STRESS RESPONSE OF CHINOOK SALMON AND STEELHEAD SMOLTS TO THE MODIFIED JUVENILE COLLECTION AND TRANSPORTATION FACILITY AT LITTLE GOOSE DAM, SNAKE RIVER

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Abstract.--Outmigrating juvenile salmonids are collected at Little Goose Dam on the Snake River and transported by truck or barge past six downstream dams to reduce dam and reservoir related mortalities. In 1990, the collection/transportation facility was modified with new dewatering systems and a 360-m-long corrugated metal flume that passed fish intercepted at the dam to new holding/sampling facilities. To ensure that these modifications did not increase to unacceptable levels the stress or fatigue already experienced by spring chinook salmon and steelhead smolts, fish were sampled and blood plasma analyzed for cortisol, glucose, and lactic acid. There were significant increases in all of these indices as fish moved through the system. However, these increases represented a normal response to acute levels of stress and fatigue, and were less than increases observed at the original facility and at similar collection/transportation facilities on the Snake and Columbia Rivers. All three indices (except glucose for yearling chinook salmon) returned to pre-stress levels within 6 h. The results of this study indicated that no additional stress or fatigue was caused by passage through the new dewatering device or the corrugated metal flume, and that the design of these modifications may be suitable for collection\transportation facilities at other dams.

In 1977, the U.S. Army Corps of Engineers (COE) began mass transport of juvenile Pacific Salmon (*Oncorhynchus spp.*) and steelhead trout (*O. mykiss*) to reduce mortality caused by hydroelectric dams on the Snake and Columbia Rivers (Raymond 1979). Most smolts collected at Lower Granite, Little Goose, and Lower Monumental Dams are transported to a release point below Bonneville Dam on the Columbia River.

At these collector dams, submersible traveling screens divert juvenile salmonids from turbine intakes into gatewells upstream of the turbines (Figure 1). From gatewells, fish enter the collection channel via orifices (25 or 30 cm in diameter) and pass through pressurized pipes that exit into wet separators, where they are separated by size before entering raceways (Matthews et al. 1977, Matthews et al. 1986, Maule et al. 1988). Fish remain in raceways for a few hours to 2 days before they are loaded into transport trucks or barges. With the addition of the Lower Monumental Dam juvenile fish facility in 1993, the COE annually transports more than 15 million migrating juvenile salmon from the four collection/transportation facilities.

The juvenile fish collection/transportation facility at Little Goose Dam was originally constructed in 1971 by the COE and the National Marine Fisheries Service (NMFS) to study the benefits of juvenile salmonid transportation on the Snake and Columbia Rivers. In these studies, survival of transported yearling chinook salmon and steelhead was 1 to 15 times higher than control fish, which had to pass seven mainstem dams and

reservoirs (Ebel 1980; Park 1985). Based on these results, juvenile salmon transportation has been used by the COE in varying degrees to enhance salmon survival on the Snake and Columbia Rivers. Since the initiation of the COE transportation program in 1977, the Little Goose juvenile collection/transportation facility has been utilized for collecting, holding, and transporting 2.5 to 3 million juvenile salmonids annually.

Various researchers have shown that the types of stress associated with collection and transportation place physical demands on juvenile salmonids that can increase mortality by disturbing metabolic, osmoregulatory, and immune system homeostasis (Pickering and Duston 1983, Barton et al. 1985, Matthews et al. 1986, Barton and Schreck 1987, Maule et al. 1987). These types of stress have also been related to reductions in swimming endurance (Maule et al. 1988), predator avoidance (Sigismondi and Weber 1988, Olla et al. 1992, Mesa 1994), and adult return rate (Schreck et al. 1989).

A new juvenile salmonid collection/transportation facility was constructed at Little Goose Dam during the winter of 1989/1990 (Fig. 2). To alleviate space constraints and to better accommodate barge loading, this facility was located approximately 340 m downstream from the original facility. A 360-m, above ground, corrugated metal flume (CMF) was installed to pass the juvenile salmonids from the exit of the original collection channel to the new facility.

