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PRELIMINARY REPORT ON THE EFFECTS OF SUSPENDED VOLCANIC SEDIMENT ON SALMON PASSAGE AND SURVIVAL

by

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PROGRESS REPORT
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to

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Office of Water Research and Technology
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Approved

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for Director

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1.0 SUMMARY

The May 18, 1980 eruption of Mt. St. Helens caused major losses of salmon in the streams and rivers draining the western side of the volcano. The passage and survival of both adult and juvenile salmonids in the silt and ash-laden river water presented management problems for hatcheries which were not directly destroyed by the initial eruption. The tolerance of juvenile coho salmon to suspended volcanic sediment was determined by field and laboratory bioassays. The 24-, 48-, and 96-hr LC50 suspended sediment concentrations determined by instream live-box bioassay were 2,895, 2,124 and 1,217 mg/l, respectively. Static bioassays conducted in the laboratory for 24-, 48-, and 96-hr LC50 suspended sediment concentrations were 21,842, 18,798, and 17,976 mg/l, respectively. The static laboratory bioassays indicated LC50 concentrations nearly ten times higher than the instream bioassays. The difference was probably due in part to higher water velocities in the field which increased abrasion of gill tissues and uncontrollable changes in physical and chemical water quality parameters. The more conservative live-box LC50's are suggested for use in the evaluation of future management strategies. Preliminary histological examination of juvenile coho salmon gill tissue indicated increased damage with increasing amounts of suspended sediment. Histological damage was found at suspended sediment concentrations below the 96-hr LC50 and may represent a threat during passage and rearing which may ultimately affect smolt survival during transition into sea water. This is the focus of continuing research.

Limited instream live-box tests of adult coho salmon indicated a

somewhat greater tolerance to suspended sediment. Some returning adults avoided the affected rivers and diverted to other streams while others died unspawned in the lower Cowlitz River. Small numbers of adults ascended the Toutle River only to die unspawned.

Estimates of the probable survival of salmon smolts through the lower Cowlitz River were made for the spring of 1981 based on USGS suspended sediment and discharge data. These estimates indicate that suspended sediment concentrations will continue to reduce smolt survival during passage under both average and low flow discharge conditions.

2.0 ACKNOWLEDGEMENTS

This study was sponsored by the Washington State Department of Fisheries (WDF), the Office of Water Research and Technology, U.S. Department of the Interior, Washington, D.C., and the State of Washington Water Research Center. Cooperation of Messrs. Bill Rees, Duane Phinney and other members of the WDF is greatly appreciated. We also express our appreciation to the U.S. Geological Survey for the provision of important water quality information; the Washington Department of Natural Resources (Southwest Region) for a portable 2-way radio critical in the conduct of this study; and the U. of W. Department of Geology for a US DH-48 water sampler.

Dr. Marsha Landolt, U. of W. College of Fisheries, conducted the histological analyses of the gill tissues. Messrs. Mark Hunter and Craig Olds carried out a portion of these field studies while Gary Tamas participated in the analysis of water samples. Personnel of the Big Beef Creek Fisheries Research Station, including Bruce Snyder, Lynn McComas, Gary Maxwell, and Cliff Whitmus were

principals in moving and placing into operation the experimental stream channels that were formerly at the Clearwater project on the Olympic Peninsula.

3.0 INTRODUCTION

The eruption of Mt. St. Helens in southwestern Washington on May 18, 1980 caused major losses of salmon in the streams and rivers draining the western side of the volcano. Major problems in the passage of juvenile and adult salmon were created by the runoff of blast debris, mudflow and volcanic ash. Immediate management concerns included strategies of release and the subsequent survival of juvenile salmon produced by major salmon hatcheries in the area. Initial tests by the Washington Department of Fisheries indicated that survival of any juvenile salmon in the streams draining the north and west sides of the mountain was very low immediately following the eruption, necessitating the transport of fish around the silt and ash-laden river water. Transport of smolts around the affected area is costly and poses additional problems of stress during transport and may impact homing behavior of these smolts when they return as adults. It is imperative to know the concentrations of suspended sediment that will allow passage of smolts and adult fish so that normal management may resume. In addition, little information on the behavior or tolerance of adult chinook and coho salmon to high suspended sediment loads was available. Because of the near-total disruption of the habitat, conventional management techniques of natural and hatchery production had to be abandoned.

