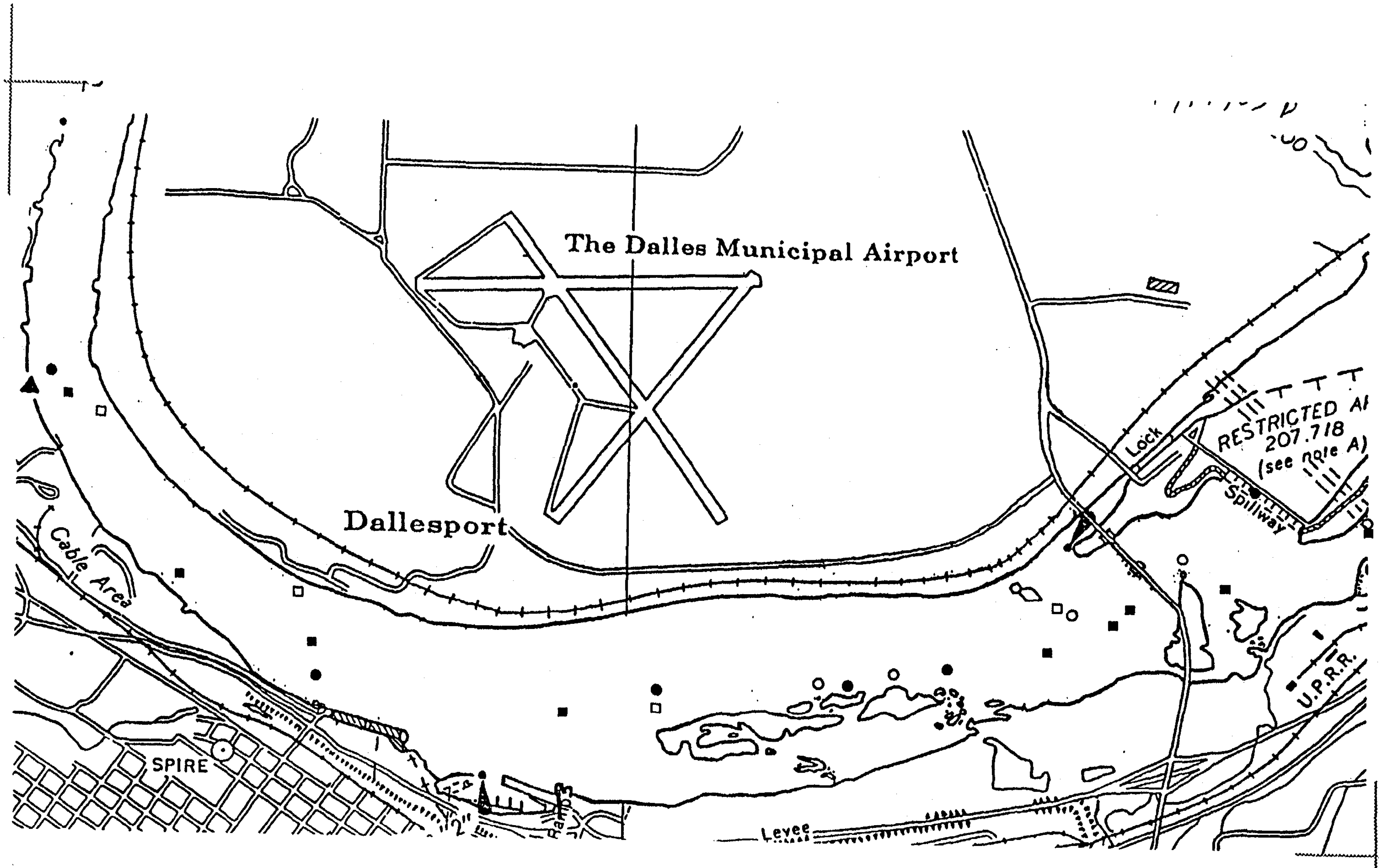
TDD Natural Passage from JDD
Release 1 June 1993
outfall release at 0806

● 9.574 non-agitated, ice/trash sluiceway
○ 9.482 non-agitated, ice/trash sluiceway
■ 9.902 agitated, spill gate 10
□ 9.763 agitated, spill gate 9



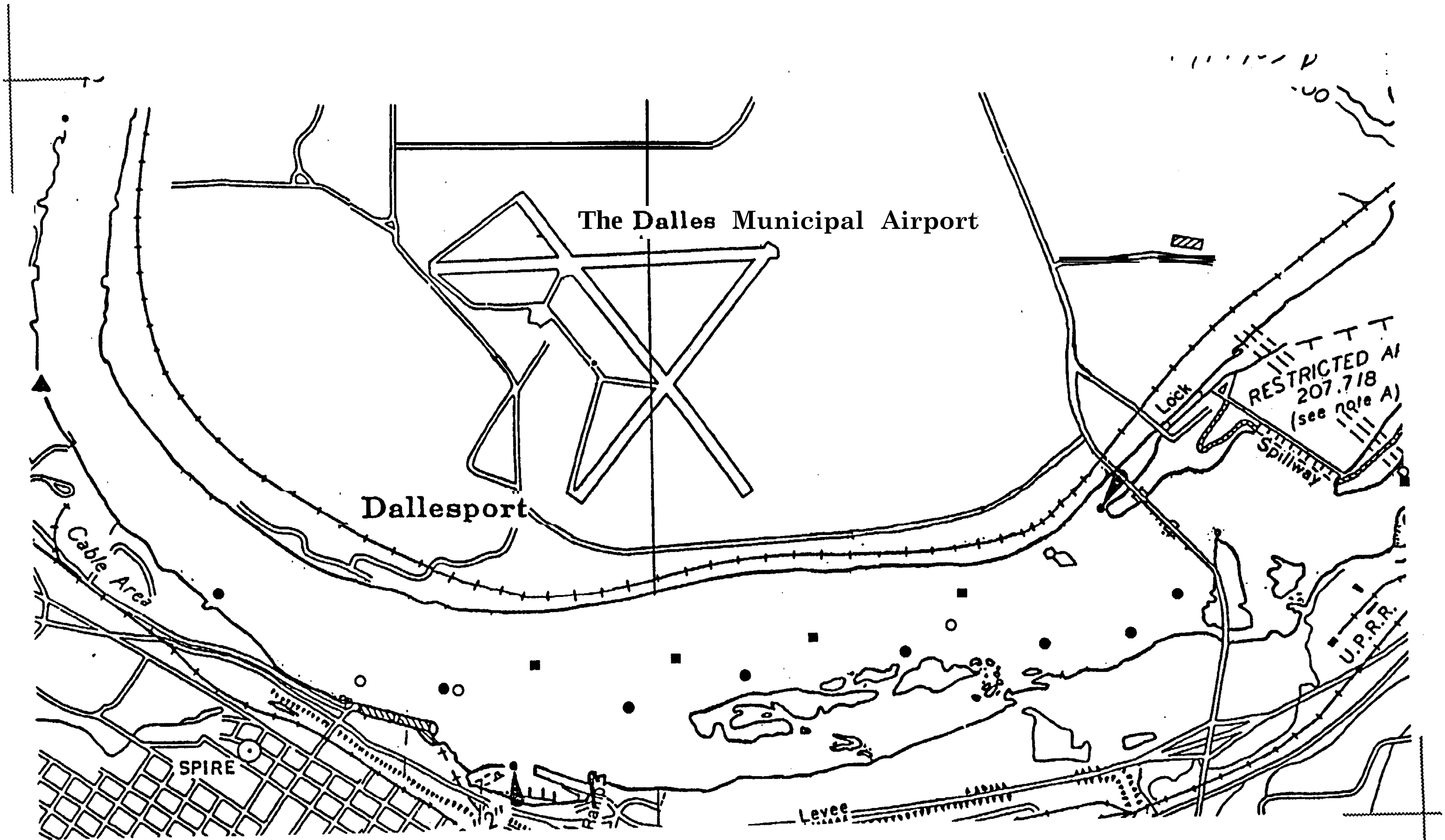
TDD Natural Passage from JDD
Release 3 June 1993
bypass release at 0654

- ● 9.782 non-agitated, spill gate 1-12
- ○ 9.624 non-agitated, spill gate 12
- ■ 9.790 non-agitated, spill gate 12
- □ 9.143 agitated, spill gate 1-12

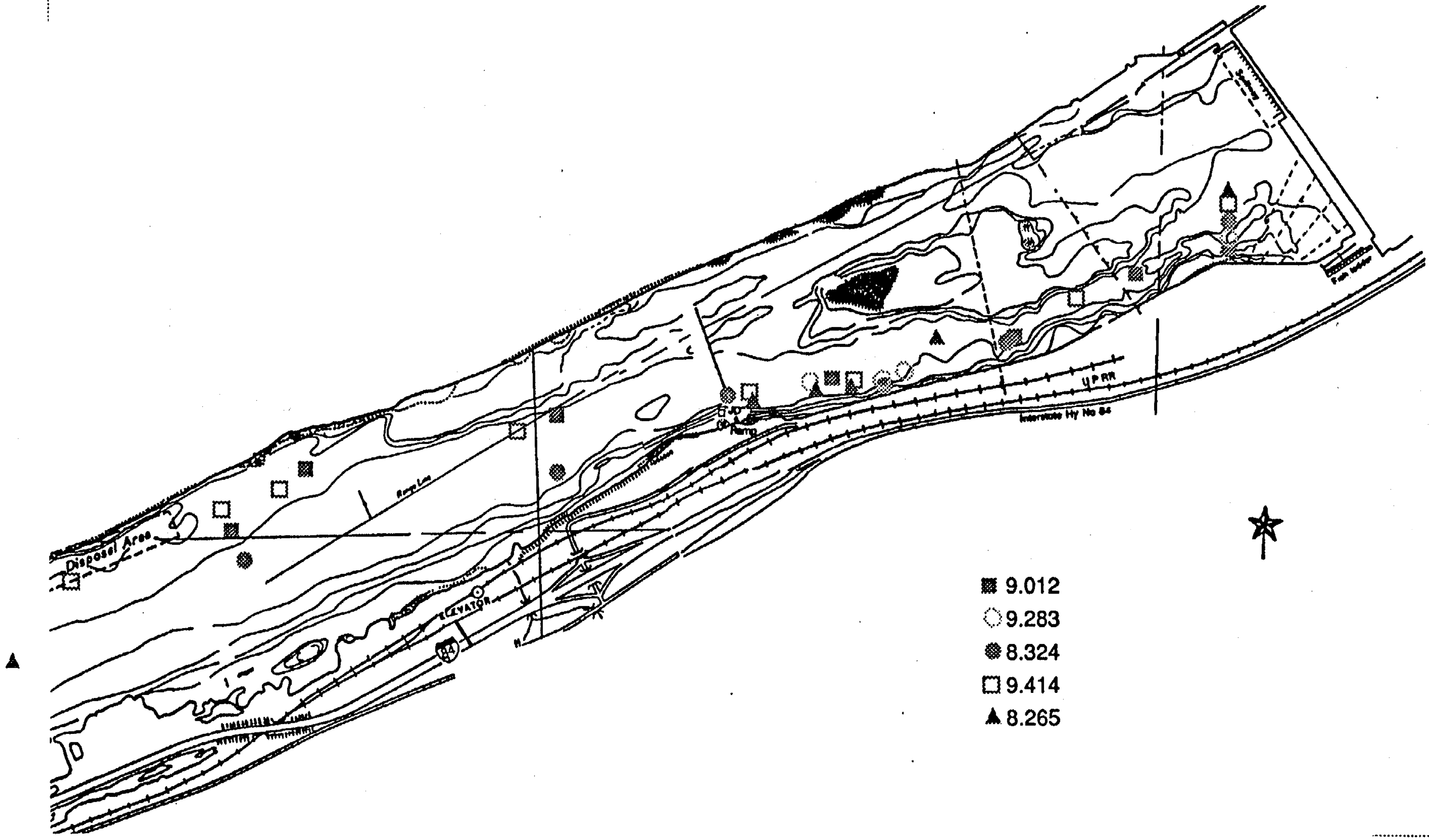


TDD Natural Passage from JDD
Release 7 June 1993
outfall release at 0727

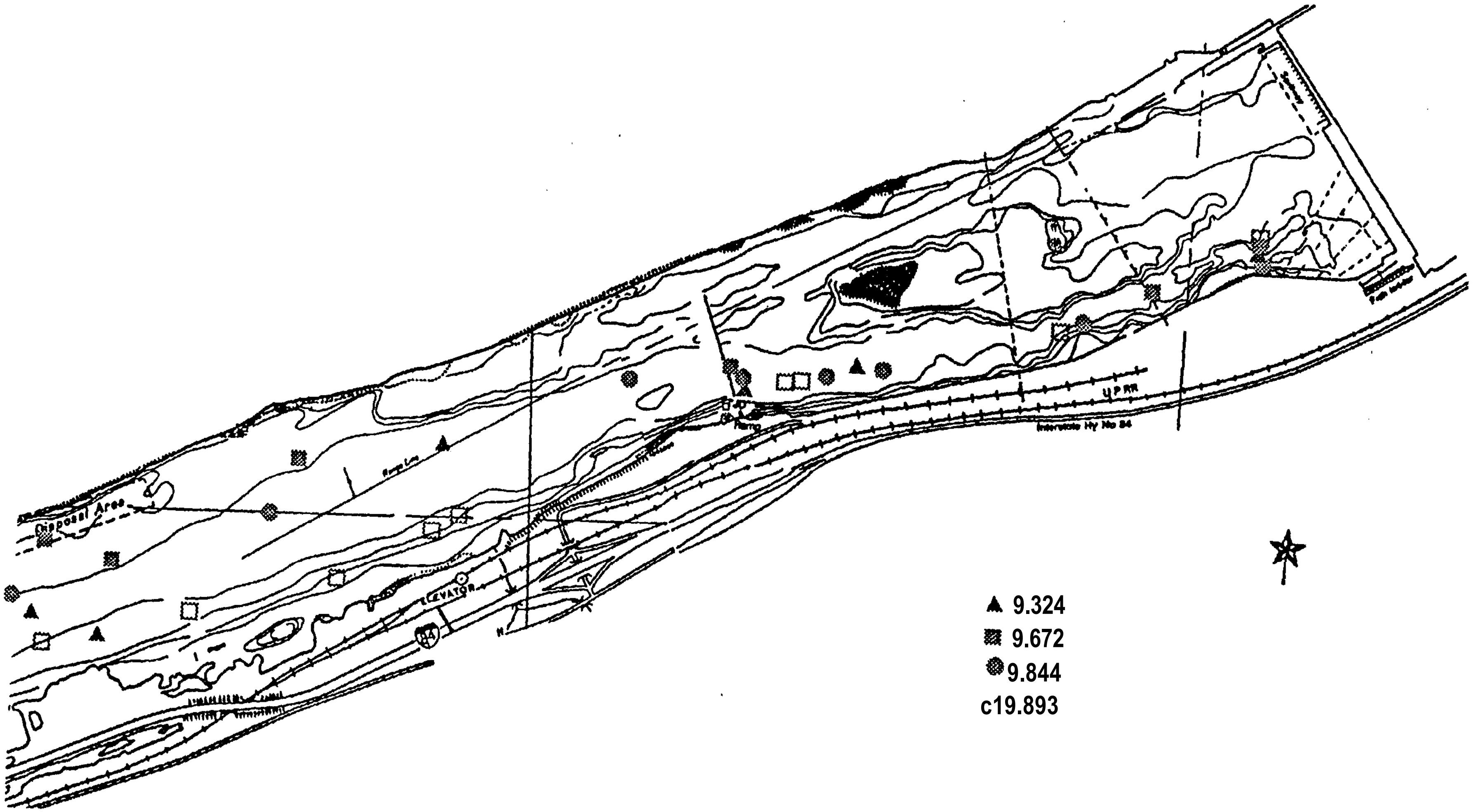
● 9.125 non-agitated, spill gate 8-12
○ 9.372 non-agitated, ice/trash sluiceway
■ 9.812 non-agitated, ice/trash sluiceway
□ 9.105 agitated, spill gate?



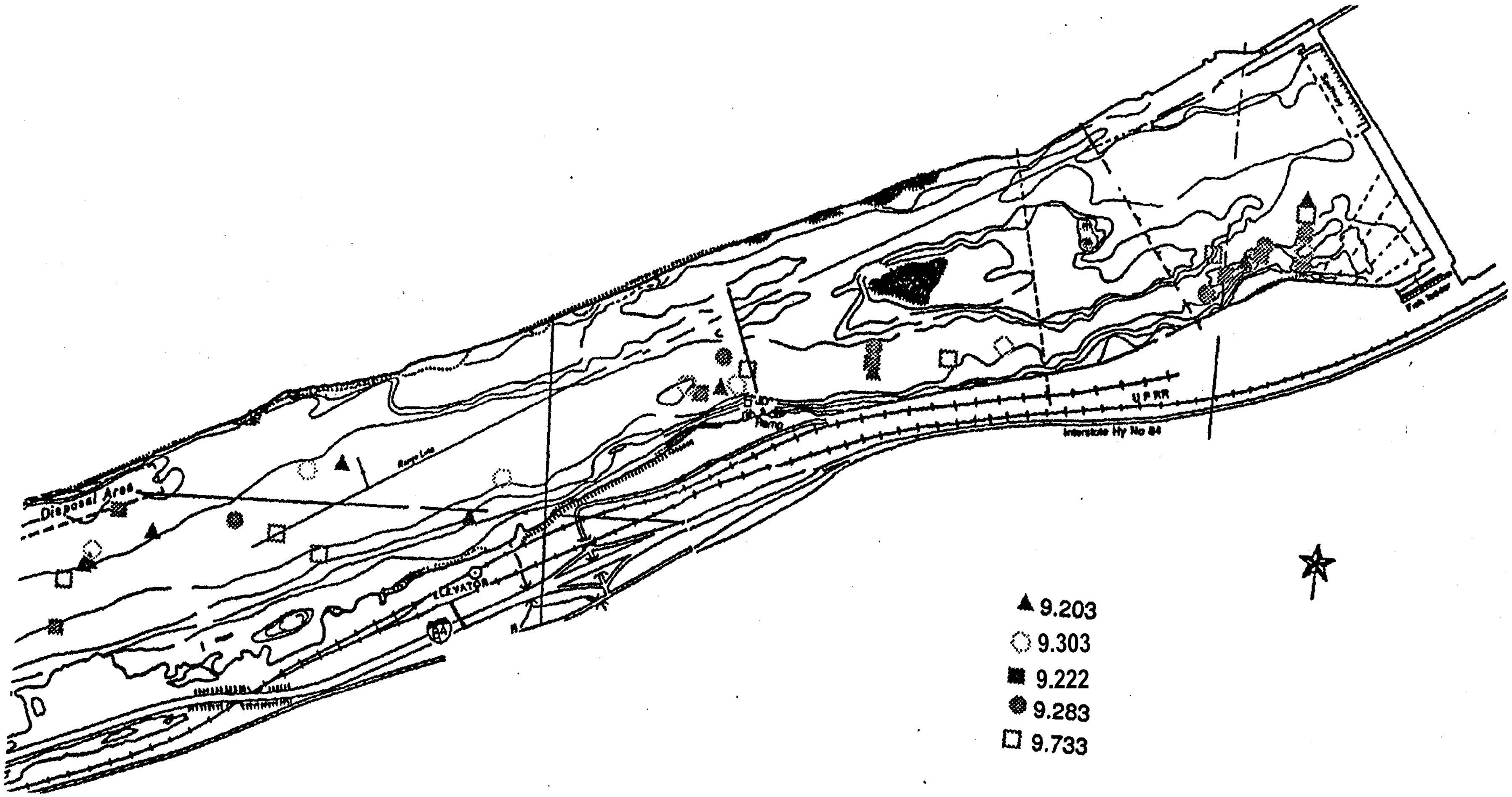
TDD Natural Passage from JDD
Release 9 June 1993
bypass release at 0759