The CMF at Little Goose Dam was chosen after preliminary research that tested three types of flume: a prototype 86-cm wide by 81-m long CMF, a 61-cm wide by 34-m long baffled flume, and a 122-cm wide by 34-m long baffled flume. These tests demonstrated no significant stress response for yearling chinook salmon (for all three flumes) and a lower stress response in the CMF for steelhead compared to the other two designs (Congleton and Wagner 1988, Congleton et al. 1988). However, because of the cumulative nature of these stressors (Congleton et al. 1985, Matthews et al. 1986, Maule et al. 1988), there was concern that the CMF and other components of the new Little Goose Dam facility would increase stress and fatigue to harmful levels for migrating juvenile salmonids. Therefore, to evaluate levels of stress and fatigue and recovery times associated with this new system, we sampled juvenile spring chinook salmon and steelhead smolts at various locations in the new facility and analyzed three physiological indices of stress: plasma cortisol, glucose, and lactic acid.

Description of New Facility

The three areas of the new facility of most concern to biologists were the primary dewaterer, the CMF, and the wet separator (Fig. 2). The primary dewaterer is a 4.7-m-deep chamber, housing a dewatering screen which is 29.5-m long by 1.8-m wide. The screen is set on a 0.067 (3°) upward slope and is used to separate fish and transportation water from excess

collection channel flow. Approach velocity to the screen (at time of testing) was approximately 1.5 m/s and the average velocity over the entire screen area (53 m^2) was approximately 0.5 m/s. Because of the lowered velocities, biologists were concerned that fish would delay in the primary dewaterer and fight the current to exhaustion before exiting into the secondary dewatering section and the CMF.

The 0.4-m radius CMF, with a slope of 0.038 (2°), transports fish and water from the primary dewaterer (el. 192 m above mean sea level) to the new fish collection facilities (el. 177 m above mean sea level). To minimize light reflection, the inside of the CMF was painted with an epoxy paint and partially darkened with hinged covers made of perforated polyethylene sheeting. Average water depth and velocity in this flume were 49 cm and 2.9 m/s, respectively. At the downstream end of the CMF, water depth increased to 73 cm and water velocity decreased from 3.4 to 1.5 m/s. Both juvenile and adult fish were observed holding in the hydraulic jump created by this decrease in velocity, but the length of time they remained in this section was unknown.

Water and fish from the CMF flow over an adjustable porosity control section and then into a wet separator, comprised of two sections, with a water depth of 2.5 to 5 cm over the top of horizontal grader bars. The first section is 12.5 m long and 6.3 m wide, and the second section is 6.3 m square. Between the bars of the first section, there are gaps of approximately 1.5 cm through which the smaller fish (primarily juvenile yearling

chinook salmon) can swim. Larger fish (primarily juvenile steelhead) pass over this section into the next section which has 3.2-cm gaps between the bars.

Underneath the grader bars of each section, a collection hopper is formed from the sloping sides of perforated plate. The volumes in the hoppers are 2.6 m^3 and 1.7 m^3 for the first and second sections, respectively. From each of these sections, a 46 by 46-cm flume carries fish and water (at 0.4 m/s) to raceways located 10 m downstream from the separator.

Methods

To measure levels of physiological stress and fatigue caused by the new facility, three replicates each of migrant yearling chinook salmon and steelhead (20 in each replicate) were sampled from five locations within the facility. The locations tested were: (1) the gatewell of a turbine intake (for baseline levels), (2) the start of the CMF (just downstream from the primary dewatering section and designated as upper flume in results section),(3) between the end of the CMF flume and the wet separator (designated as lower flume in results section), (4) the raceways, and (5) the transport barges (Fig. 2). To determine if the stress indices changed while the smolts were held in the raceways, blood samples were taken after fish had been in the raceway for 0, 2, 4, 6, and 9 h, and once more immediately prior to being loaded into the transport barges (after approximately 17 h in the raceways).

Since juvenile chinook salmon and steelhead tend to enter and move through Columbia River dams in the evening (Gessel et al. 1986), fish were sampled from the first three locations between 1800 and 1900 hours. This was done to maximize the possibility that fish sampled in these locations were from a single population moving through the facility, and to minimize the sampling of fish that had remained overnight or longer in the system.

The new raceways at the Little Goose Dam facility were designed to hold 45,425 L of water each, with a maximum of 1,045 kg of fish per raceway and a flow rate of 4,542 L/min. To conduct realistic tests, we wanted to hold fish in the raceways at maximum density levels; however, we needed to shorten the time during which fish were collected in the raceway prior to the start of sampling. Therefore, before any fish were introduced, the raceway crowder was moved up to reduce the size of the raceway by one-half or three-quarters of its original length.