This study determined the tolerance of juvenile and adult coho salmon

(Oncorhynchus kisutch) to suspended sediment concentrations found in the Toutle, Cowlitz and Columbia Rivers. The specific objectives were 1) to monitor the tolerance of juvenile and adult salmon by in-situ live-box bioassay in affected portions of the Toutle, Cowlitz and Columbia Rivers; 2) to monitor the water quality at each bioassay location, including analysis of the discharge-related concentrations of the suspended sediment components; 3) to determine the 96-hr LC50 suspended sediment concentrations for juvenile salmon; and 4) to determine the effects of sublethal exposures to suspended sediment concentrations. Over the years the numbers of fish exposed to sublethal suspended sediment concentrations may be much greater than those killed outright, and this may be of greater ultimate concern than the loss of those killed by the initial eruption and mudflows. Definition of this aspect will be the focus of subsequent research.

The results of this study will be integrated with the investigations of the fluvial geomorphology (T. Dunne, U.W. Geology) designed to determine a sediment budget for the Toutle drainage basin. Predictions of the sediment stabilization rates are essential to the strategy for recovery of salmon production in the basin.

4.0 STUDY AREA

The May 18, 1980 volcanic eruption of Mt. St. Helens caused damage and devastation through blast effects, poisonous gases, fire, heat and ashfall over a 200-square-mile area north of the mountain (Rosenfeld 1980) (Fig. 1). In addition, an estimated 46 billion gallons of melted glacial ice mixed with the overflow from Spirit Lake and an estimated 1.15 billion cubic meters