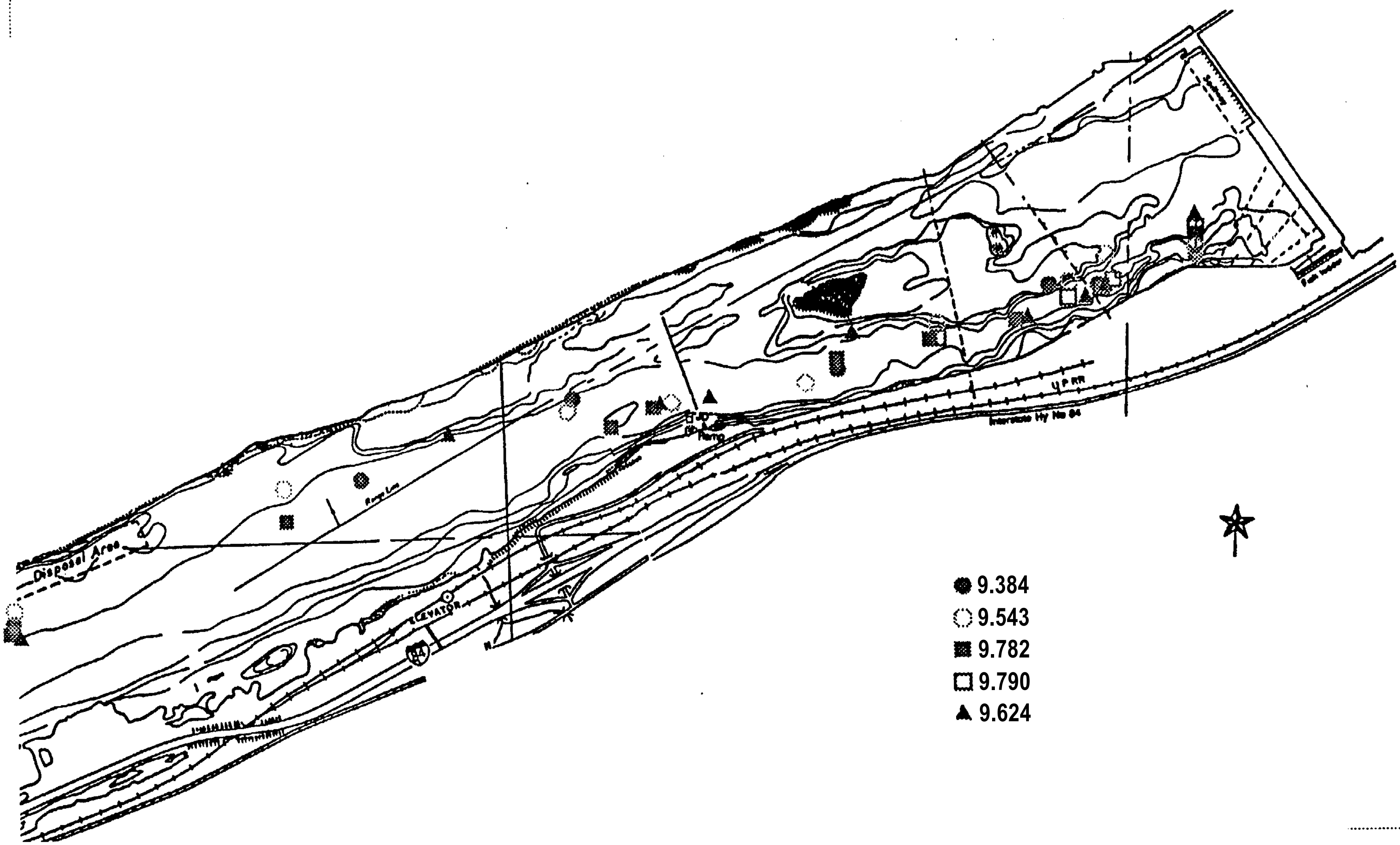
JDD Release 23 April 1 993
bypassl release at 0823
non-agitated



JDD Release 6 May 1993
bypass release at 0818
non-agitated



JDD Release 14 May 1993
bypassl release at 0827
non-agitated



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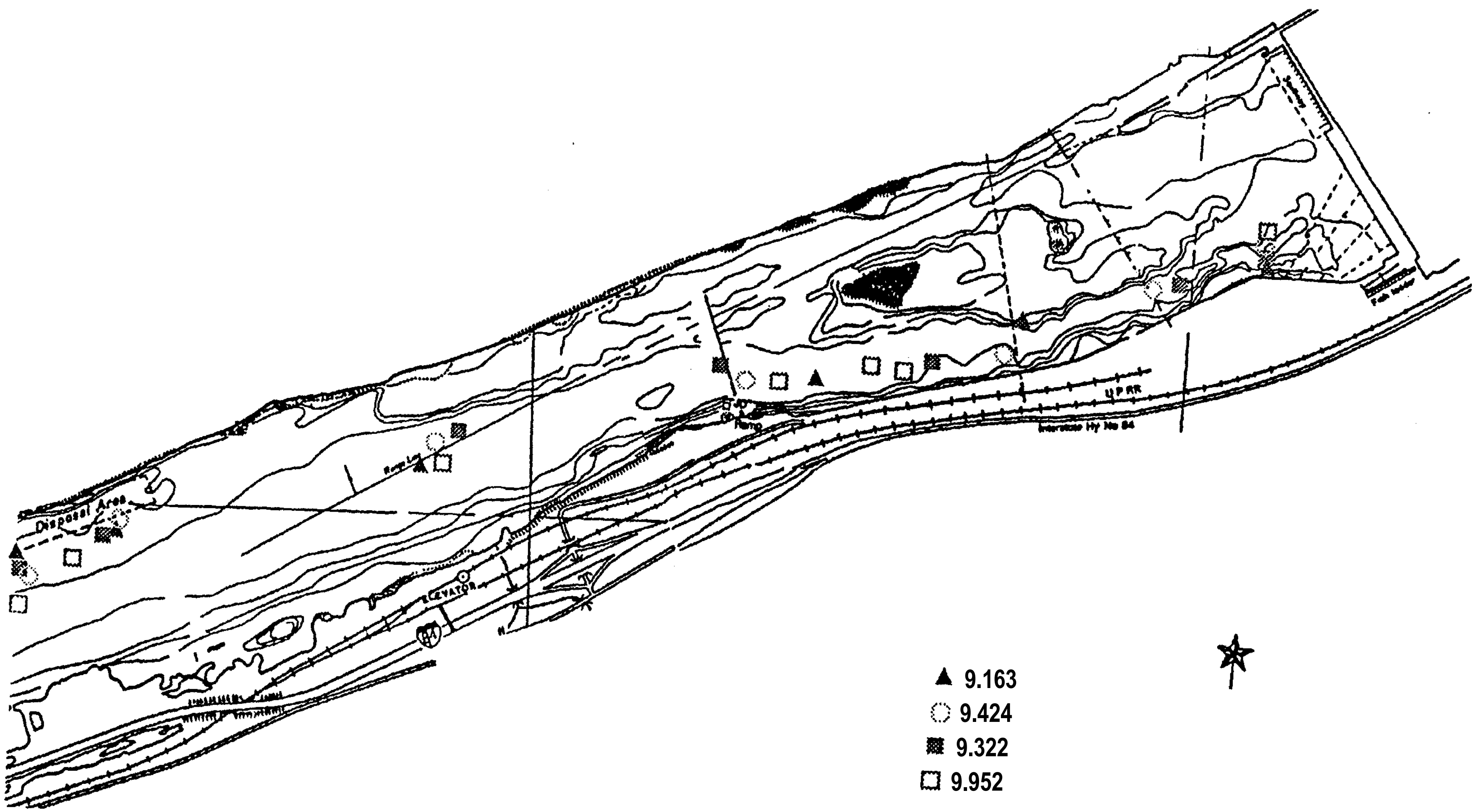
bypass release at 0654
non-agitated



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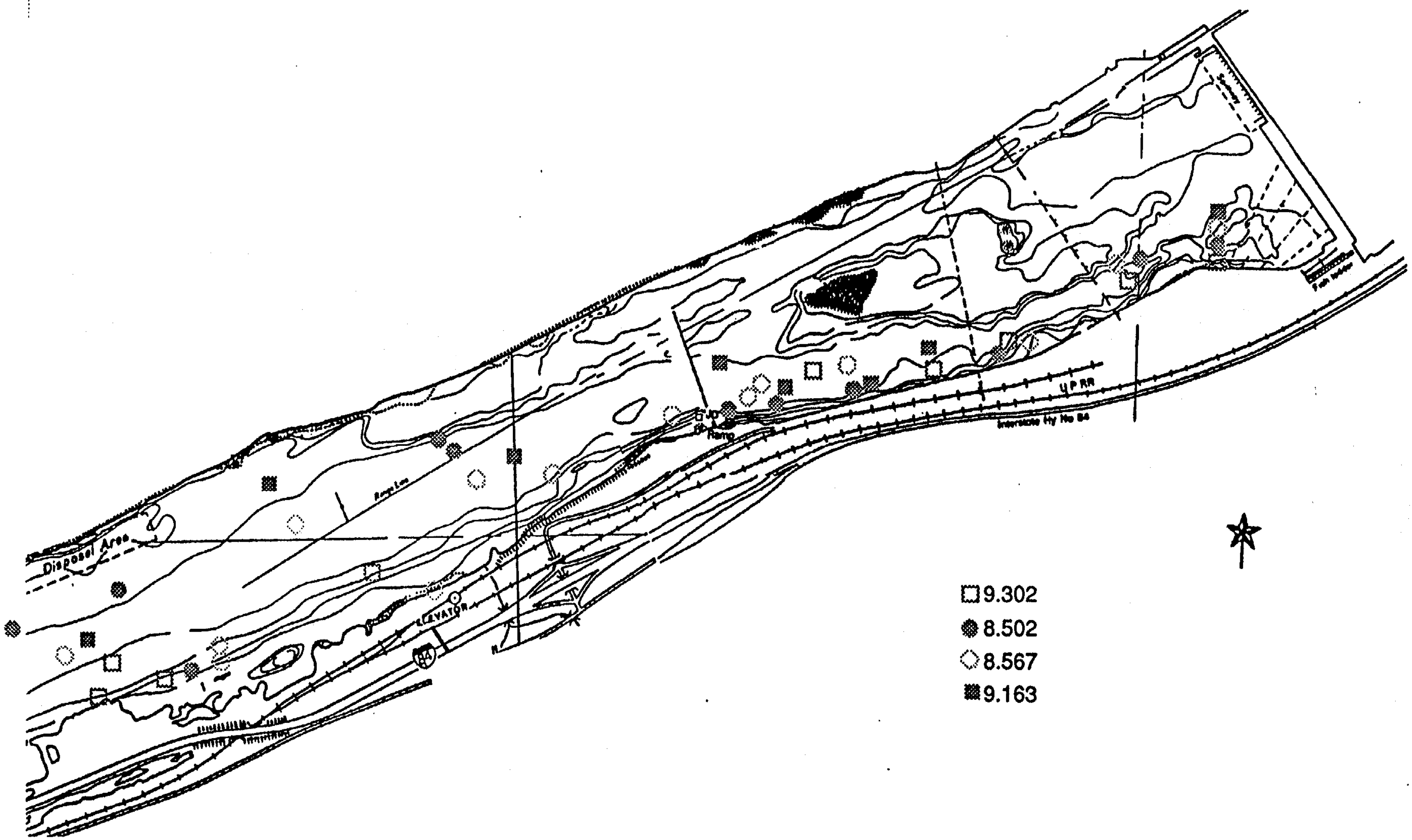

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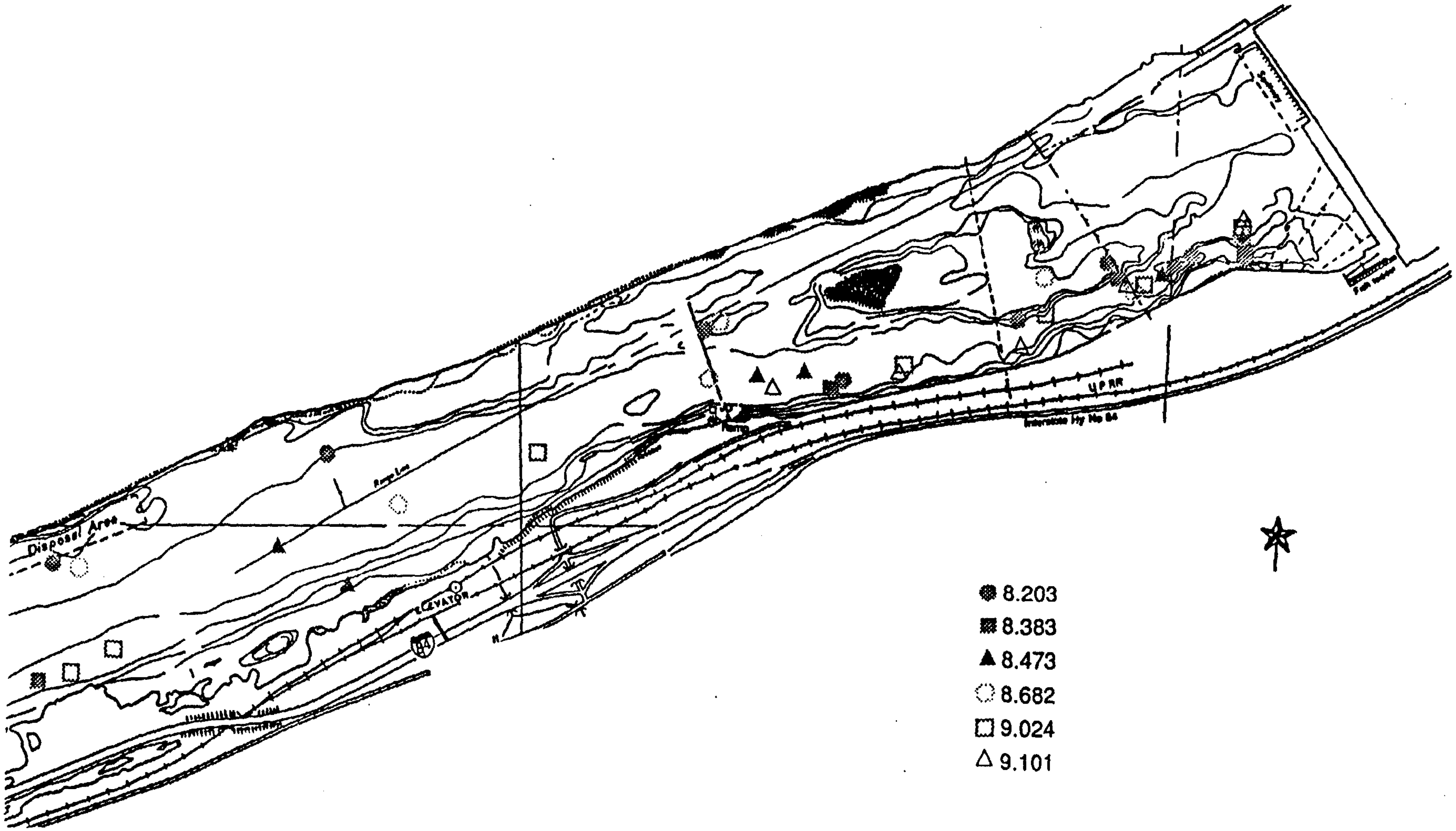
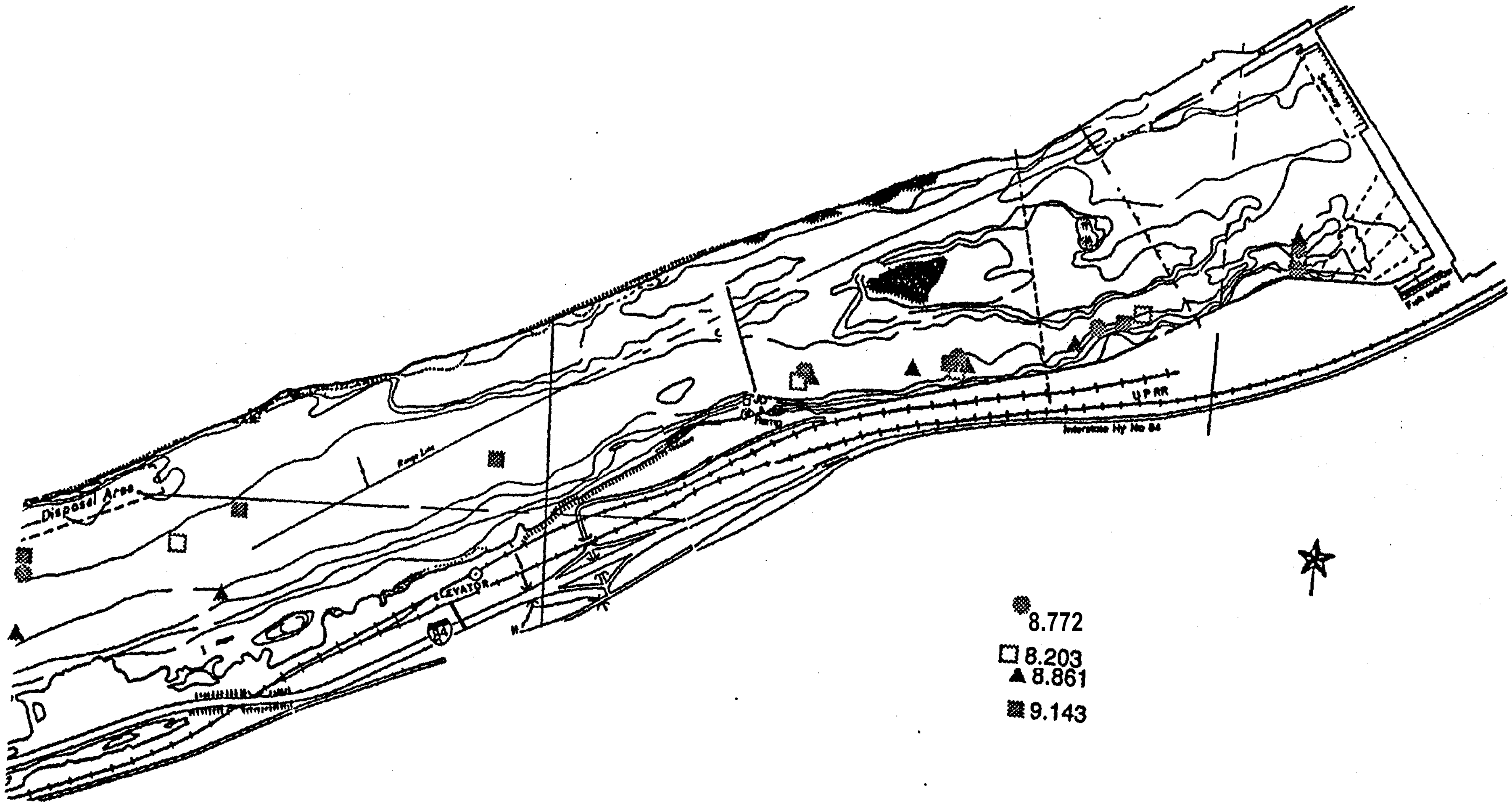