Fish were then collected for 4 h. Therefore, when the raceway sampling was started, individual fish in the sample population had actually been in the raceway from 0 to 4 h. In the three replicates for each species, densities ranged from 229 to 670 kg per raceway for yearling chinook and from 260 to 1,049 kg per raceway for steelhead. These densities were calculated using an estimate of the number of fish entering the raceway per hour (by a sample count) and the species composition and average weight by species of the daily sample.

Fish were sampled from the gatewells using a dip basket similar to that described by Bentley and Raymond (1968). In the other locations, a standard dip net was used to collect fish as quickly as possible, and raceway samples were taken at night to minimize fright response of the remaining fish. Sampled fish were immediately placed in 200 mg/L tricaine methane sulfonate (MS-222), a concentration that does not significantly alter plasma cortisol, glucose, or lactic acid levels (Black and Conner 1964; Strange and Schreck 1978).

After complete immobilization, the caudal peduncle of each fish was severed and blood was obtained from the caudal vasculature with a 0.25-ml ammonium-heparinized Natelson capillary tube. Blood samples were centrifuged, and the plasma was separated and frozen immediately on dry ice. Thawed plasma was assayed at Oregon State University for cortisol using the radioimmunoassay techniques described by Foster and Dunn (1974) and later modified by Redding et al. (1984). Plasma was also assayed for glucose using the *o*-toluidine method (Wedemeyer and Yasutake 1977), and lactic acid using a fluorimetric enzyme reaction (Passonneau 1974).

Standard errors (SE) and comparisons among means for all three parameters at the various locations and raceway times were calculated using Analyses of Variance (ANOVA) (Sokal and Rohlf 1981) with t = 10 treatments (locations/raceway times) and n = 3 replications (days) throughout the bypass season (n = 2 for pre-barge and barge groups). Subsamples of twenty fish from each

replicate (day) were averaged before analyses (replicates were not pooled). Significance was established at $P \leq 0.05$. Fisher's Protected Least Significant Difference method (Petersen 1985) was used to compare locations and/or raceway times.

Results and Discussion

Significant increases in plasma cortisol, glucose, and lactic acid levels indicated that the new collection/transportation facility at Little Goose Dam caused stress and fatigue in yearling chinook salmon (Fig. 3). Since cortisol did not increase until arrival at the lower flume and glucose did not increase until entry into the raceways, passage from the gatewell into the collection channel and through the collection channel and primary dewaterer seemed to be fairly benign. However, the step increases in cortisol from the upper CMF to the raceways indicated that the CMF and the wet separator were stressful and the effects seemed to be cumulative. This cumulative effect of multiple stressors on yearling chinook salmon was also seen by Maule et al. (1988) at the McNary Dam collection/transportation facility and by Barton et al. (1986) in laboratory studies.

In most cases, the maximum levels of all three indices for yearling chinook salmon were less than the maximum levels recorded by other researchers at similar collection\transportation facilities (Matthews et al. 1986; Maule et al. 1988). The highest average cortisol value observed for

yearling chinook salmon after 2 h in the raceway (160.5 ng/ml) was comparable to raceway levels (before recovery) seen at Lower Granite Dam by Congleton et al.(1985) and Matthews et al. (1987). At similar levels, Maule et al.(1988) found no indication of chronic stress (no hypertrophy of interrenal blood cells) and, from white blood cell counts and swimming challenge tests, ascertained that yearling chinook salmon fully recovered within 12-48 h. These levels were also comparable to results obtained by Mesa (1994) where juvenile chinook salmon were subjected to single or multiple handling or agitation stresses. In that study, cortisol levels returned to pre-stress levels in 6 to 12 h; however, within 1 hour, the ability to avoid predation by northern squawfish was equal for test and control fish.

Between yearling chinook salmon from the gatewell and the raceways, the changes in glucose were similar but delayed compared to changes in cortisol. Since changes in glucose are a secondary metabolic response induced by changes in endocrine levels (both corticosteroids and catechloamines) (Mazeaud et al. 1977), the protracted response of glucose was expected and was similar to results at other collection\transportation facilities (Congleton et al. 1985, Maule et al. 1988) and to laboratory studies (Barton and Schreck 1987). The highest level of glucose (164.9 mg/dl after 2 h in the raceways) was higher than the peak values measured at other collection/transportation facilities (Congleton et al. 1985, Maule et al. 1988) but comparable to

values measured by Matthews et al. (1987) after fish had been marked or transported at Lower Granite Dam.