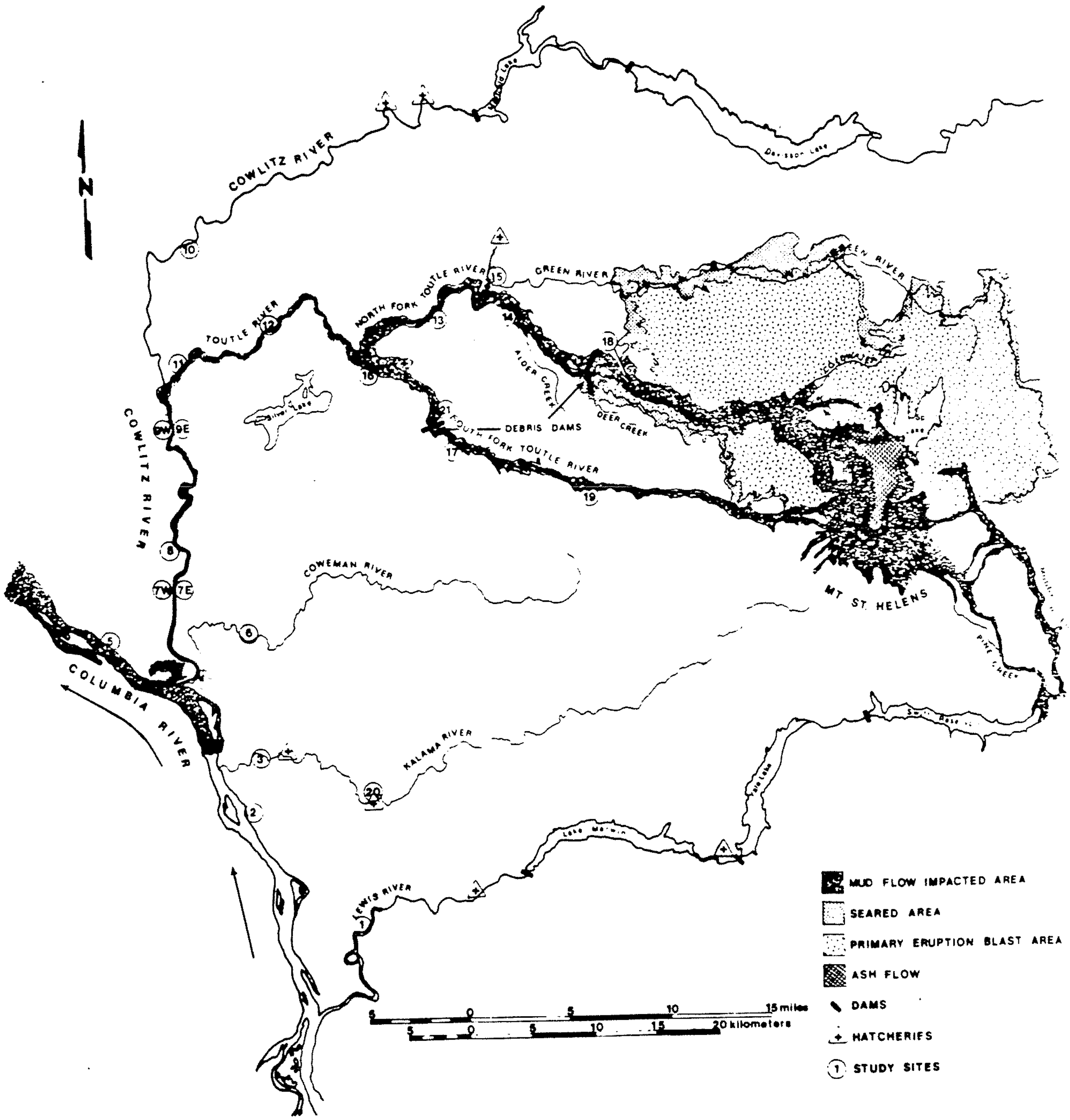

Fig. 1. Mt. St. Helens showing the areas and types of impact. The study sites are located on the tributaries draining the west side of the volcano.

(1.5 billion cubic yards) of volcanic ash, mud and debris flowed off the northwest flank of the mountain down the north and south forks of the Toutle River into the Cowlitz River and on into the Columbia River (U.S. Army Corps of Engineers 1980). The habitat and associated aquatic life in the north and south forks of the Toutle River and the lower 22 miles of the Cowlitz River were destroyed by mudflows which severely scoured and buried the river channel. The upper Toutle River channel was buried to depths of 137 m (450 feet) while the lower Cowlitz River channel was filled with 4.6 m (15 feet) of mud and debris.

The Green River drainage was partially affected by the blast and heavy accumulations of air-fall ash. The timber over large areas of the valley was scorched or blown down. The infall and runoff of volcanic ash into the Green River destroyed fish and other aquatic life throughout this drainage basin. The Kalama River was impacted with lesser amounts of air-fall ash from eruptions subsequent to the May 18 blast. The upper Lewis River received a mudflow from tributaries draining the southeast side of the volcano. This mudflow entered Swift Reservoir; however, the three reservoirs on this system have served as sediment catch basins and removed most of the suspended particles. The Coweman and upper Cowlitz Rivers received light dustings of air-fall ash and were the least affected rivers draining the western side of the volcano.

In an effort to control the further runoff of sediment and debris and to control potential future flooding, the Army Corps of Engineers constructed two debris dams, one on each fork of the Toutle River (Fig. 1). Extensive channel clearance and dredging was conducted on the main Toutle, lower Cowlitz and affected portion of the Columbia River (U.S. Army Corps of Engineers 1980).

Approximately 25 percent of Washington State's salmon hatchery production occurred at seven hatchery facilities in the drainages surrounding Mt. St. Helens. Table 1 shows the average adult chinook (O. tshawytscha) and coho salmon escapements to four of these facilities. One of the largest salmon hatcheries in the world is located on the upper Cowlitz River (Fig. 1), and although the hatchery was not affected, the sediment concentrations in the lower Cowlitz River posed a major threat to the survival of juvenile and adult salmon during passage. The Toutle Hatchery located at the mouth of the Green River was flooded by the mudflow which traveled down the north fork Toutle River. The hatchery and production were lost with the mudflow. Fish production facilities on the Kalama River have been hindered by suspension of ash in the water supply and some fish mortality has occurred. This has been most severe following rainfall events. The Lewis River Hatchery has more recently become seriously affected with additional rainfall.