● 8.203
▩ 8.383
▲ 8.473
○ 8.682
□ 9.024
△ 9.101

JDD Release 14 May 1993
bypass release at 0827
agitated



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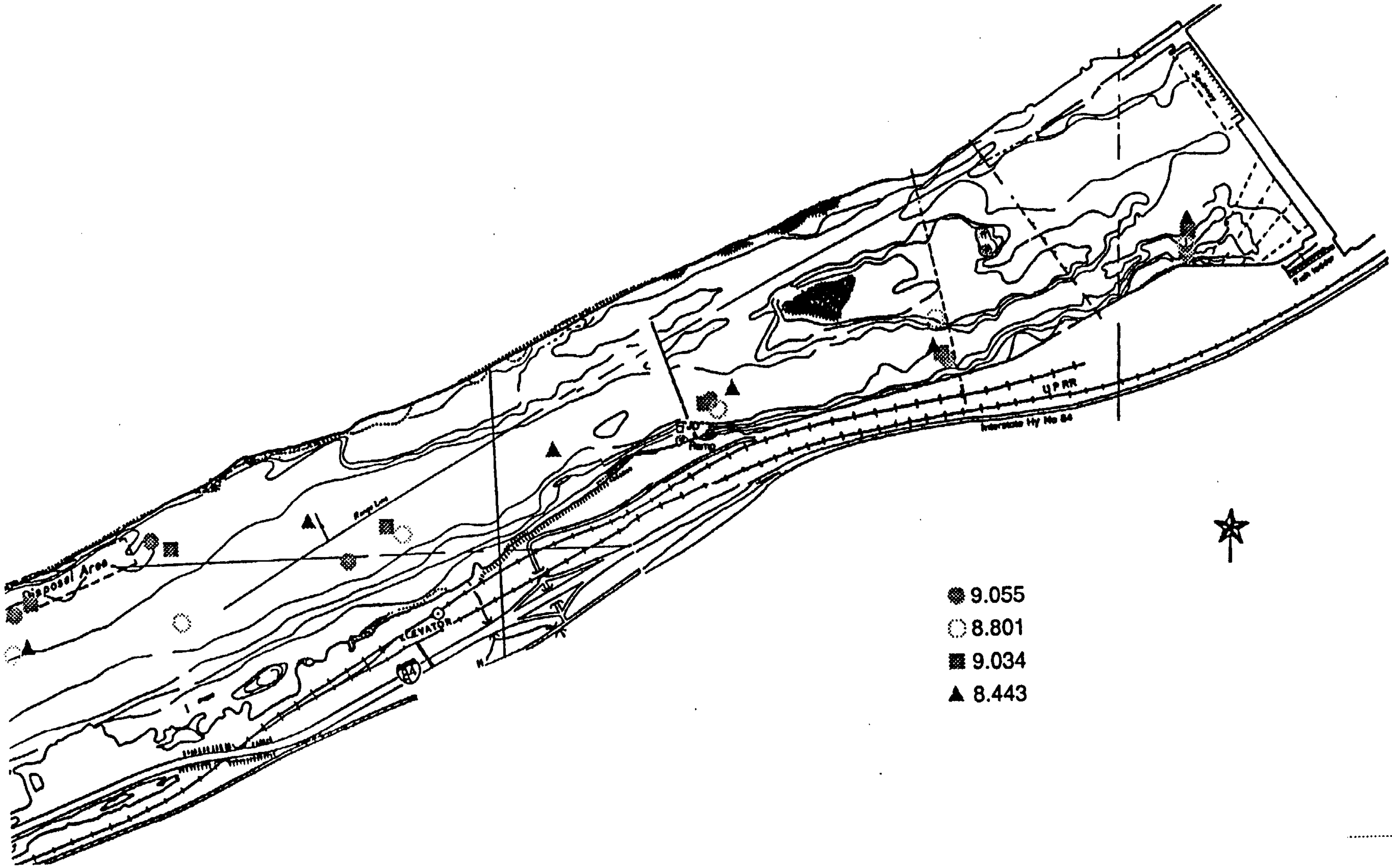

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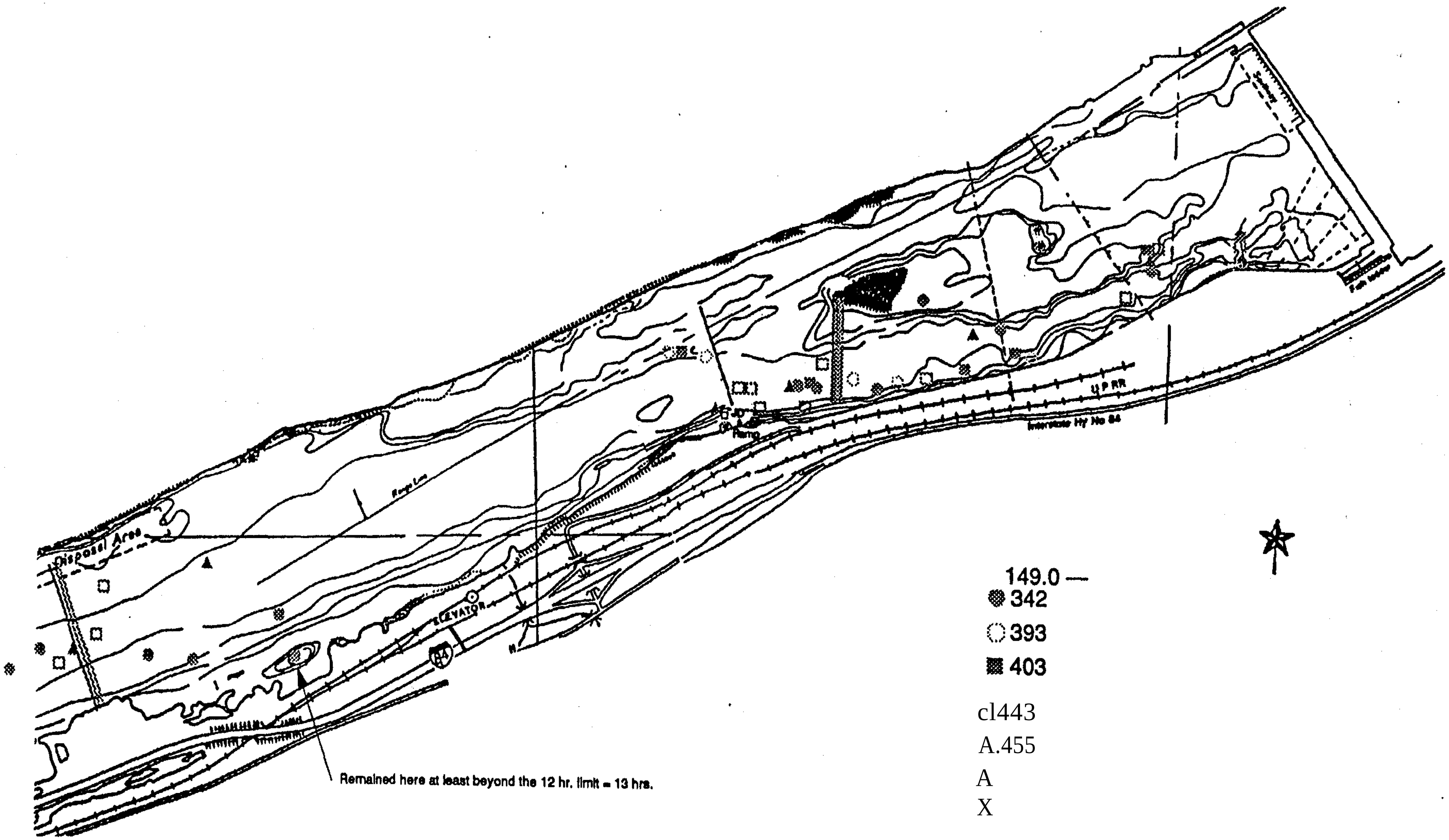
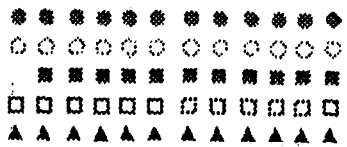
agitated



149.0 —
342
393
403
cl443
A.455
A
X



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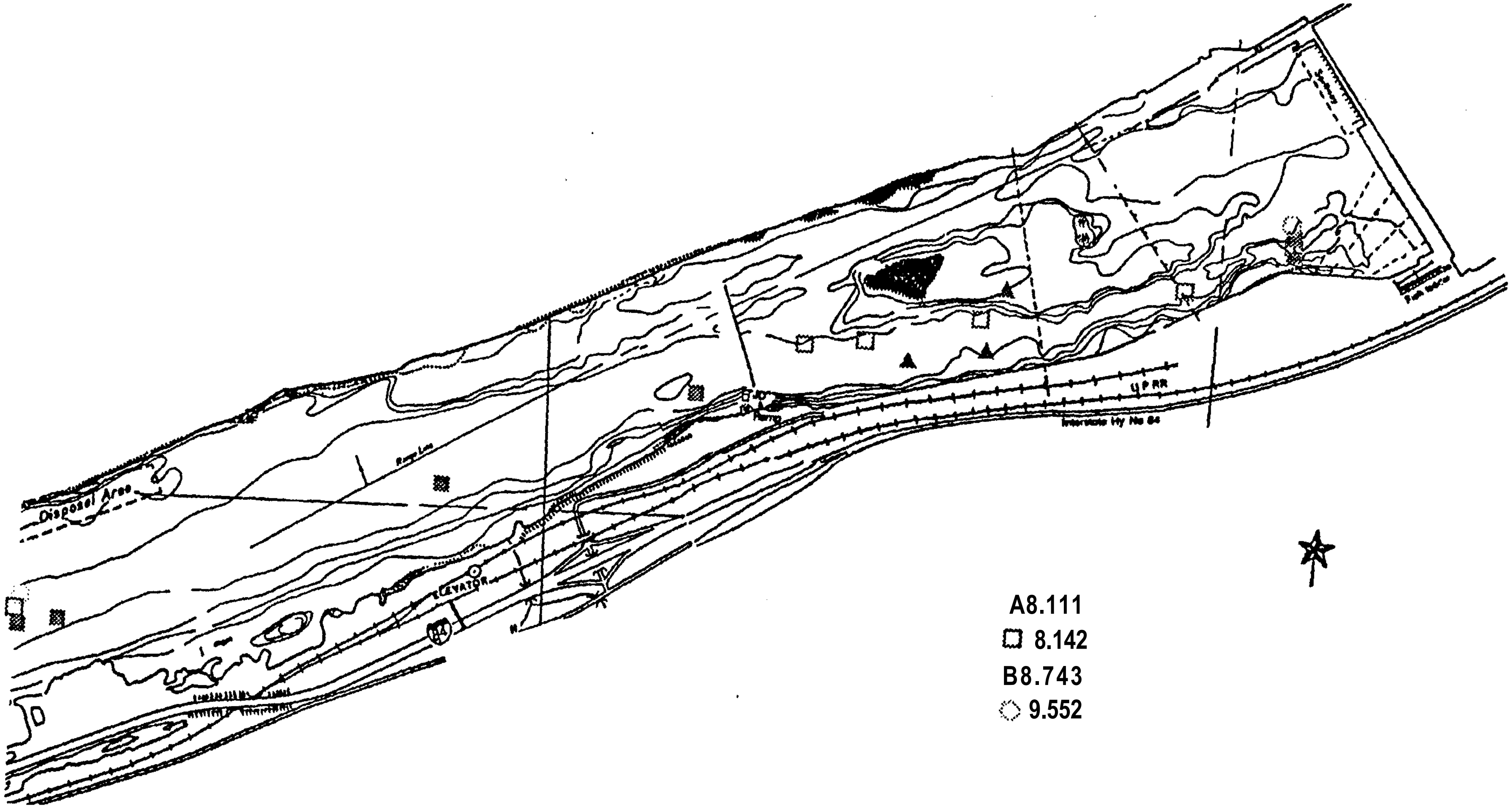
outfall release at 0822
non-agitated



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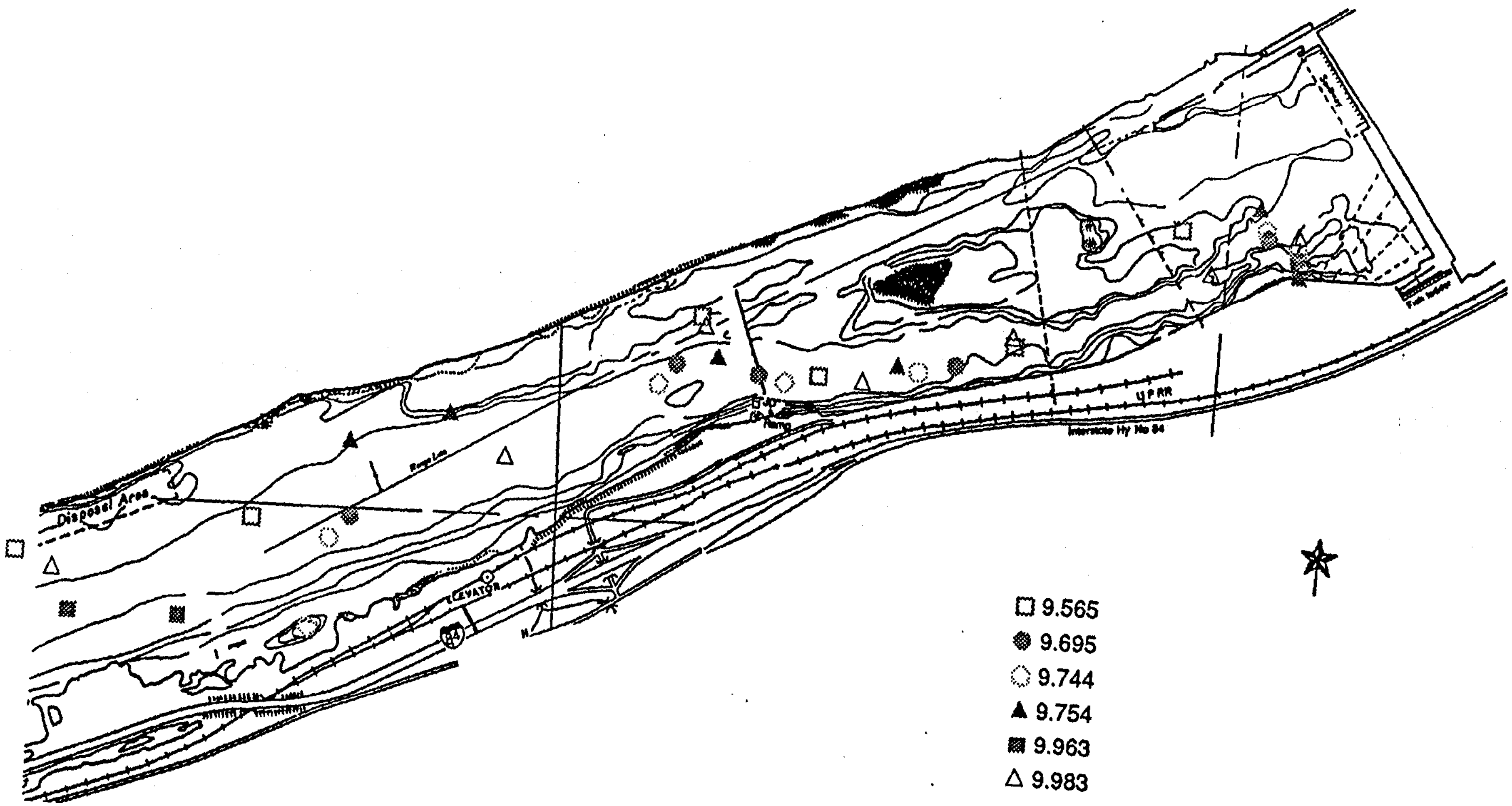
outfall release at 0805
non-agitated



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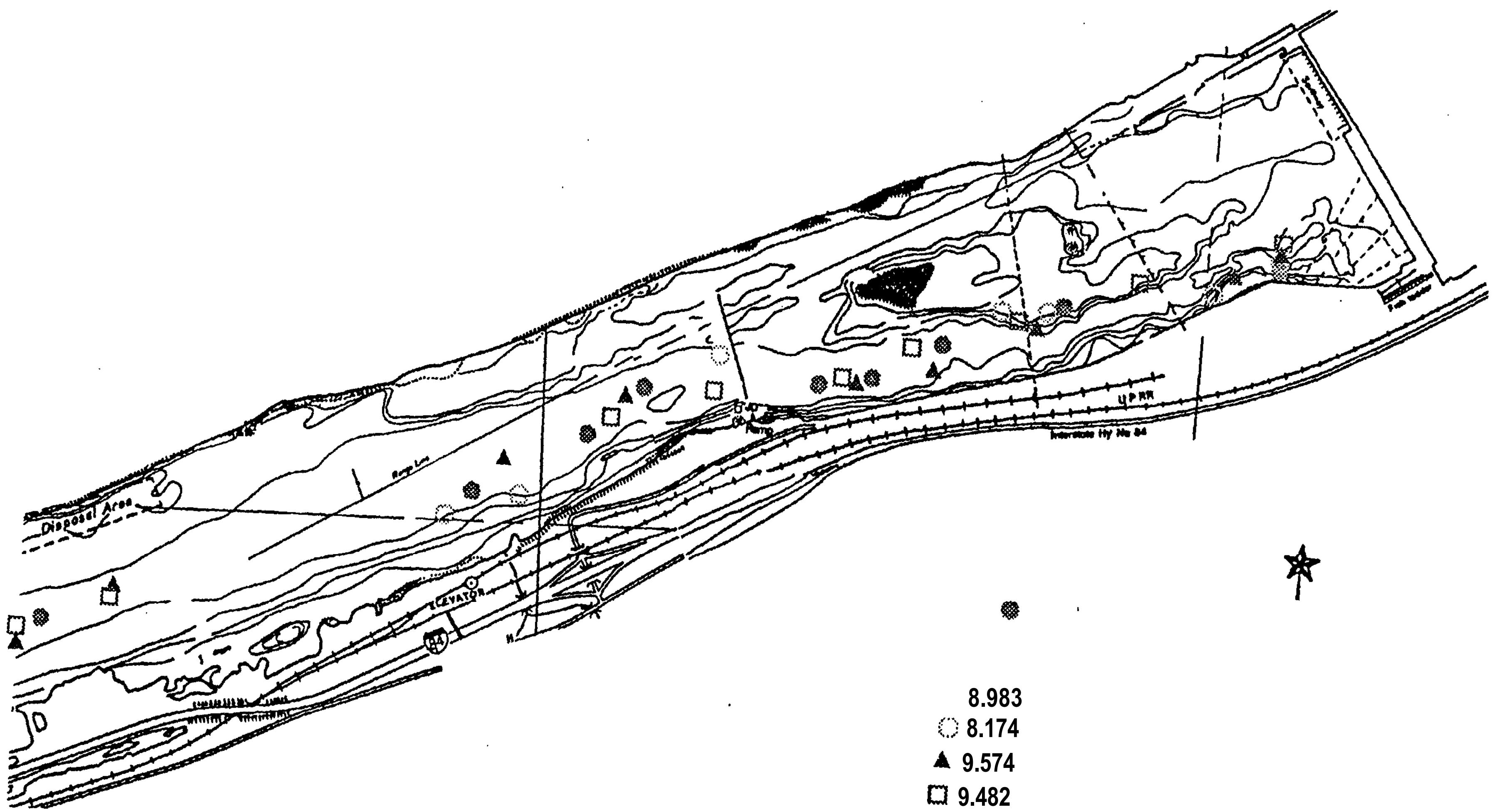
non-agitated