The significant increases in lactic acid between the gatewell and the upper flume for yearling chinook salmon suggested that fish were holding in the collection channel or the primary dewaterer (also supported by observations) and experiencing some level of swimming fatigue. These increases were similar to those between the fish in a gatewell and post-bypass fish measured by Congleton et al. (1985) and were also similar to increases measured by other researchers following handling or confinement stress (Barton et al. 1986; Barton and Schreck 1987). However, the concentrations we observed did not indicate levels of extreme exhaustion, and both species recovered after 2 to 4 h in the raceways. In addition, these levels were equal to or lower than lactic acid levels measured by Mesa et al. (1994) for yearling chinook salmon exposed to agitation stresses that did not have a pronounced or long-lasting effect on predator avoidance.

Cortisol returned to gatewell (or pre-stress) levels within 6 h, glucose within approximately 17 h, and lactic acid within 2 h for yearling chinook salmon. The increase in lactic acid from the 6-hour to the 9-hour raceway sample was marginally significant, but the increase was not sustained, as concentrations measured the following day had decreased to previous levels.

Immediately after being loaded onto a barge, all three indices for yearling chinook salmon reached levels which approximated the highest levels reached during the entire collection/transportation process. These elevations were similar to those observed by Congleton et al. (1985), Matthews et al. (1986), and Maule et al. (1988), all of which showed that loading fish into either trucks or barges was the most stressful single operation in a collection/transportation facility. Although no samples were taken after the immediate loading sample, most studies by the same three researchers showed that stress indices had returned to pre-loading levels within 3-4 h in transit.

In most cases, the pattern of increase and recovery for all three indices for steelhead paralleled those for yearling chinook salmon (Fig. 4). Both cortisol and lactic acid levels increased significantly from the gatewell to the upper flume, indicating a response to acute levels of stress and fatigue with recovery times of 2-4 h. However, for all three indices, barge-loading did not cause a significant response with steelhead. This may have been due to the short time in which the fish were in this flume. Congleton and Wagner (1988) suggested that a decrease in swimming time for steelhead in a CMF compared to those in a baffled flume was the cause of lower levels of cortisol.

The increase in steelhead cortisol levels after 9 h in the raceway (at 0600 h) could have been either a diel variation or a response to increases in light intensity. These responses in

steelhead were demonstrated by Congleton and Wagner (1988) and by Congleton et al. (1988), respectively. In these studies, a diel cortisol cycle was not detected in steelhead held in raceways; however, cortisol concentrations in fish sampled from the gatewell were significantly higher during daylight hours than at night, indicating a probable diel cycle.

Glucose levels for steelhead remained nearly constant throughout the system; however, passage through the system produced a non-significant increase from about 120 mg/dl at the lower flume to about 150 mg/dl after 2 h in the raceways.

In summary, significant increases in cortisol, glucose, and lactic acid in yearling chinook and cortisol and lactic acid in steelhead indicated a stress response to the new collection/transportation facility at Little Goose Dam. However, in most cases, these responses and the recovery times were less than observed at the original facility or at similar collection/transportation facilities. In both species, all three indices had returned to pre-stress levels within 6 h (except for glucose in yearling chinook salmon). Studies of responses to stress at other collection/transportation facilities and in laboratory studies indicate that stress responses at comparative levels were not maladaptive to either yearling chinook salmon or steelhead, and that fish stressed to these levels were able to recover endocrine, metabolic, osmoregulatory, and immune system homeostasis within 12-24 h.