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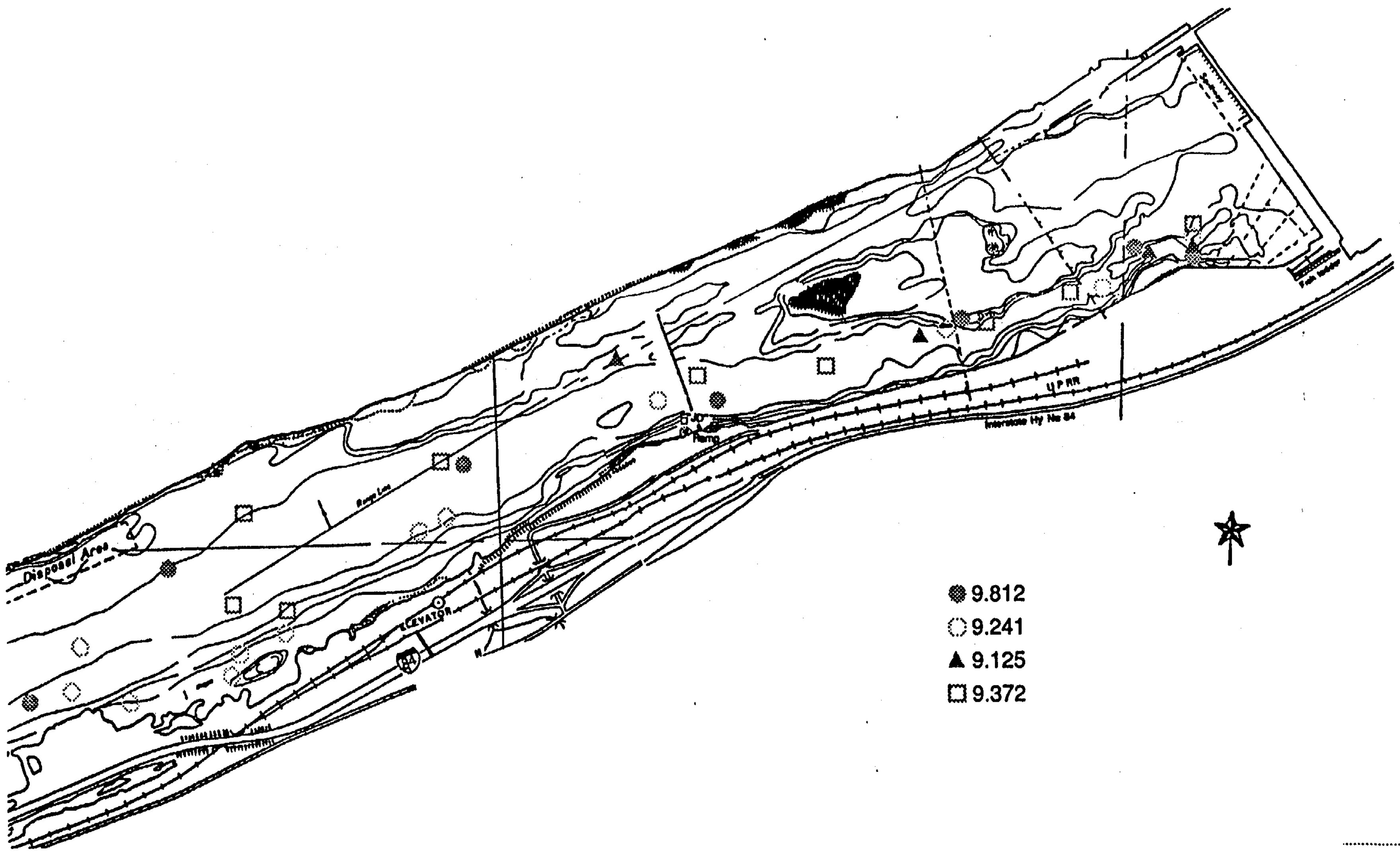

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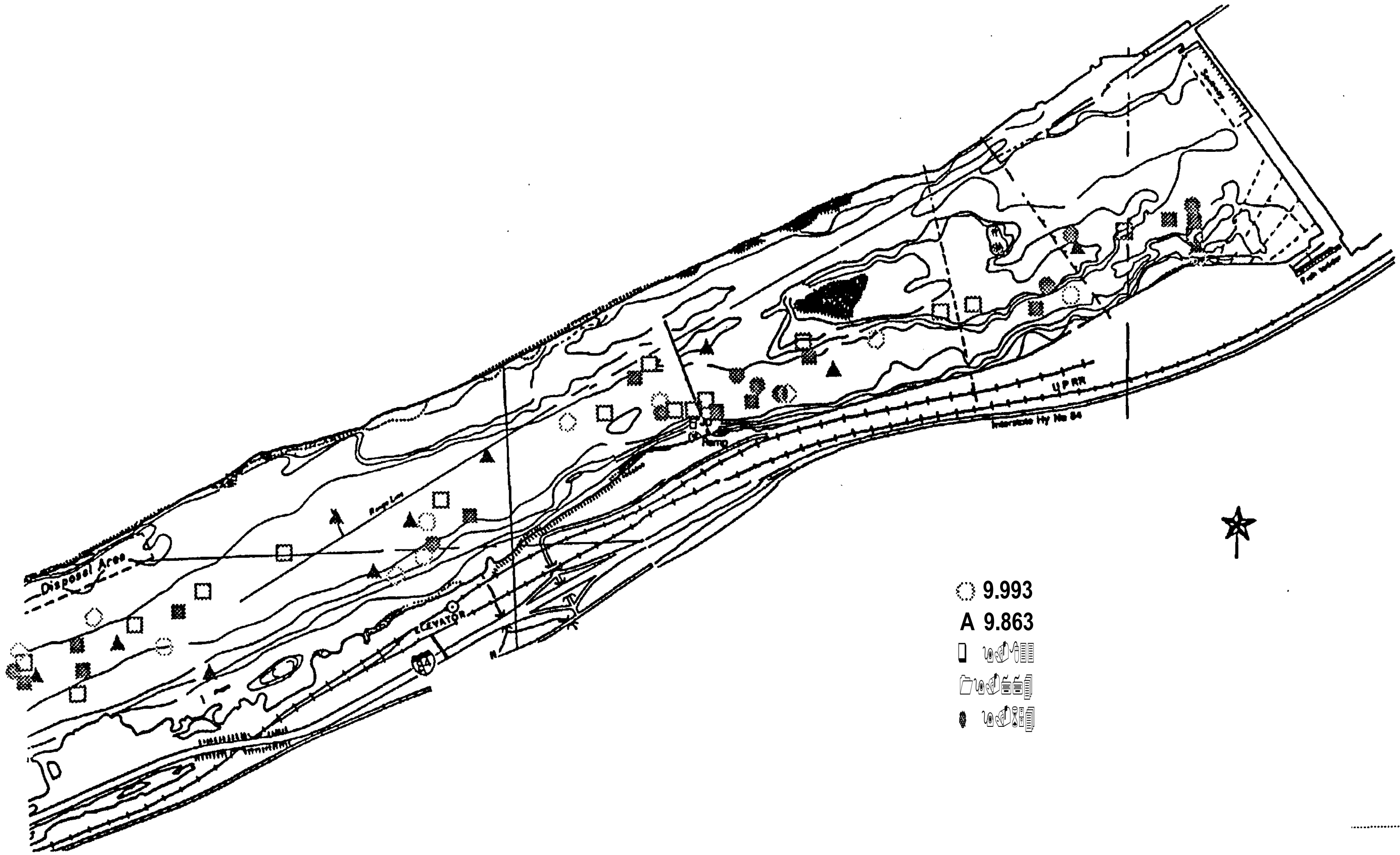

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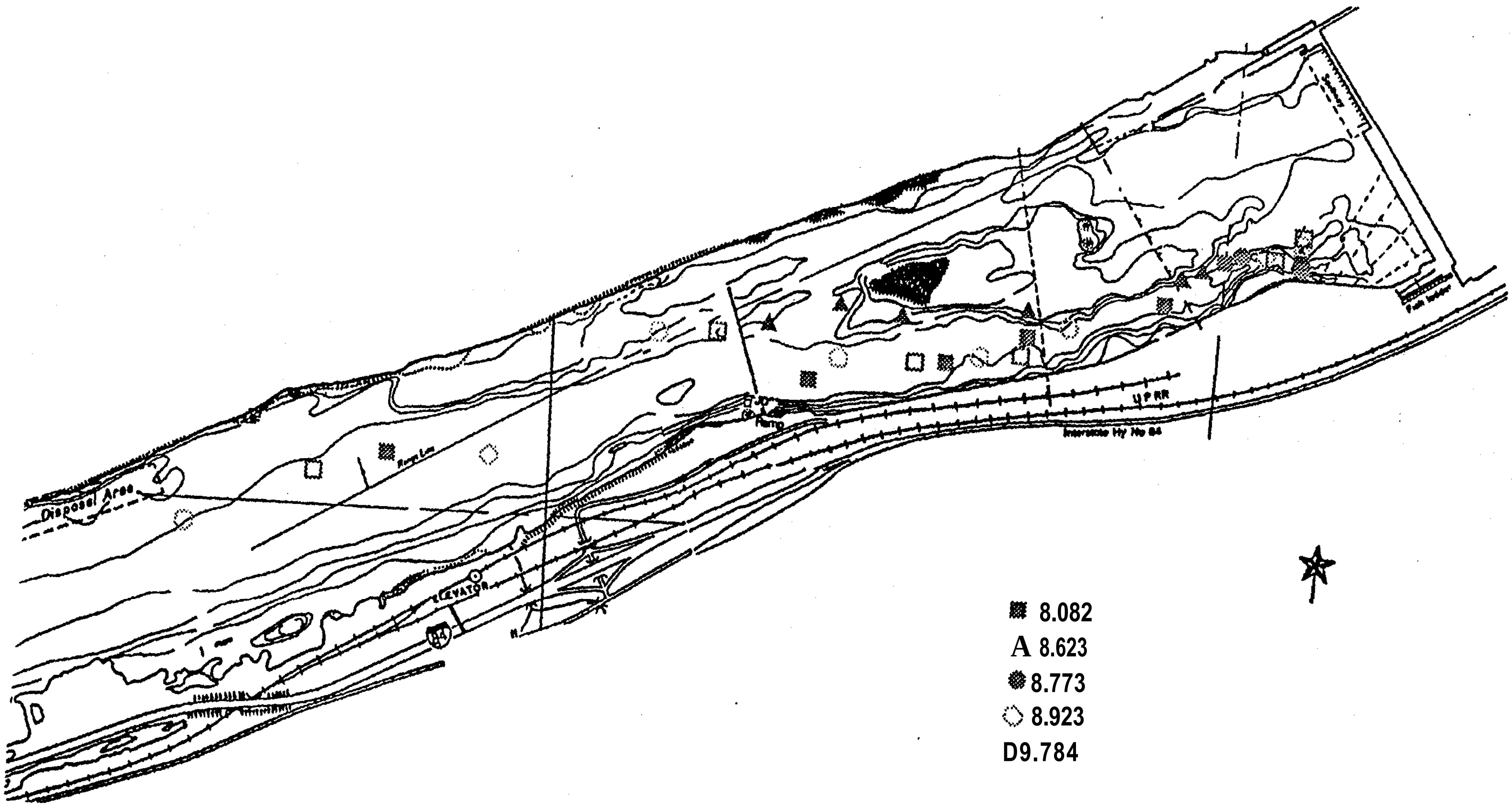
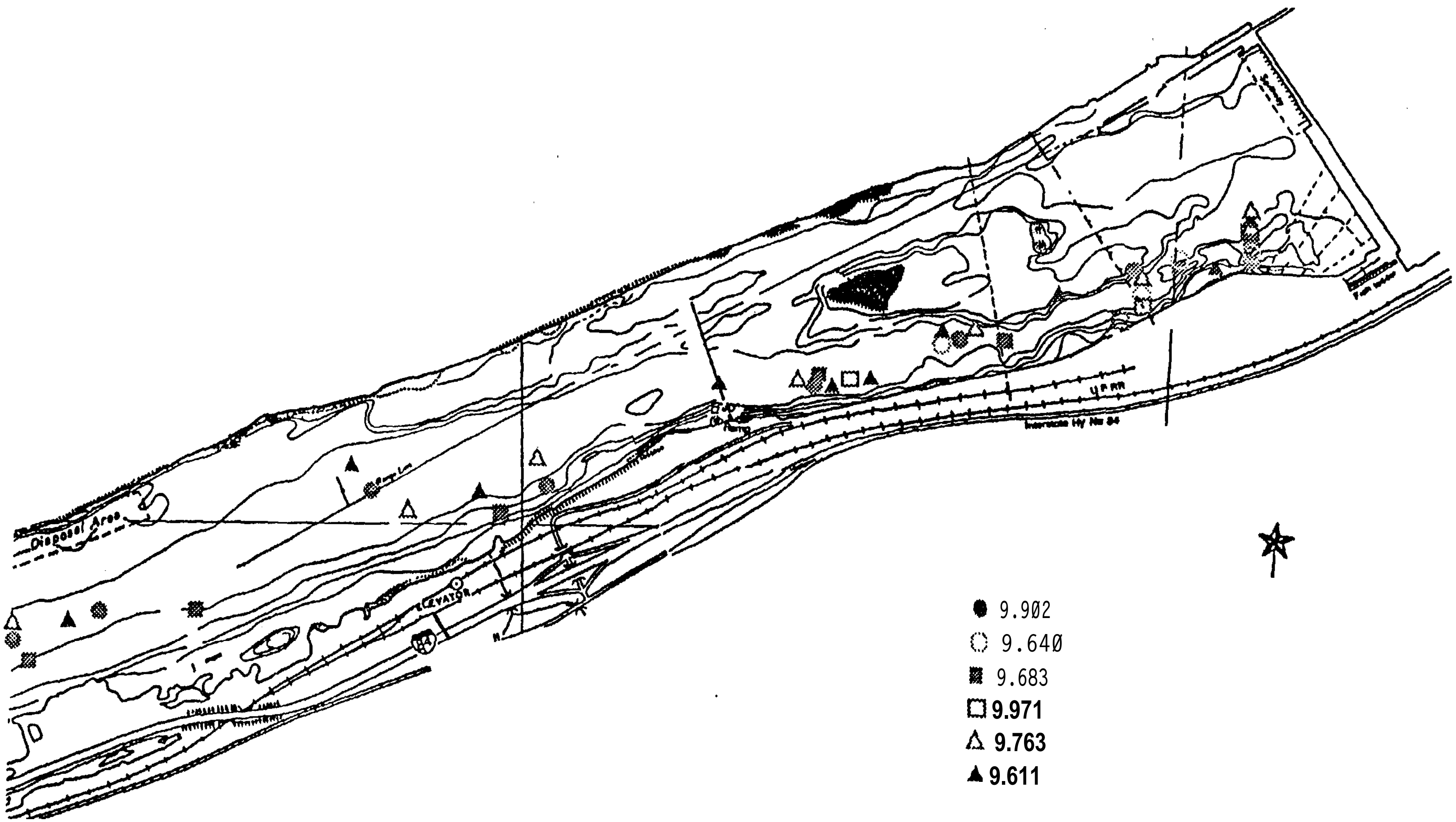
outfall release at 0805

agitated



▦ 8.082
A 8.623
● 8.773
◇ 8.923
D9.784

JDD Release 12 May 1993
outfall release at 0741
agitated



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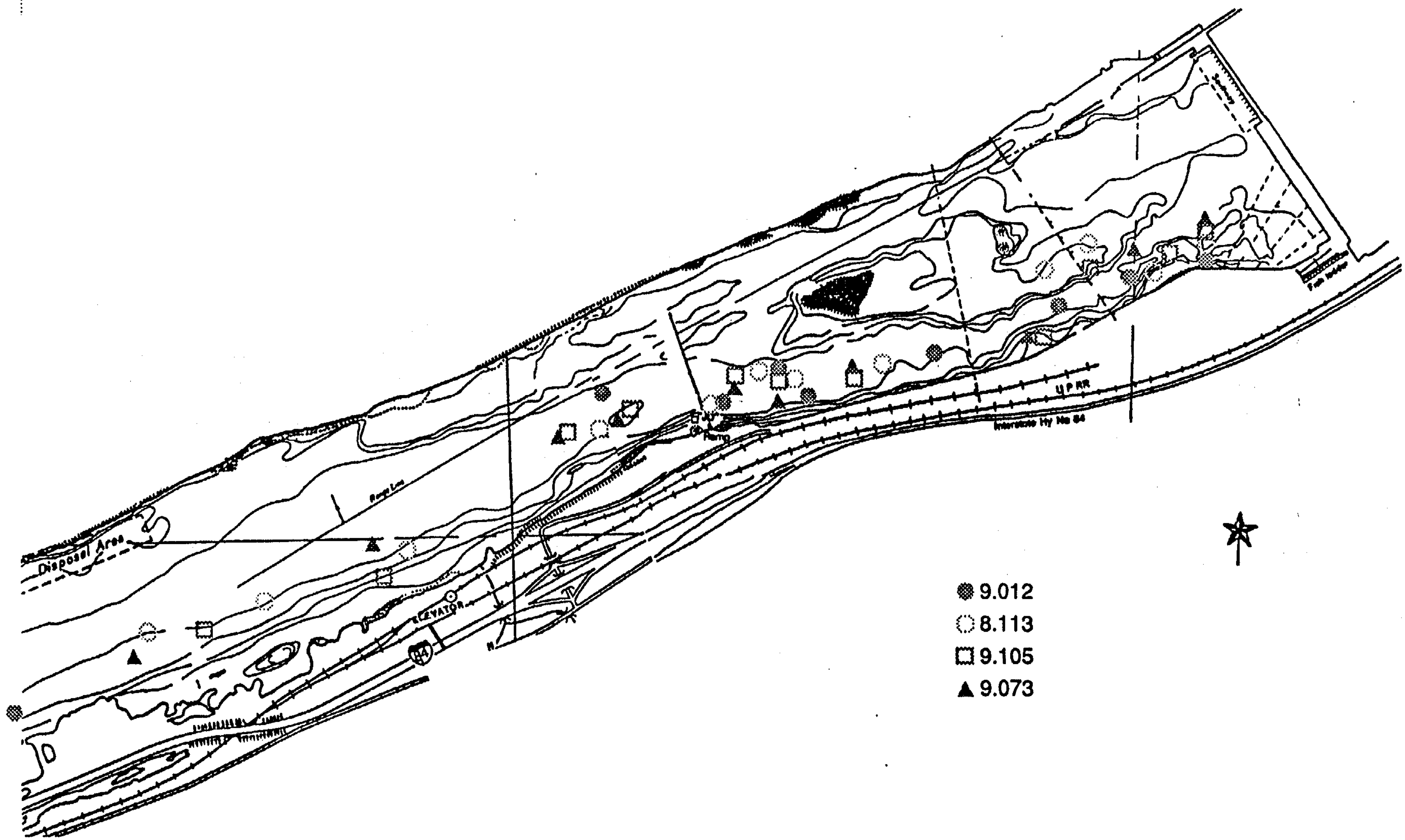

JDD Release 7 June 1993
outfall release at 0727
agitated

Part 6

Movements of Northern Squawfish in the Lower Snake River During 1993

Annual Progress Report - February 1993 - February 1994

by

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Seattle National Fisheries Research Center

1994

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Abstract

We continued a study initiated in 1992 designed to evaluate the movements of northern squawfish (*Ptychocheilus oregonensis*) downstream of hydroelectric facilities in the lower Snake River in relation to the smolt migration. The study's main objective in 1993 was to monitor changes in the abundance and distribution of squawfish in tailrace areas before, during, and after the smolt migration and relate these changes to possible causative agents.

Transmitters were implanted in 80 northern squawfish in 1993, 63 downstream of Lower Granite Dam and 17 downstream of Ice Harbor Dam. The peak abundance of squawfish in the tailrace of Lower Granite Dam coincided with squawfish spawning and did not occur until after the majority of smolts had moved past the dam. Squawfish present in tailrace areas during the smolt migration were influenced by cold water temperatures and the occurrence of spill, as a result, few squawfish were found in positions where they would encounter smolts.

After the period of spill and smolt migration, squawfish in the tailraces of both Lower Granite Dam and Ice Harbor Dam moved to areas where they could prey upon fish emerging from the powerhouse discharge. The majority of squawfish observations near the bypass outfall at Lower Granite Dam and the ice/trash sluiceway exit at Ice Harbor Dam occurred during crepuscular and nocturnal hours.

Changes in the distribution of squawfish downstream of tailrace areas varied between dams and seasonally. Downstream of Ice Harbor Dam, the majority of squawfish held midway between the Columbia River Confluence and the dam from May 25 to June 17, before moving downstream to the Columbia River sometime before June 30. The distribution of squawfish with transmitters in Little Goose Reservoir was consistent from June 26 to August 11, with 80 - 90% of the relocations occurring in the upper third of the reservoir or the tailrace. During September and November, a larger proportion of the squawfish were observed in the lower two-thirds of the reservoir.

Introduction

Predation by northern squawfish is a cause of mortality for salmon and steelhead smolts migrating downstream to the ocean (Thompson 1959; Uremovich et al. 1980; Rieman et al. 1991; Poe et al. 1991). This predation has been exacerbated in recent decades by the formation of reservoirs in the lower Snake and Columbia rivers which have probably lead to increased abundance of predators and increased the exposure of smolts to these predators by slowing their migration. Predation may be especially intense downstream of hydroelectric facilities where predator aggregations have been documented (Faler et al. 1988; Beamesderfer 199 1) and smolts are disoriented after passing a dam through the spillway, powerhouse, or bypass system.

The main objective of our study was to use radio-telemetry to monitor and assess the movements of northern squawfish downstream of two lower Snake River darns, particularly in tailrace areas and near outfalls from smolt bypasses. Building on methodologies developed and information gained in 1992, we again monitored movements of squawfish downstream of Lower Granite Dam and expanded the project to include Ice Harbor Dam in 1993 (Figure 1).

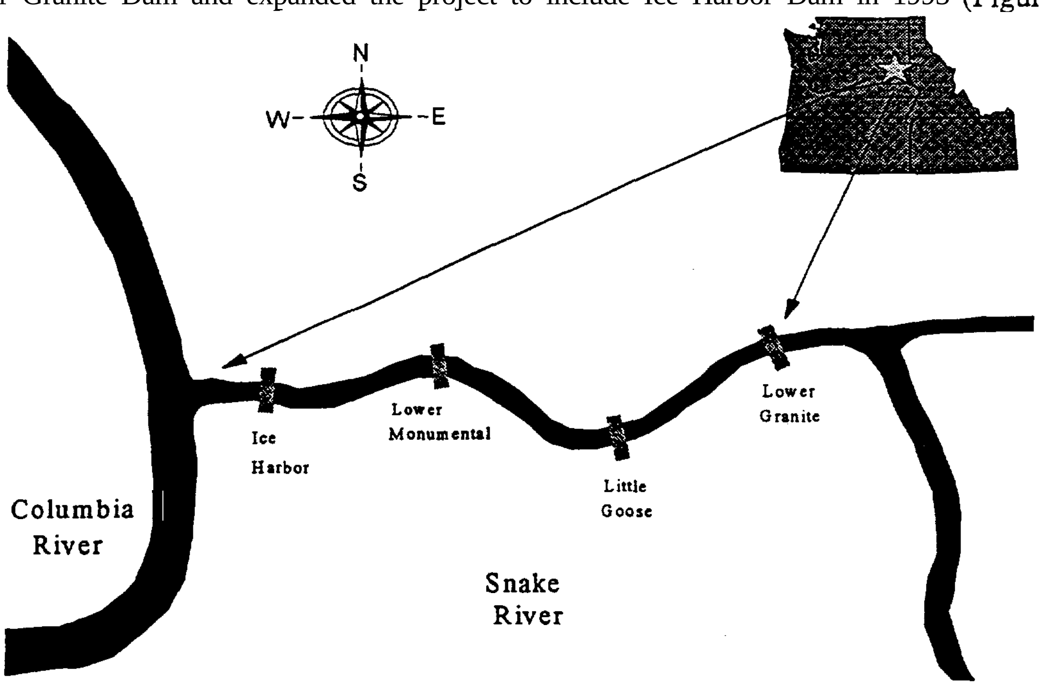


Figure 1. Map of lower Snake River study area in 1993.

Specific objectives for 1993 were as follows:

Ice Harbor Dam Objectives

1. Monitor the effect that spill has on the distribution of squawfish in the tailrace.
2. Monitor the presence/absence of squawfish near the ice/trash sluiceway in the tailrace.
3. Monitor the distribution of squawfish between Ice Harbor Dam and the Columbia River confluence.

Lower Granite Dam, Objectives

4. Monitor the presence/absence of squawfish in the tailrace in relation to the smolt migration.
5. Monitor the distribution of squawfish in the tailrace in relation to spill, smolt migration, diel periods, and squawfish spawning.
6. Determine whether squawfish use specific areas in the tailrace in proportion to their availability.
7. Monitor the presence/absence of squawfish near the smolt bypass outfall in the tailrace.
8. Monitor the distribution of squawfish throughout Little Goose Reservoir.

Methods

Transmitters were implanted in 80 northern squawfish using a shielded-needle technique (Ross and Kleiner 1982) during 1993, with 63 squawfish released downstream of Lower Granite Dam from April 3 to June 12 (Appendix A). We caught 2.11 squawfish (> 340 mm total length) per hour during 35.5 hours of boat electrofishing downstream of Lower Granite Dam. High flows and cold water temperatures in the lower Snake River during the spring of 1993 (Figure 2) kept squawfish dispersed downstream from the tailrace and thus, most of the squawfish were captured 1/2 to 3 miles downstream of Lower Granite Dam. Low catch rates made it impractical to implant transmitters in each fish as it was caught, therefore, we electrofished until several fish were captured, took the fish to Boyer Marina (1.7 miles

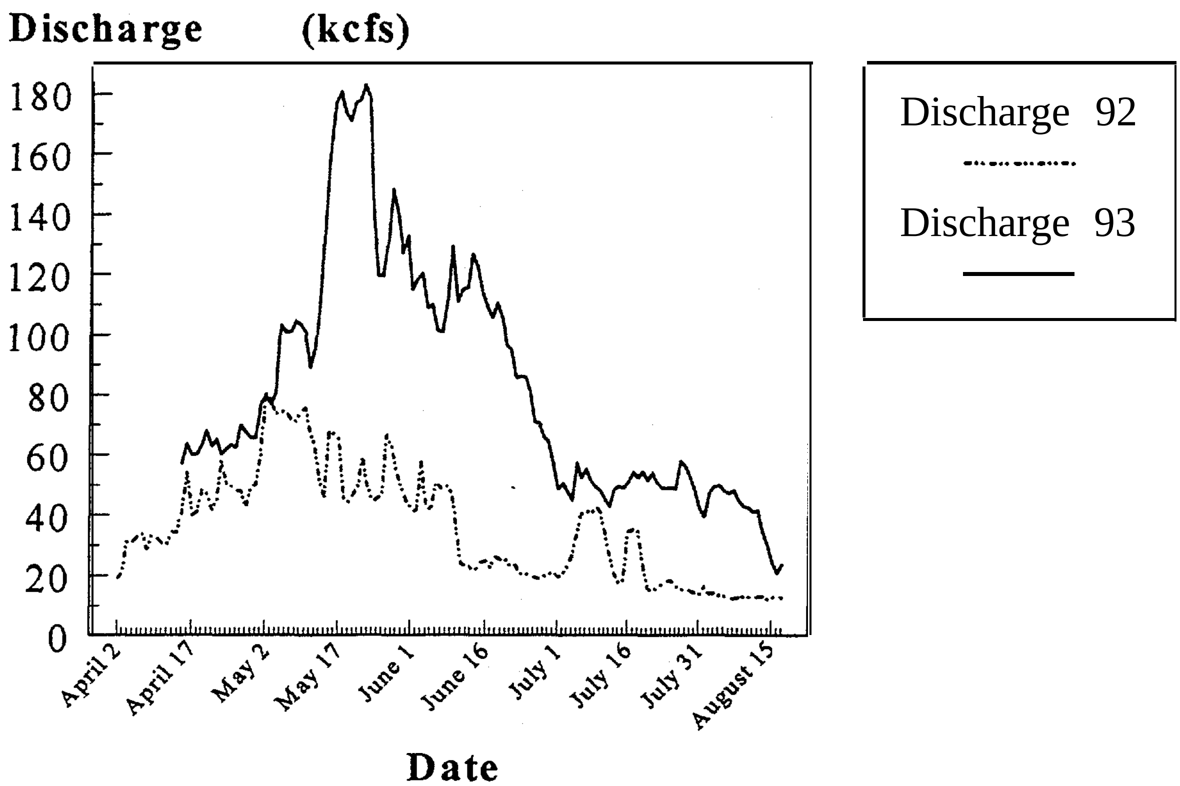


Figure 2. Comparison of 1992 and 1993 hydrographs at Lower Granite Dam.

downstream from Lower Granite Dam), implanted the transmitters, and released the fish in the marina. All fish eventually left the marina and many were subsequently relocated in areas similar to those from which they had been captured. The final eight fish were captured in the tailrace of the dam on June 12, implanted with transmitters, and released there.

A jetboat equipped with a Yagi antenna, telemetry receiver, and a global positioning receiver was used approximately three times a week from April 21 to August 19 to locate all transmitter equipped squawfish near Lower Granite Dam. Half the surveys were conducted during the night and half during the day. Once a signal from a transmittered squawfish was received, we moved the jetboat to a position over the fish and that location was then recorded using the global positioning receiver. During periods of spill when the boat could not be used, squawfish were located within the tailrace by taking two simultaneous bearings on their positions using Yagi antennas and telemetry receivers. Several fixed receiving sites consisting of a datalogging receiver and a Yagi antenna were used to continuously monitor squawfish movements in portions of the Lower Granite Dam tailrace (Figure 3). The distribution of squawfish throughout Little Goose Reservoir was monitored from June 26 to November 11 using the jetboat.

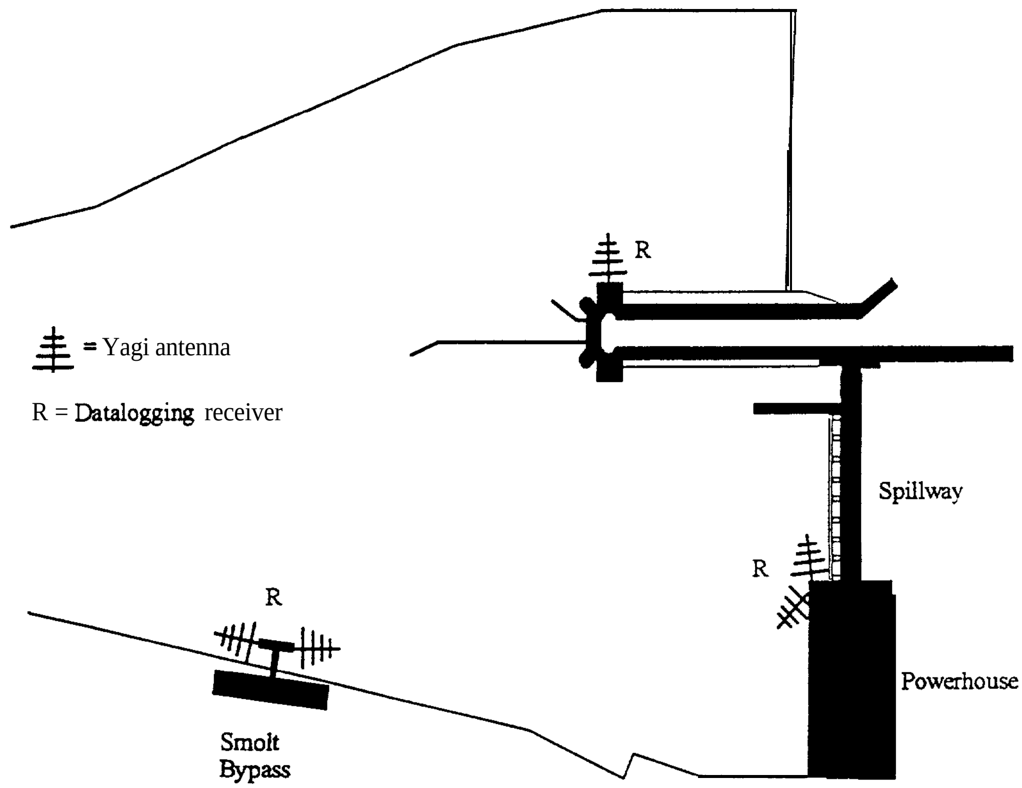


Figure 3. Fixed receiving sites used to monitor movements of northern squawfish in the tailrace of Lower Granite Dam in 1993.

Seventeen squawfish were implanted with transmitters and released downstream of Ice Harbor Dam between May 13 and June 19 (Appendix A). During 48 hours of boat electrofishing downstream of Ice Harbor Dam, we had a catch rate of 0.52 squawfish (> 340 mm total length) per hour. Similar to the situation at Lower Granite Darn, squawfish tended to be dispersed downstream from the dam.

All squawfish equipped with radio-transmitters between Ice Harbor Dam and the Snake-Columbia river confluence were located approximately every ten days from May 25 to August 17 using a jetboat equipped with a Yagi antenna, telemetry receiver, and a global positioning receiver. All fish were located during daylight hours. Several fixed receiving sites were used to continuously monitor squawfish movements near Ice Harbor Dam (Figure 4).

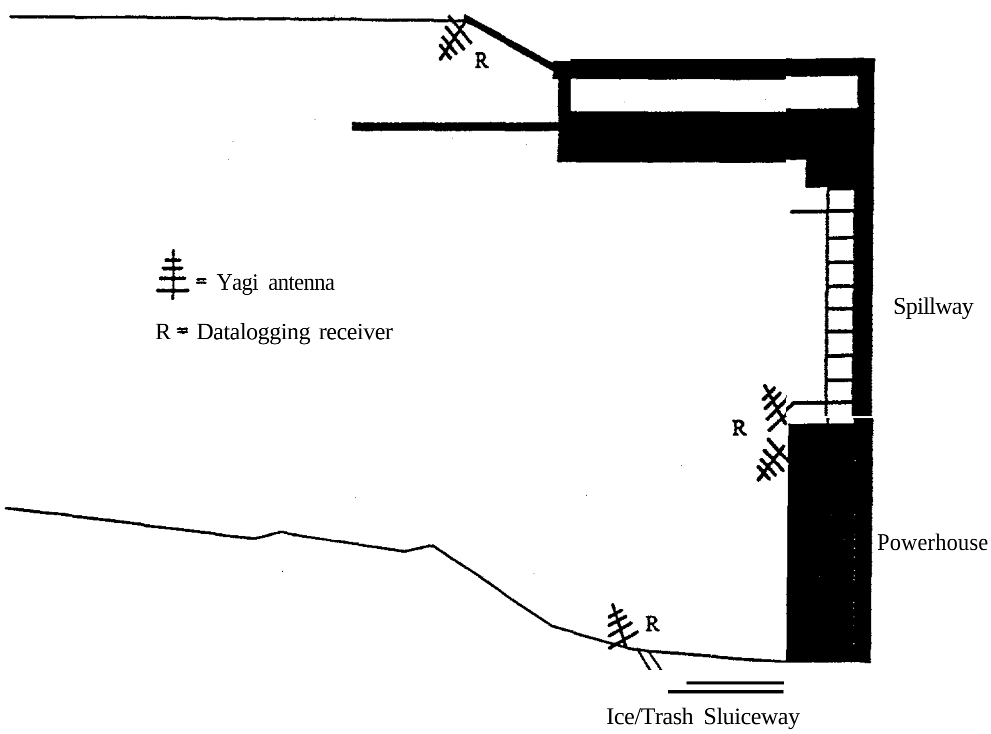


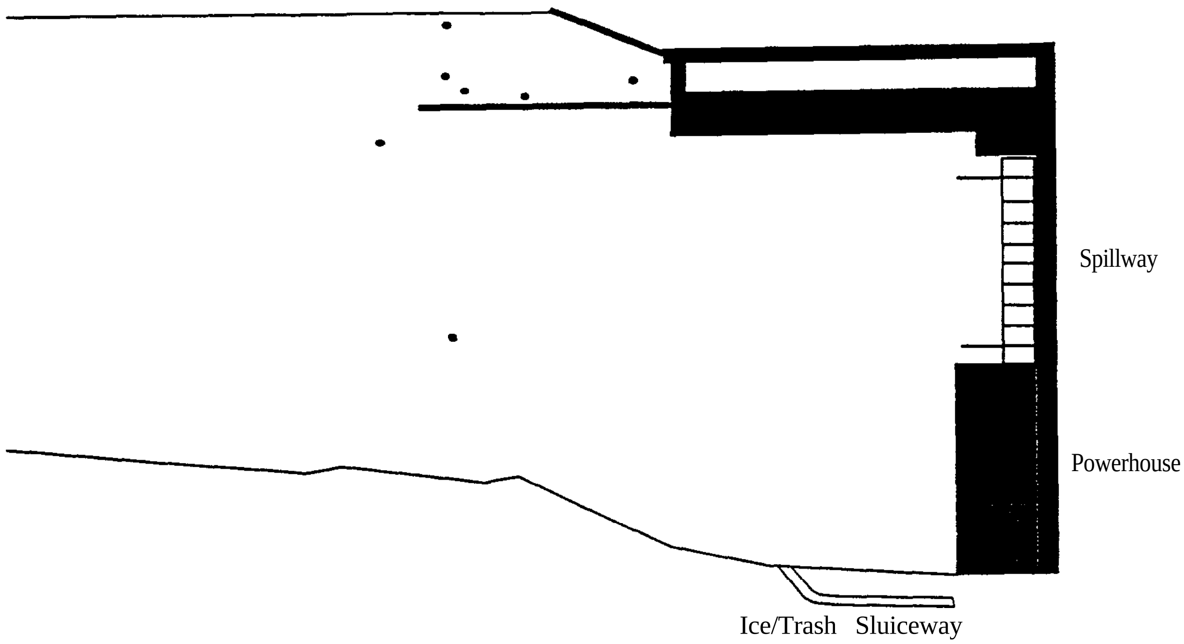
Figure 4. Fixed receiving sites used to monitor the movements of northern squawfish in the tailrace of Ice Harbor Dam in 1993.

Results

Spill and the distribution of squawfiih in the tailrace of Ice Harbor Dam.

Tailrace observations of squawfish with transmitters were partitioned based on the amount of spill at Ice Harbor Dam (Corp of Engineers, unpublished). Observations from May 25 to June 17 were made when spill was occurring almost continuously. During this period, two fish were heard but could not be located because of the spill pattern. Observations from June 30 to August 17 were made after spill during daylight hours had ceased (Figure 5). During periods of continual spill, squawfish were usually found in the slackwater behind the lock guidewall, after spill during the day had ceased, fish were located in the still water of the spilling basin or downstream of the tailrace, but in the main river channel. In both cases, the majority of squawfish were located in areas of little or no water velocity. Although the data is limited, we conclude that the distribution of squawfish varied in response to the amount of spill that was occurring.

Observations taken during continuous spill (n = 7; May 25 to June 17, 1993).



Observations taken with no daytime spill (n = 13; June 30 to August 17, 1993).