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Figure Captions

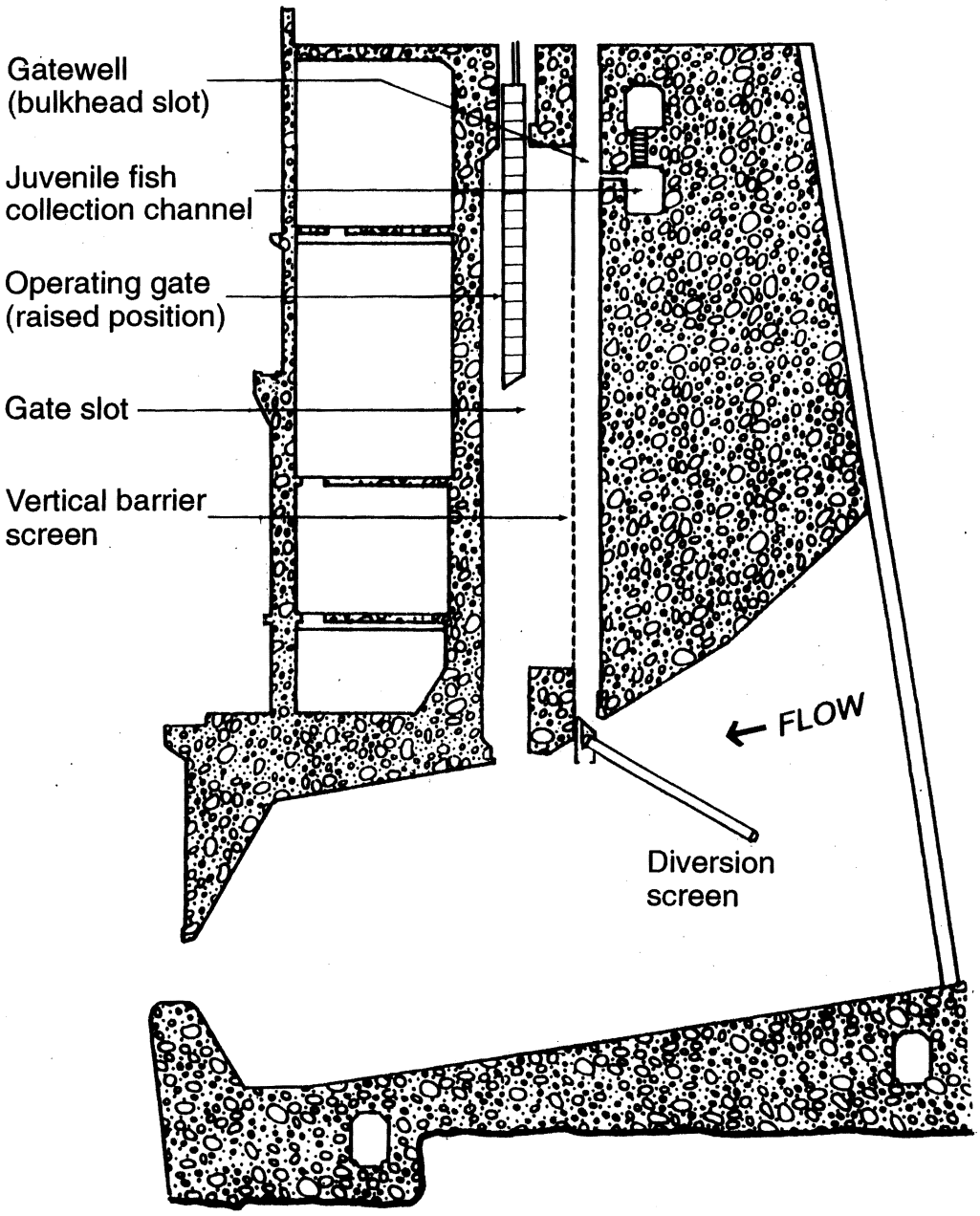
Figure 1.--Cross section of turbine intake at Little Goose Dam on the Snake River.

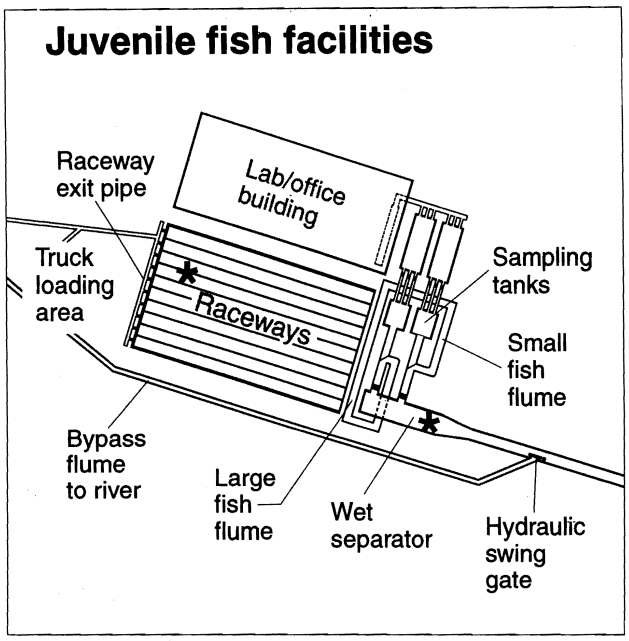
Figure 2.--Overhead view of new juvenile fish collection and transportation facility at Little Goose Dam. Asterisks show areas where fish samples were taken for blood analyses.