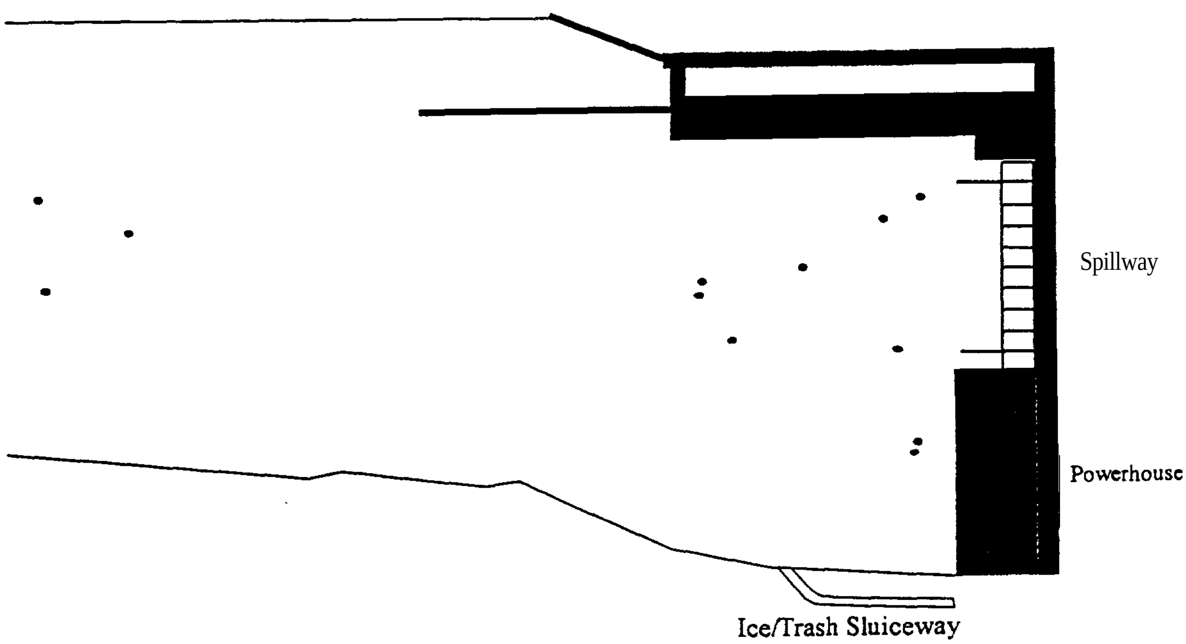


Figure 5. Distributions of squawfish in relation to spill level in the tailrace of Ice Harbor Dam during 1993.

Presence of squawfish near the ice/trash sluiceway exit in the tailrace of Ice Harbor Dam.

Six different fish were recorded from June 8 to August 10 by the receiver located near the sluiceway exit. The receiver recorded multiple records on individual fish if they remained within the reception range of the antennas for extended periods of time or if they iteratively moved into the area and left. To avoid weighting our sample with a few fish which remained in the area for extended periods, no more than one observations was given to each fish during a six hour period, whether that fish was recorded 100 or 10 times during a six hour interval. The hourly distribution of these observations was tested for uniformity using a Watson edf test (Figure 6; Stephens 1974). The null hypothesis of uniformity was rejected (U^2 = 1.2289,

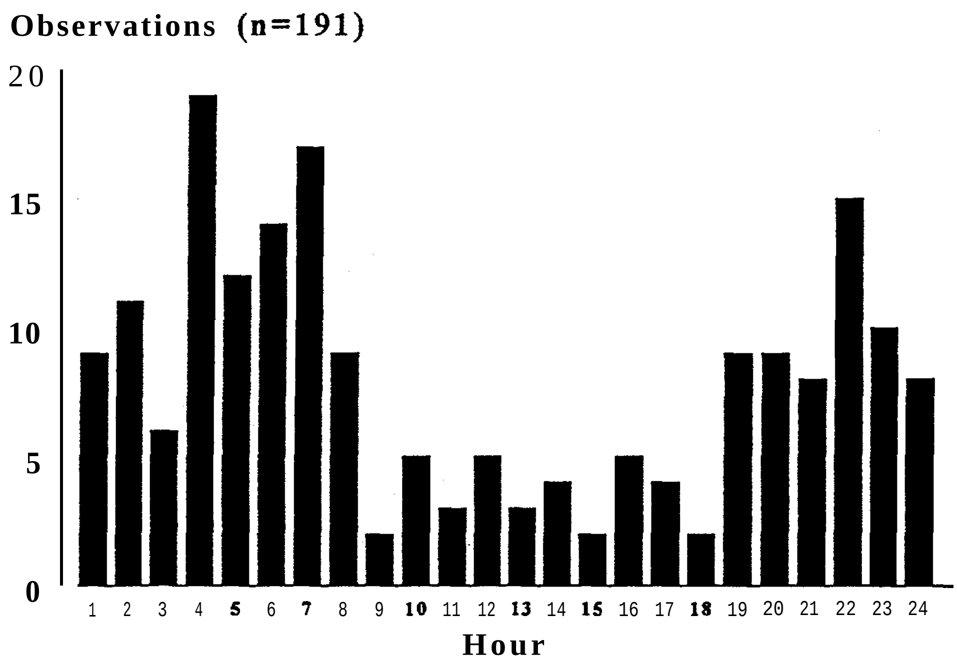


Figure 6. Histogram displaying northern squawfish observations by hour near the ice/trash sluiceway in the tailrace of Ice Harbor Dam during 1993.

p c 0.01) and we conclude that the hourly distribution of squawfish observations near the ice/trash sluiceway was not uniform. It appears that the majority of observations occurred from 7:00 pm to 8:00 am. The interpretation of these results must be exercised with caution because of the small number of fish represented in the sample (n = 6) and the impossibility of quantifying the antenna range due to the turbulent waters near the ice/trash sluiceway. Additionally, the reception range of the antenna may have been altered by periodic changes in electrical interference from nearby powerlines.

Distribution of squawfish between Ice Harbor Dam and the Snake-Columbia river confluence.

The distribution of transmitter equipped squawfish in the Snake River downstream from Ice Harbor Dam was surveyed nine times from May 25 to August 17 using the jetboat. The majority of fish were found midway between the dam and confluence during the first four surveys (Figure 7). This changed between the June 17 and June 30 surveys, when most of the squawfish moved from the sample reach. Several squawfish were subsequently relocated in the Columbia River and we believe this is where the majority of fish went.

Abundance of squawfish in the tailrace of Lower Granite Dam in relation to the smolt migration.

Fifty-five of the 63 squawfish released downstream of Lower Granite Dam were released in Boyer Marina (1.7 miles downstream), the first 40 of these were released in April before the smolt migration began. We monitored the proportion of these fish that were present in the tailrace through the spring and into summer to look for associations between their behavior, the smolt migration, and river discharge (Figure 8). During the latter half of April, the percentage of transmitter equipped squawfish located in the tailrace rose in concert with increases in the number of smolts passing Lower Granite Dam. The percentage then declined as discharge peaked, suggesting that fish were being physically excluded from the tailrace. The percentage of squawfish found in the tailrace then increased during June and July to a peak in mid-July. This peak coincided with squawfish spawning based on the condition of fish being turned in at the bounty checkstation located at Boyer Marina (personal communication, squawfish checkstation attendants) and was after the majority of smolts had migrated through the system.

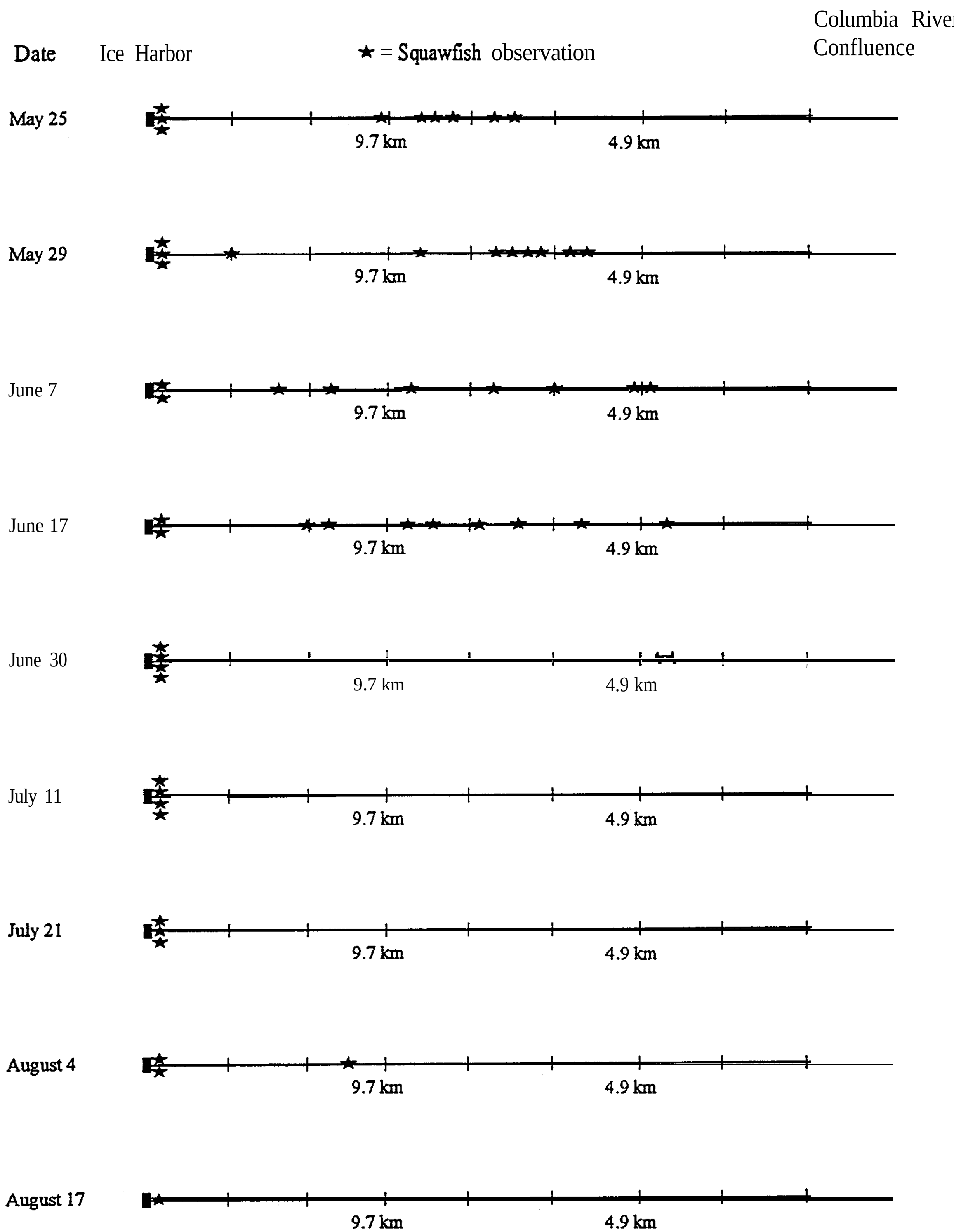


Figure 7. Distribution of squawfish between Ice Harbor Dam and the Columbia River Confluence from May 25 to August 17, 1993.

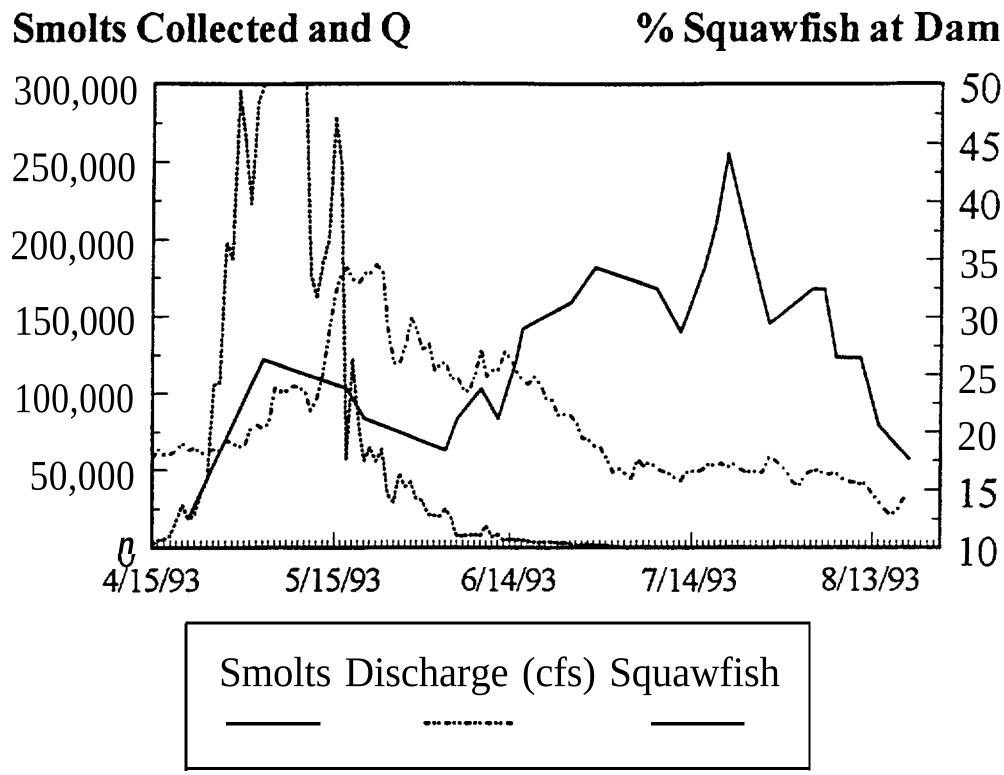


Figure 8. Percentage of northern squawfish found in the tailrace of Lower Granite Dam in relation to river discharge and the smolt migration in 1993.

Distribution of squawfish in the tailrace of Lower Granite Dam in relation to spill, smolt migration, diel periods, and the squawfish spawn.

Mobile tracking observations were partitioned by spill period, diel period, and stage of the squawfish spawn based on which comparisons were desired. We first evaluated the distribution of squawfish in response to spill by subdividing our observations into pre-spill (April 21 to May 7), spill (May 17 to June 5), and post-spill periods (June 9 to November 20) (**Figure** 9). It is important to note that pre-spill and spill periods coincided with the smolt migration in 1993 (Figure 8). We assumed that the majority of smolts in the tailrace were found in areas of discharge from the powerhouse and spillway. Few squawfish were found in tailrace areas where they would encounter smolts until after the migration was nearly complete; most were found in the slackwater areas north of the lock and in the spilling basin.

Differences in the distribution of squawfish after the completion of spill and the smolt migration were subtle in nature and were evaluated using a loglinear approach to the analysis

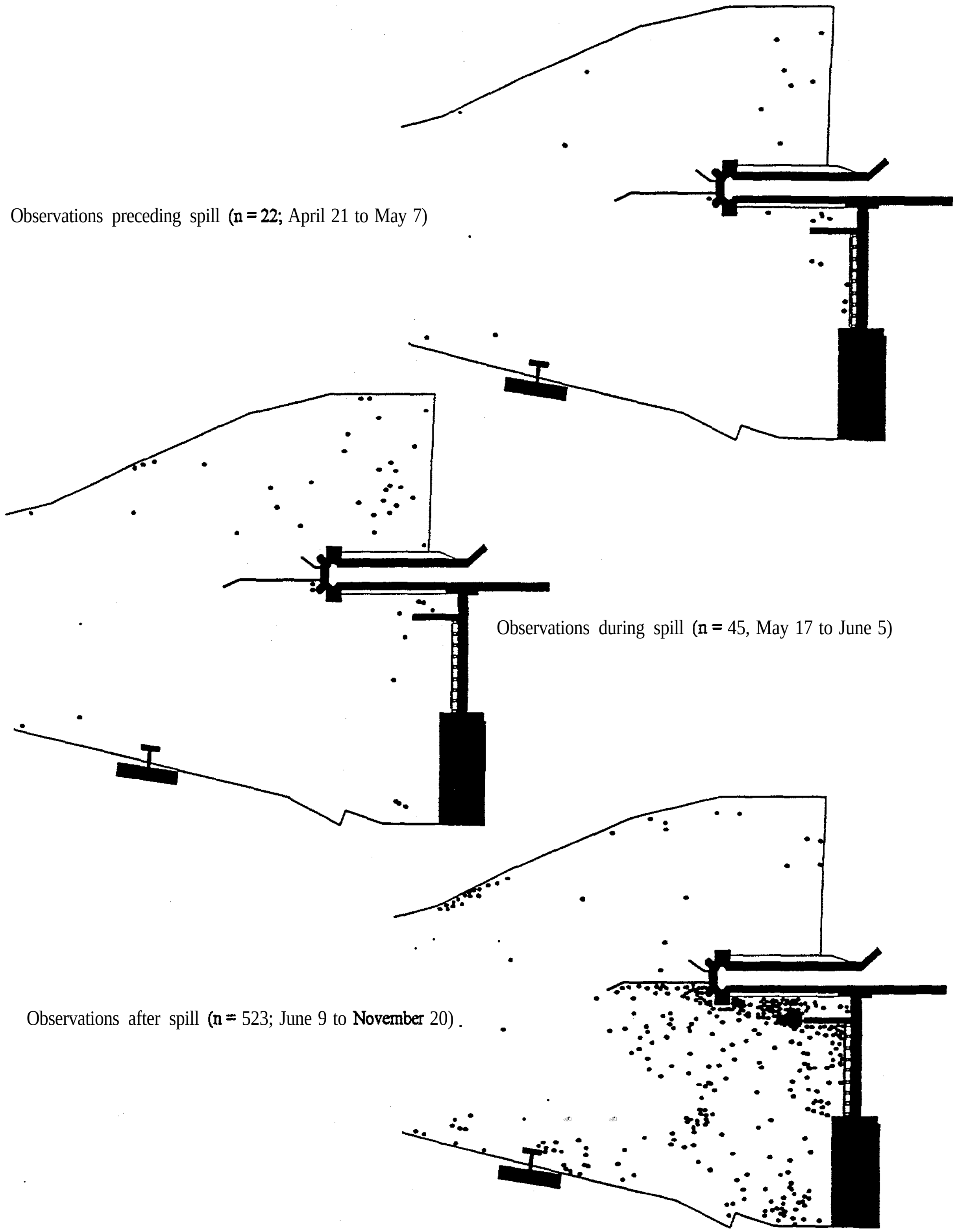


Figure 9. Distribution of squawfish in relation to spill in the tailrace of Lower Granite Dam during 1993.

of cross-classified categorical data (Fienburg 1985). Squawfish observations after June 5 were cross-classified by diel period (day or night; Figure 10), spawning period (prespawn = June 12 to June 24, spawn = June 28 to July 19, postspawn = July 20 to August 19; Figure 11), and cell (Figure 12). This data was initially analyzed using the model:

$$\lambda_{ij} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij}$$

where: λ_{ij} = log of the odds ratio
μ = the overall population mean
α_i = the effect of spawn period i
β_j = the effect of diel period k
$(\alpha\beta)_{ij}$ = the interaction effect of α_i and β_j.