Figure 3.--Mean concentrations (+ SE) of plasma cortisol, glucose, and lactic acid concentrations for yearling chinook salmon sampled at five locations and over time in the raceways at the Little Goose Dam collection/transportation facility. Bars marked (a) are significantly higher than gatewell levels, bars marked (b) are significantly lower than 0-hour raceway levels, and bars marked (c) are significantly higher than pre-barge levels.

Figure 4.--Mean concentrations (+ SE) of plasma cortisol, glucose, and lactic acid for steelhead sampled at five locations and over time in the raceways at the Little Goose Dam collection/transportation facility. Bars marked (a) are significantly higher than gatewell levels, and bars marked (b) are significantly lower than 0-hour raceway levels.

Little Goose Dam cross section




Juvenile fish facilities
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Lab/office building
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Raceways
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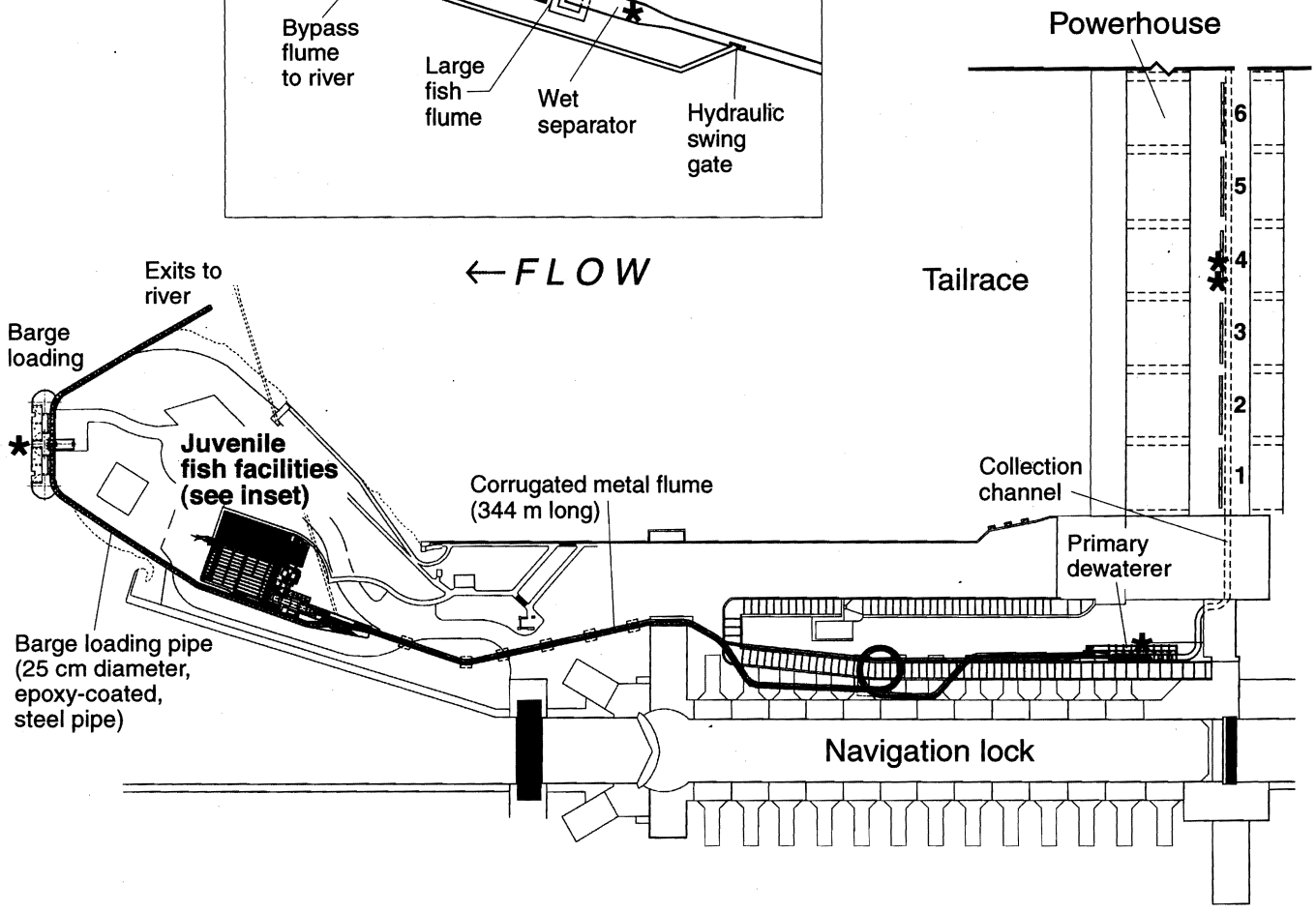