Because of the insignificant interaction effect, we dropped this term and reran the analysis using the simplified model (Table 1):

$$\lambda_{ij} = \mu + \alpha_i + \beta_j$$

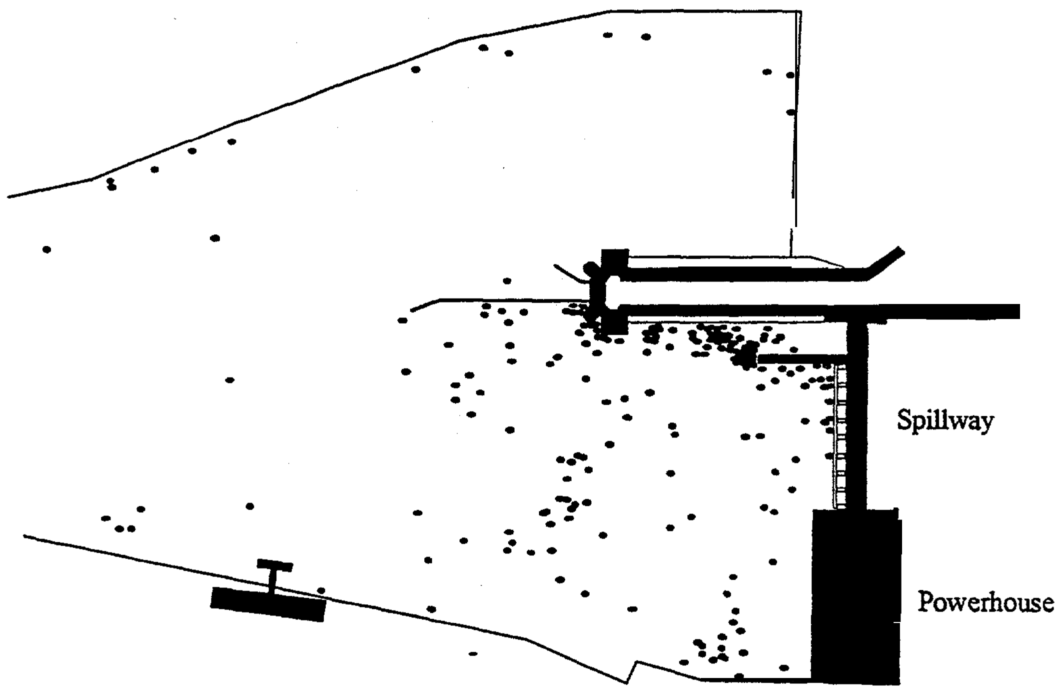
where: λ_{ij} = log of the odds ratio
μ = the overall population mean
α_i = the effect of spawn period i
β_j = the effect of diel period k

We infer from this analysis that the distribution of squawfish in the tailrace of Lower Granite Dam after the completion of spill differed significantly by diel period and spawning period and that no interaction of the two main effects occurred. The difference in diel distributions was attributable to the increased proportion of fish observed in cells 3,5, and 9 at night (Figure 13). Distributional differences associated with spawning period resulted from decreasing proportions of squawfish observed in cells 1, 3, 5, 6, 7, and 8 and concurrent increases in cells 2 and 4 (Figure 14).

Squawfish use of specific areas in relation to their availability.

Five hundred eighty-nine mobile tracking records were collected from April 21 to November 20 within the tailrace of Lower Granite Dam (Figure 15). These observations were partitioned into nine cells (Figure 12) and used as the observed values in a chi-square analysis of resource selection (Neu et al. 1974). Expected values were calculated by multiplying the total number of observations by the-percentage of the total area covered by a cell. The

Day observations (n = 259; June 9 to August 19)



Night observations (n = 236; June 12 to August 19)

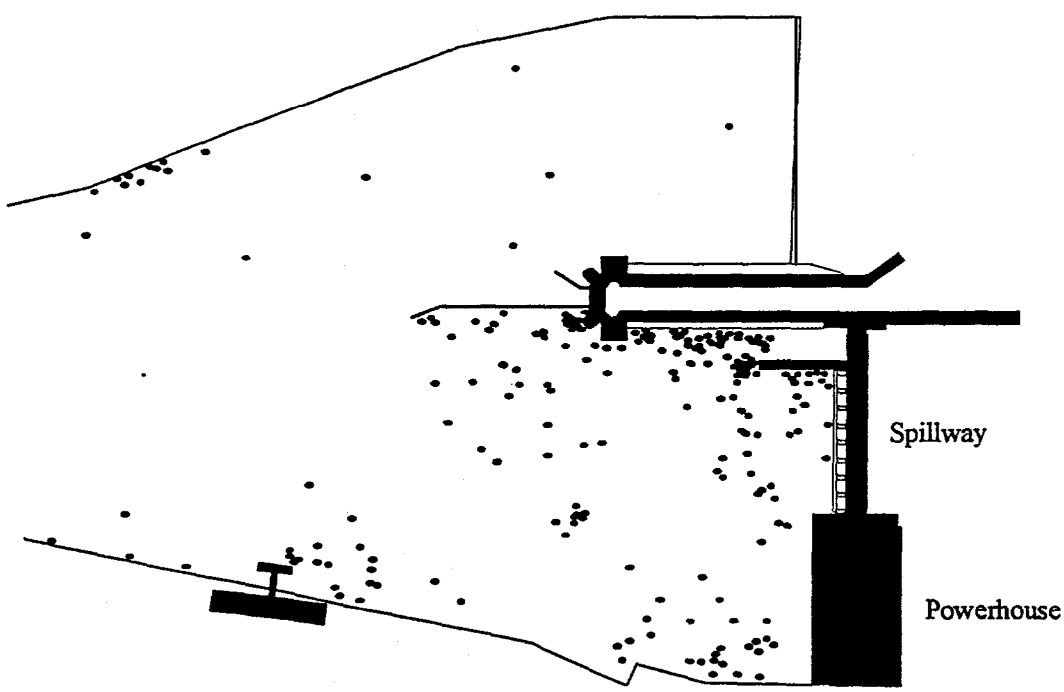


Figure 10. Distributions of squawfish downstream of Lower Granite Dam during two diel periods after the completion of spill in 1993.

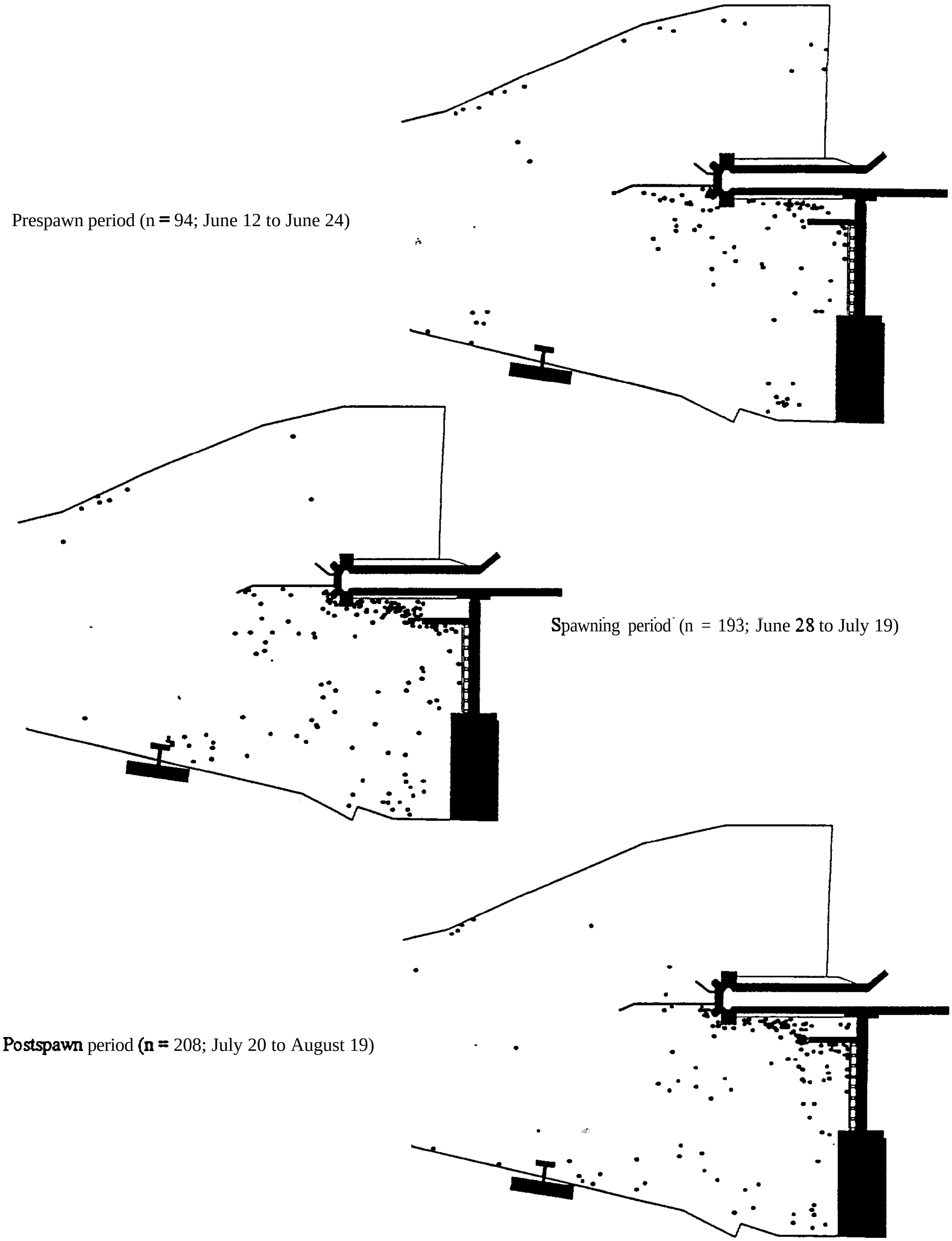


Figure 11. Distributions of squawfish downstream of Lower Granite Dam in relation to spawning period after the completion of spill in 1993.

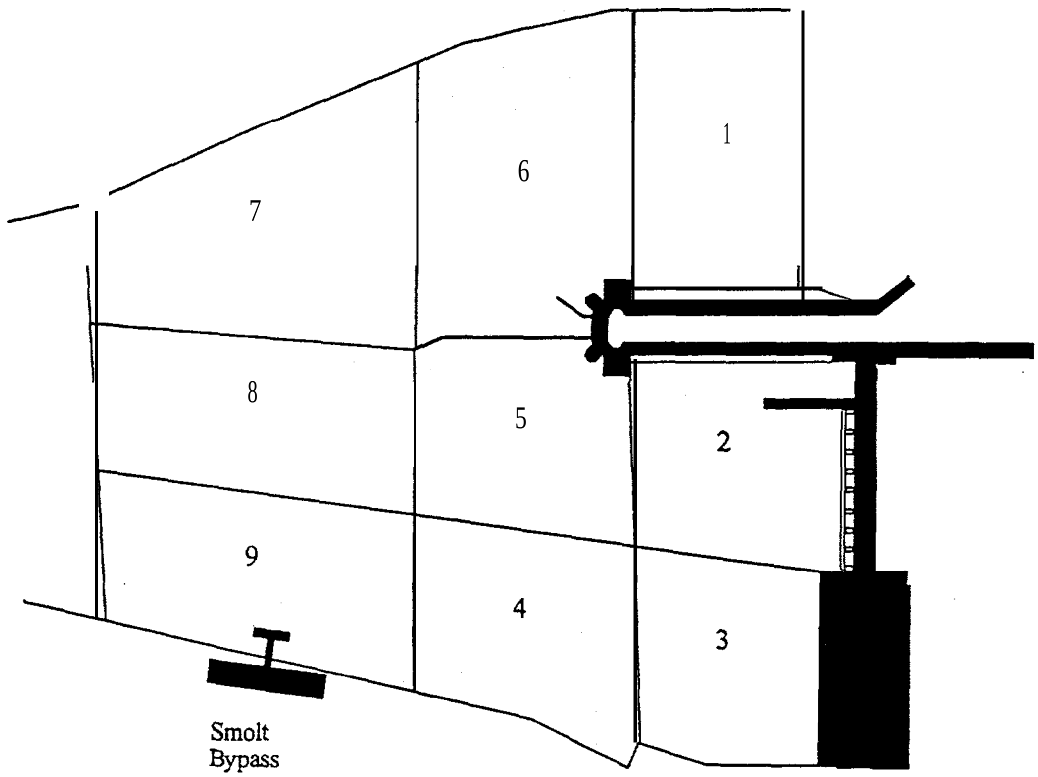
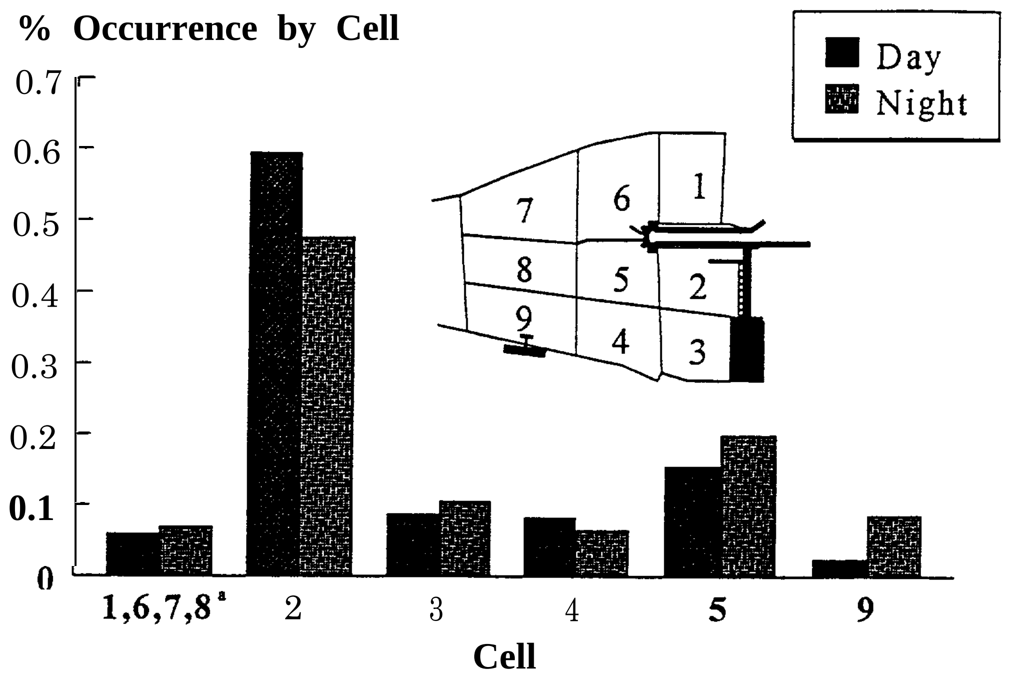


Figure 12. Cells used to partition squawfish observations within the tailrace of Lower Granite Dam in 1993.

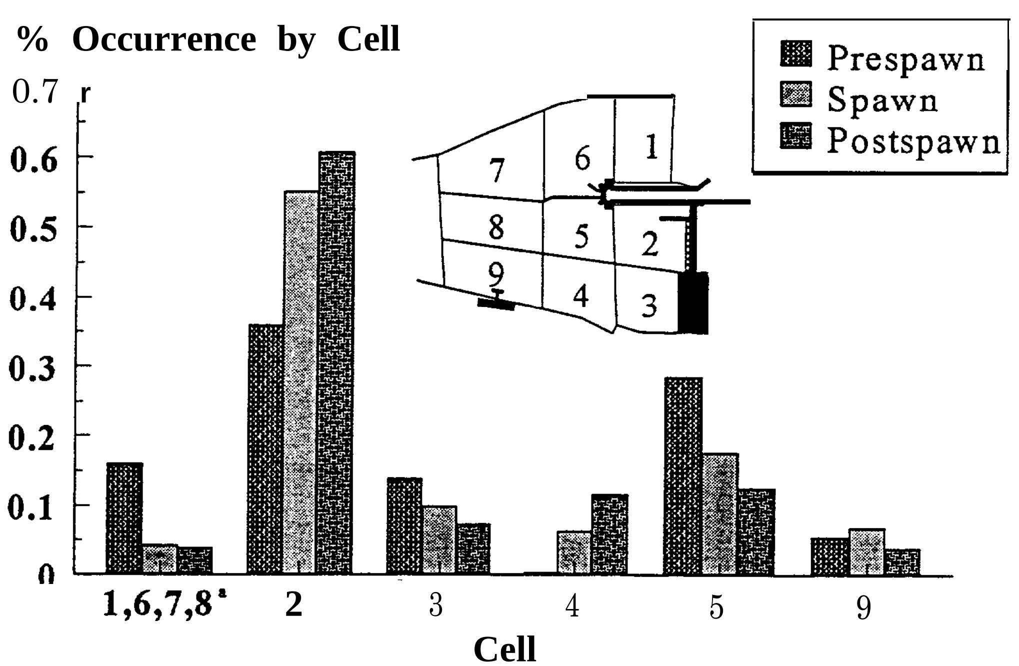
Table 1. Results of loglinear analysis of cross-classified squawfish observations in the tailrace of Lower Granite Dam during 1993.

Model $\lambda_{ij} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij}$				Model $\lambda_{ij} = \mu + \alpha_i + \beta_j$			
Source	**df**	**Chi-square**	**Probability**	**Source**	**df**	**Chi-square**	**Probability**
Intercept	5	242.19	0.000	Intercept	5	234.41	0.000
Spawn period	10	38.20	0.000	Spawn period	10	38.10	0.000
Dielperiod	5	9.69	0.085	Dielperiod	5	13.10	0.023
Interaction	10	13.61	0.192				



[a]Cells 1, 6, 7, and 8 were combined due to the small number of observations in each cell.

Figure 13. Comparison of day and night distributions of squawfish downstream of Lower Granite Dam after the completion of spill in 1993.



[a]Cells 1, 6, 7, and 8 were combined due to the small number of observations in each cell.

Figure 14. Comparison of squawfish distributions in relation to spawning activity downstream of Lower Granite Dam after the completion of spill in 1993.

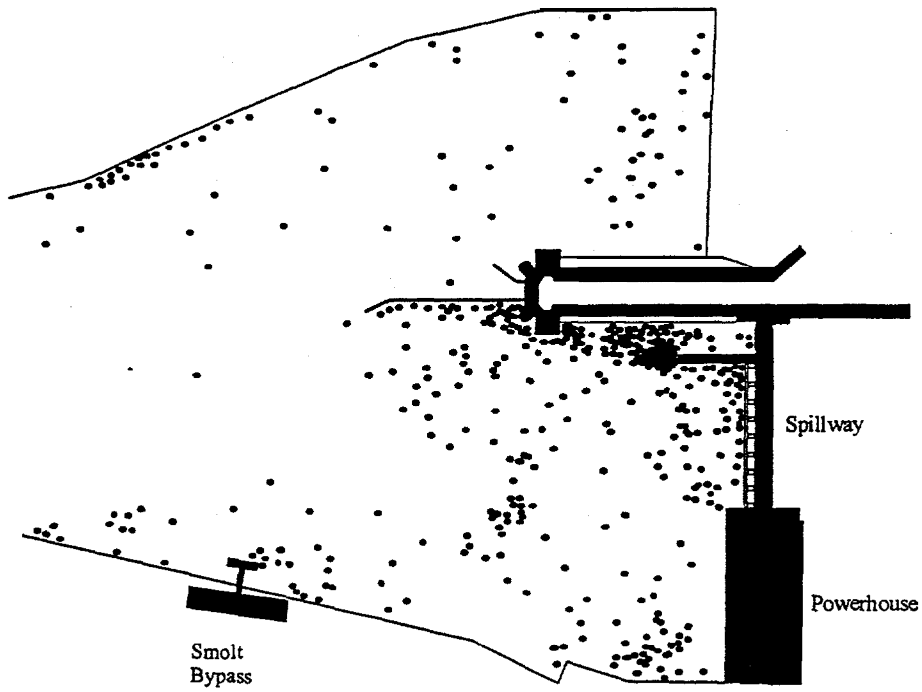


Figure 15. Northern squawfish observations (n = 589) from April 21 to November 20, 1993 used to quantify area selection downstream of Lower Granite Dam.

calculated chi-square statistic was significant (χ^2 = 1299.15, p < .Ol) and we concluded that squawfish utilized areas tailrace disproportionately to their availability. Confidence intervals were then calculated for each of the nine cells using the Bonferroni Z-statistic (Miller 1981) to determine which cells were used more or less than expected (Table 2). If the confidence interval did not include the percentage of the total area covered by a cell, we concluded that it was used disproportionately. Only cell 2 was used significantly more than its availability, while cells 6, 7, and 8 were used less.