Bypass flume to river
Large fish flume
Wet separator
Hydraulic swing gate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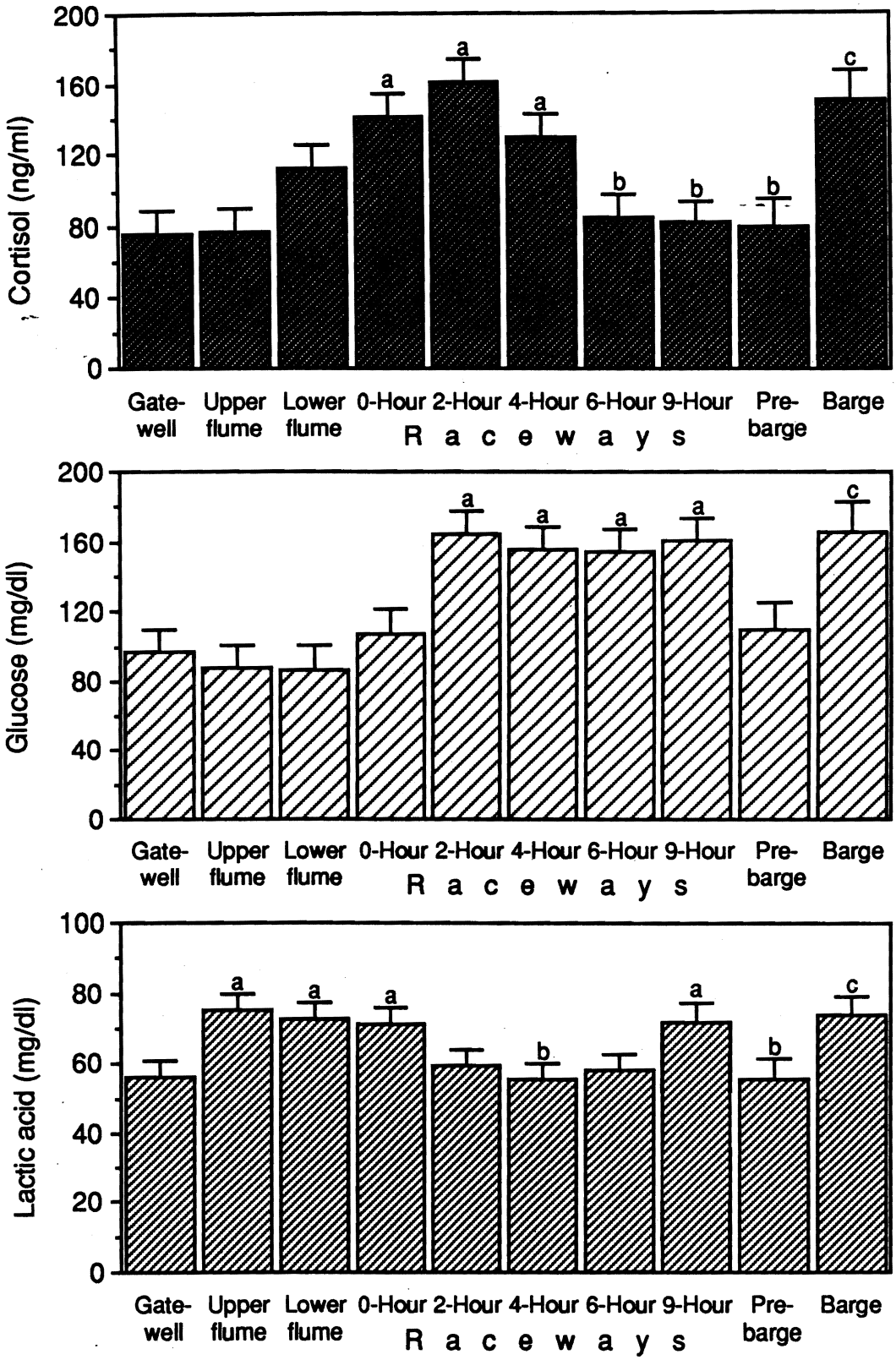
Collection channel
Primary dewaterer
Barge loading pipe (25 cm diameter, epoxy-coated, steel pipe)
Navigation lock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Pre-barge
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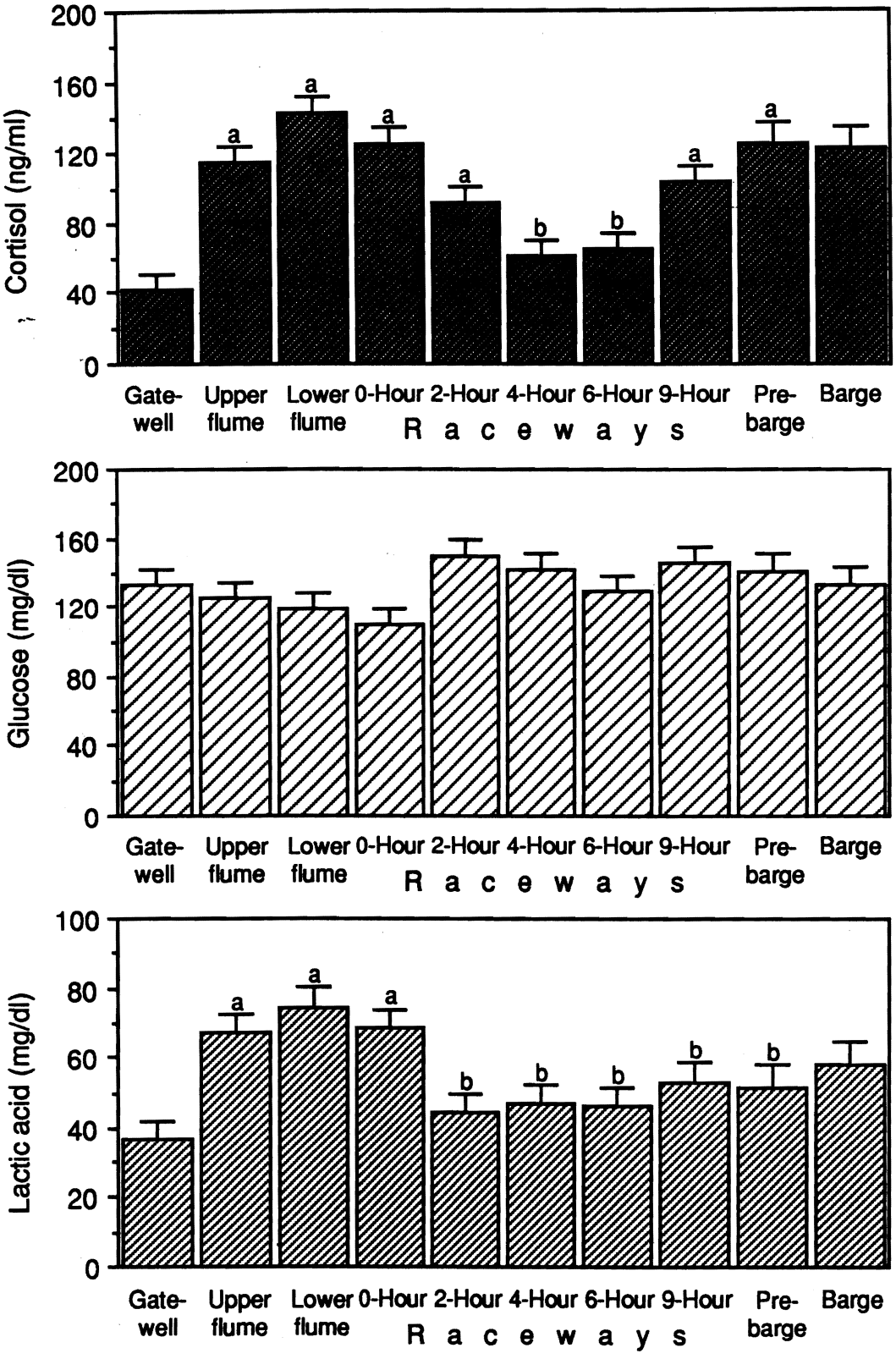
Raceways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