Presence of squawfish near the smolt bypass in the tailrace of Lower Granite Dam.

Forty-two different fish were recorded from April 17 to November 30 by the receiver near the bypass outfall. The datalogging receiver located near the bypass outfall recorded a total of 362 observations on 42 different fish from April 17 to November 30. The receiver recorded multiple records on individual fish if they remained within the reception range of the antennas for extended periods of time or if they iteratively moved into the area and left. To avoid weighting our sample with a few fish which remained in the area for extended periods,

Table 2. Use-availability analysis of squawfish observations within the tailrace of Lower Granite Dam during 1993.

Cell	Total area (m^2)	Percent of total area	Squawfish observed	Squawfish expected	Percent of observations	Confidence interval (95%)
1	32,978	0.09 16	32	53.95	0.054	$0 \leq p_1 \leq 0.132$
2	34,849	0.0968	304	57.02	0.516	$0.46 \leq p_2 \leq 0.572$*
3	30,982	0.086	51	50.65	0.087	$0.01 \leq p_3 \leq 0.164$
4	33,754	0.0937	36	55.19	0.06 1	$0 \leq p_4 \leq 0.138$
5	35,638	0.099	94	58.31	0.16	$0.087 \leq p_5 \leq 0.233$
6	52,327	0.1453	14	85.58	0.024	$0 \leq p_6 \leq 0.103$*
7	50,939	0.1414	27	83.28	0.046	$0 \leq p_7 \leq 0.124$*
8	44,472	0.1235	3	72.74	0.005	$0 \leq p_8 \leq 0.084$*
9	44,220	0.1228	28	72.33	0.048	$0 \leq p_9 \leq 0.126$
Total	360,159		589	589		

* = significant at the .05 level

no more than one observations was given to each fish during a six hour period, whether that fish was recorded 100 or 10 times during a six hour interval. The hourly distribution of these observations (Figure 16) was tested for uniformity using a Watson edf test (Stephens 1974).

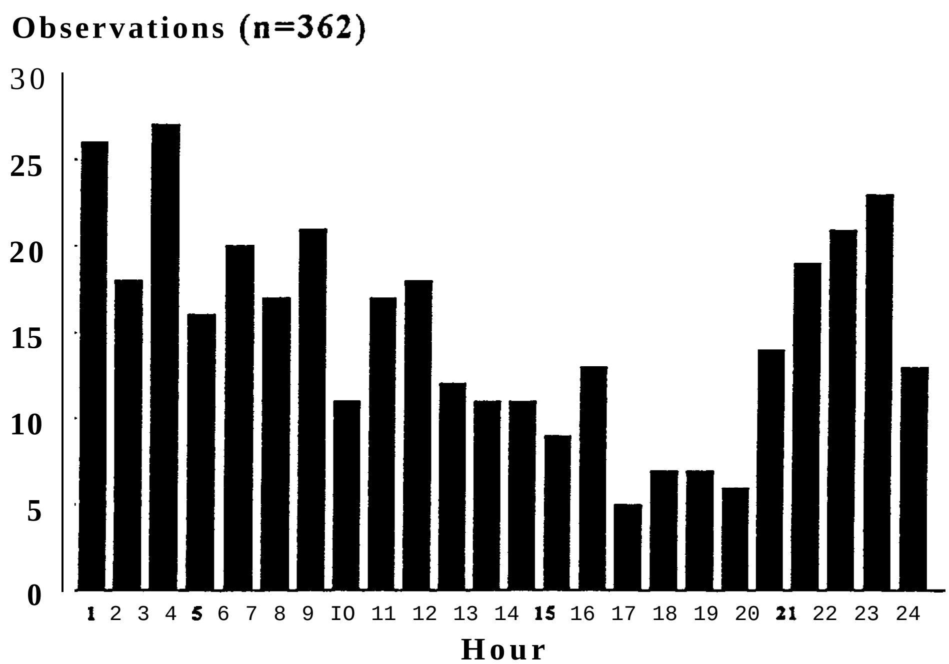


Figure 16. Histogram displaying northern squawfish observations by hour near the juvenile facility at Lower Granite Dam.

The null hypothesis of uniformity was rejected ($U^2 = 1.3365$, $p < 0.01$) and we concluded that the hourly distribution of squawfish near the smolt bypass was not uniform. It appears that the majority of observations near the smolt bypass occurred from 9:00 pm to 10:00 am. A sign test (Daniels 1990) was used to determine whether squawfish were equally likely to be found off the upstream or downstream ends of the bypass facility barge dock. The null hypothesis was rejected (n = 273, test statistic = 88, $p < .0004$) and we concluded that significantly more fish were found off the upstream end of the dock.

Distribution of squawfish throughout Little Goose Reservoir.

The jetboat was used on five occasions from June 26 to November 20 to find squawfish which had moved downstream into Little Goose Reservoir. The five distributions were tested for homogeneity using a replicated G-test (Sokal and Rohlf 1981). We rejected the null hypothesis ($G_H = 33.00$, $p < .05$) and concluded that the distributions were heterogeneous. During the first three surveys, 80 - 90% of the observations occurred in the tailrace or upper third of the reservoir, but the September 18 and November 20 surveys revealed that a larger percentage of fish had moved into the lower two-thirds of the reservoir (Figure 17). It is interesting to note that 39% of the observations on the September 18 survey were in the tailrace of the dam, but this decreased to 5% by November 20.

Miscellaneous

Surgical mortality was estimated at 1% (1 of 80) within the first two weeks and 11% (8 of 74) within the first three months of release. These estimates are conservative because they fail to account for fish which may have died in deep water or moved outside the study areas before dying.

Six squawfish were returned through the bounty program in 1993. Five of six recaptures were in excellent condition and displayed no ill effects of the surgery in stark contrast to fish recaptured in 1992. We believe the improved condition of squawfish in 1993 resulted from the use of transmitters with less abrasive antenna material, braided silk sutures which did not incise the flesh as nylon sutures had in 1992, and colder water temperatures that

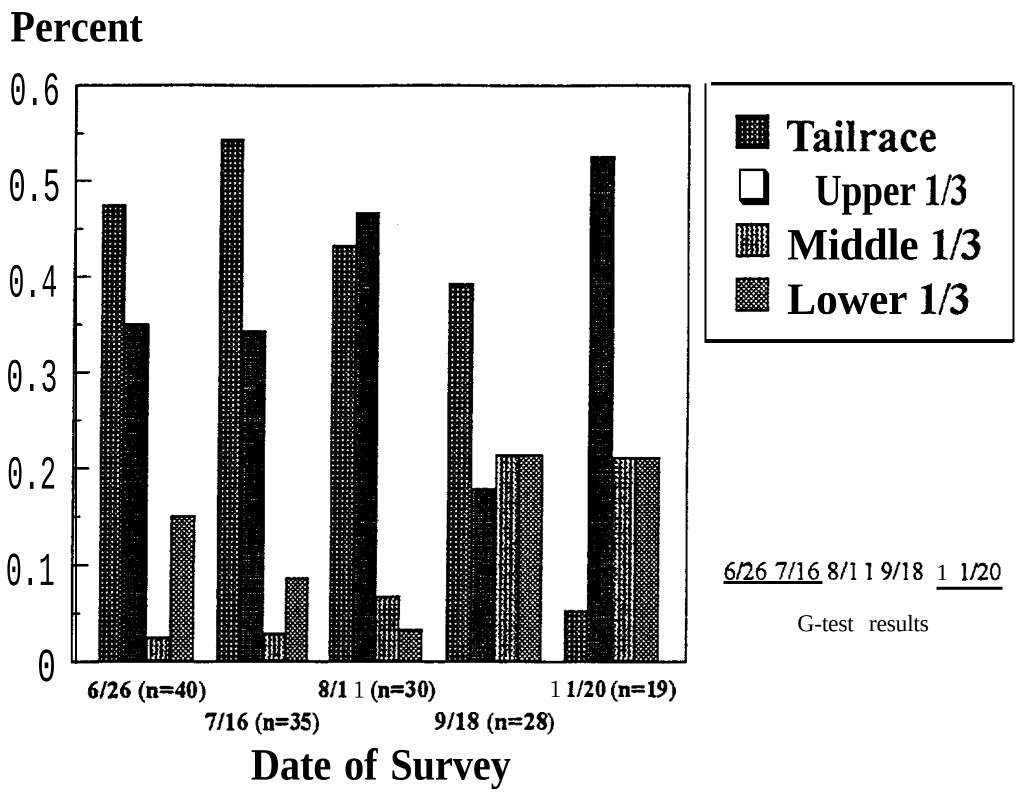


Figure 17. Distribution of northern squawfish throughout Little Goose Reservoir from June 26 to November 20, 1993.

reduced the risk of post-operative infection. All six fish were recaptured within Little Goose Reservoir, three were caught near Almota and three near the juvenile bypass facility. Additionally, five of the six recaptures occurred from July 5 to July 16, this may have been linked to peak spawning activity.

From August 12 to August 17, 1993 we used the boat to locate all squawfish in the lower Snake River which had moved from the two study areas. Of the fish that were tagged in Little Goose Reservoir, one was found upstream in Lower Granite Reservoir, three in the tailrace of Little Goose Dam, and one in Lower Monumental Reservoir. Of the fish that were tagged downstream of Ice Harbor Dam, one had moved into the tailrace of Lower Monumental Dam, two were found within the Columbia River, three miles downstream of the confluence with the Snake River, and one fish was reported to be in the collection channel at Priest Rapids Dam (NMFS, personal communication).

Discussion

Discharge had a major effect on the movements and distributions of squawfish in the lower Snake River in 1993. At Lower Granite Dam, high discharge and the resulting spill appear to have retarded the movement of squawfish into the tailrace area and may have physically displaced some fish which had moved up to the dam (Figure 8). While no comparable data exists from Ice Harbor, the distribution of fish during collection efforts and the small number of fish which eventually moved into the tailrace suggests that the effect of discharge may have been exacerbated at this dam. Because of the spill, the abundance of squawfish did not peak in tailrace areas until most of the smolts had passed through the system.

Once fish moved into tailrace areas, their distribution was influenced by several factors. Initially, we believe temperature had the greatest influence on the distribution of squawfish. Most of the squawfish in the tailrace of Lower Granite Dam during the pre-spill period were found in the slackwater areas of the spilling basin and the culdesac north of the lock (Figure 9), despite the large number of smolts available in the powerhouse discharge. We speculate that cold water temperatures (9” - 10” C) during the pre-spill period resulted in lethargic fish that exhibited limited predatory activity. The distribution of squawfish during spill was similar to their pre-spill distribution and few fish were found in areas where they would encounter smolts. This distribution was mirrored in the tailrace of Ice Harbor Dam, where fish were not found in high velocity areas, but were located in the slackwater area behind the lock guidewall (Figure 5). Based on the low abundance of squawfish and their distribution in the tailrace during the smolt migration, we believe that the loss of smolts to squawfish predation in tailrace areas was not high in 1993.

After the completion of spill, a shift occurred in the distribution of squawfish (Figures 5 and 9). Water temperatures were now warmer (13” - 2 1 ° C) and presumably the activity level of squawfish had increased. After the shift, a majority of fish in the tailrace of Lower Granite Dam were found in the slackwater adjacent to the lock rather than the powerhouse discharge where we would expect food to be most abundant. The same distribution was observed in 1992 and we believe squawfish used this slackwater area when loafing and that when actively foraging they moved into flowing water. This theory is supported by ancillary data from the Native American dam angling program; their highest catch rates consistently occurred directly downstream of the turbine discharge, despite the majority of fish at any given time being found adjacent to the lock (Becky Ashe - CRITFC, personal communication).

The abundance of squawfish in the tailrace of Lower Granite Dam peaked during late June and mid-July (Figure 8) and coincided with squawfish spawning based on the condition of fish being brought to the bounty checkstation at Boyer Marina. If the surge in tag returns at this time is an accurate reflection of foraging intensity, age-0 fall chinook salmon were being exposed to a significant predation risk because their migration took place at a time when squawfish abundance in the tailrace was high and distributional overlap would have occurred.

Based on the results of the loglinear analysis, we concluded that the distribution of squawfish in the tailrace of Lower Granite Dam varied by spawning period and diel period. Close inspection of the spawning distributions (Figure 11) reveals that this result was due to continuing trends in squawfish distribution rather than movement into specific areas during the spawning period. Squawfish observations were partitioned by diel period (Figure 10) because work has been done demonstrating that squawfish forage more actively under low light conditions (Vigg et al. 1991; Petersen and Gadomski 1992), therefore we thought a major shift in the distribution of squawfish might occur at night in relation to foraging activity. Although significant differences were detected, we attribute these results more to the large sample size rather than the size of the distributional shifts which materialized.

One noteworthy occurrence was the movement of squawfish into the vicinity of the juvenile bypass at night (Figure 10). Squawfish which exhibited this behavior congregated near a flume of water which entered the river 20 m upstream of the bypass outfall. Additionally, the number of observations near the bypass was underestimated because bounty squawfishermen removed three study specimens from this area. Further evidence of this night shift was supplied from the fixed receiving site located at the bypass facility (Figure 16). This pattern was repeated near the ice/trash sluiceway in the Ice Harbor Tailrace (Figure 6), suggesting that squawfish are being attracted to these areas by flowing water and the fish which may be entrained in the discharge. Based on this data, if smolts were to be bypassed at some point in the future, it would be wise to do so during the day rather than the night.

The behavior of squawfish downstream of tailrace areas differed between the two study sites in 1993. In Little Goose Reservoir the distribution of squawfish was fairly consistent until early fall (Figure 17), with 80 - 90% of the observations occurring in the upper third of the reservoir or the tailrace. As fall progressed, fish moved further downstream in the reservoir, possibly to seek overwintering areas. In contrast, squawfish downstream of Ice Harbor Dam held midway between the tailrace and the Columbia River Confluence until shortly before June 30, when the majority of fish left the Snake River and moved into the Columbia River (Figure 7).

In summary, the behavior of northern squawfish in the lower Snake River was affected by numerous environmental and biological factors in 1993. High discharge and cold water temperatures were the dominant factors that limited the predatory efficiency of squawfish in tailrace areas during the majority of the smolt migration. However, age-0 fall chinook salmon were exposed to higher predation risk in the tailrace because of their later migration time and larger numbers of squawfish which were becoming more active with increased water temperatures. We believe the results of our study suggest that predation in tailrace areas was not as intense as 1992 because high discharge retarded squawfish movement into tailrace areas while smolts were migrating through the system.

References

Beamesderfer, R. C. and B. E. Rieman. 199 1. Abundance and distribution of northern squawfish, walleyes, and smallmouth bass in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:439-447.

Daniels, W. W. 1990. Applied nonparametric statistics, second edition. PWS-KENT Publishing Company, Boston.

Faler, M. P., L. M. Miller, and K. I. Welke. 1988. Effects of variation in flow on distributions of northern squawfish in the Columbia River below McNary Dam. North American Journal of Fisheries Management 8:30-35.

Fienberg, S. E. 1985. The analysis of cross-classified categorical data, second edition. The MIT Press, Cambridge, Massachusetts.

Petersen, J. H., and D. M. Gadomski. 1992. Effects of light intensity on northern squawfish capture of juvenile salmonids in the laboratory. Pages 92 - 103 *in* T. P. Poe, editor. Significance of Selective Predation and Development of Prey Protection Measures for Juvenile Salmonids in Columbia and Snake River Reservoirs. Report (contract DE-AI79-88BP91964) to Bonneville Power Administration.

Miller, R. G. 198 1. Simultaneous statistical inference. Second edition. Springer-Verlag, New York, New York.

Neu, C. W., C. R. Byers, and J. M. Peek. 1974. A technique for analysis of utilization-availability data Journal of Wildlife Management 38:541-545.

Poe, T. P., H. C. Hansel, S. Vigg, D. E. Palmer, and L. A. Prendergast. 199 1. Feeding of predaceous fishes on out-migrating juvenile salmonids in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:405-420

Rieman, B. E., R. C. Beamesderfer, S. Vigg, and T. P. Poe. 1991. Estimated loss of juvenile salmonids to predation by northern squawfish, walleyes, and smallmouth bass in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:448-458.

Ross, M. J., and C. F. Kleiner. 1982. Shielded-needle technique for surgically implanting radio-frequency transmitters in fish. Progressive Fish-Culturist 44:41-43.

Sokal, R. R., and F. J. Rohlf. 1981. Biometry. W. H. Freeman and Company.

Stephens, M. A. 1974. EDF statistics for goodness of fit and some comparisons. Journal of the American Statistical Association 69:730-737.

Thompson, R. B. 1959. Food of the squawfish *Ptychocheilus oregonensis* (Richardson) of the lower Columbia River. U. S. Fish and Wildlife Service Fishery Bulletin 60:43-58.

Uremovich, B. L., S. P. Cramer, C. F. Willis, and C. 0. Junge. 1980. Passage of juvenile salmonids through the ice-trash sluiceway and squawfish predation at Bonneville Dam, 1980. Report to U. S. Army Corps of Engineers, Portland, Oregon.

Vigg, S., T. P. Poe, L. A. Prendergast, and H. C. Hansel. 1991. Rates of consumption of juvenile salmonids and alternative preyfish by northern squawfish, walleyes, smallmouth bass, and channel catfish in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:421-438.

Table 1 (continued). Date, transmitter code, fish length, and release location of squawfish implanted with radio-transmitters in 1993.

Date	Code	Length (mm)	Release Site
4/17/93	26-80	347	Boyer Marina
4/17/93	27-76	390	Boyer Marina
4/17/93	28-78	362	Boyer Marina
4/17/93	29-74	385	Boyer Marina
4/17/93	30-68	390	Boyer Marina
4/17/93	31-66	355	Boyer Marina
4/17/93	32-74	354	Boyer Marina
4/17/93	33-76	345	Boyer Marina
4/17/93	34-66	400	Boyer Marina
4/18/93	26-70	408	Boyer Marina
4/18/93	35-66	423	Boyer Marina
4/21/93	27-78	375	Boyer Marina
4/21/93	28-72	448	Boyer Marina
4/21/93	29-78	480	Boyer Marina
4/21/93	30-76	365	Boyer Marina
4/21/93	31-70	418	Boyer Marina
4/21/93	32-66	395	Boyer Marina
5/1/93	33-64	368	Boyer Marina
5/5/93	34-76	545	Boyer Marina
5/5/93	35-64	345	Boyer Marina
5/5/93	26-06	339	Boyer Marina
5/5/93	27-74	350	Boyer Marina
5/17/93	28-68	451	Boyer Marina
5/20/93	30-74	460	Boyer Marina
5/20/93	31-64	350	Boyer Marina
5/20/93	32-72	443	Boyer Marina
5/20/93	34-64	344	Boyer Marina
5/20/93	29-04	356	Boyer Marina
5/20/93	33-02	485	Boyer Marina
5/21/93	26-08	360	Boyer Marina
5/21/93	27-72	377	Boyer Marina
5/21/93	35-72	418	Boyer Marina
6/3/93	33-72	415	Lower Granite Dam
6/12/93	34-74	415	Lower Granite Dam
6/12/93	35-76	435	Lower Granite Dam
6/12/93	28-70	410	Lower Granite Dam
6/12/93	29-02	457	Lower Granite Dam
6/12/93	30-78	390	Lower Granite Dam
6/12/93	31-74	408	Lower Granite Dam
6/12/93	32-02	393	Lower Granite Dam