The Washington Department of Fisheries estimated the loss of juvenile coho, fall and spring chinook salmon following the May 18 eruption. Including the Toutle Hatchery production, Toutle River natural production and Cowlitz River natural production, they estimated a total combined loss of at least $7.8 million. This estimate did not include reduction in survival or return of fish trucked from the Cowlitz River Hatchery to the lower Columbia River. The losses due to subsequent eruptions which affected the Kalama and Lewis rivers and associated hatcheries, the 1980 brood year, and losses due to chronic effects until the environment recovers were also not included. This

Table 1. Average adult chinook and coho salmon escapement to hatchery racks (ranges in parentheses) (Hall and Fletcher 1980).

	Cowlitz	Toutle	Lower Kalama	Kalama Falls
Year	1967-79	1964-79	1972-79	1964-79
Chinook	14,302	3,374	1,237	4,471
	(4,902-22,850)	(1,297-6,727)	(83-2,089)	(1,556-8,700)
Year	1967-79	1966-79	1967-79	1966-79
Coho	20,951	21,591	3,516	11,806
	(4,913-63,407)	(8,929-49,694)	(2-6,025)	(626-40,350)

estimate is therefore preliminary and conservative.

Twenty-one water quality sampling stations were established (Fig. 1). Site location descriptions are given in Table 2. Stations 2, 3, 5, 7 E and W, 8, 9 E and W, 10, 11, 13 and 16 were monitored with juvenile coho salmon in live-boxes.

5.0 MATERIALS AND METHODS

5.1 Water Quality

Water quality was monitored at 21 sample sites weekly from July 12 through November 14, 1980. Temperature, pH, dissolved oxygen and conductivity were measured in-situ with a Model 4041 Hydrolab and water velocity was measured with a Marsh-McBirney current meter. Integrated suspended sediment samples were taken with a US DH-48 sampler lowered and raised through the water column. Water samples in polyethylene containers were transported to the laboratory for determination of settleable solids, total non-filterable residues (TNFR) (APHA 1976) and organic and inorganic components of the sediment.

Settleable solids (ml/l) were determined by placing a thoroughly mixed one-liter sample into a graduated Imhoff cone, allowed to settle for 45 minutes, stirred gently, allowed to settle for an additional 15 minutes and then a volumetric reading of the settleable solids was taken. Total non-filterable residues (suspended) (mg/l) were determined by filtering a 200-ml sample through a pre-weighed 4.25-cm-diameter glass microfiber filter. The filter was dried and weighed again and the difference was multiplied by 5 to obtain the concentration in mg/l. The organic versus inorganic component of the

Table 2. Water sampling and bioassay sites.

Site No.	Location/description
1	Lewis River — on Route 503, N.E. of Woodland, Washington.
2*	Columbia River — at Kalama City boat basin.
3*	Kalama River — at Wash. Dept. of Game public boat launch.
4	Lower Cowlitz — at railroad bridge south of Kelso.
5*	Columbia River — at Longview, Weyerhaeuser pulp gate.
6	Coweman River — off Allen Street out of downtown Kelso.
7 E*	Cowlitz River — downtown Kelso, east bank.
7 W*	Cowlitz River — downtown Kelso, west bank.
8*	Cowlitz River — Lexington City Park.
9 E*	Cowlitz River — Castle Rock fairgrounds, east bank.
9 W*	Cowlitz River — Castle Rock fairgrounds, west bank.
10*	Cowlitz River — Jackson Highway under I-5 bridge.
11*	Lower Toutle River — just east of I-5, near mouth of Toutle.
12	Middle Toutle River — at Tower Road.
13*	Lower N. Fork Toutle River — 2 miles east of intersection of Routes 504 and 505.
14	Middle N. Fork Toutle River — 1½ miles upstream from confluence of Green River.
15	Green River — at hatchery intake, just above Toutle Hatchery.
16*	Lower S. Fork Toutle River — at bridge just east of Four Corners.
17	Middle S. Fork Toutle River — just outside red zone line.
18	Upper N. Fork Toutle River — 1 mile above USACE dam.
19	Upper S. Fork Toutle River — end of logging road 4100.
20	Kalama Falls Hatchery — spillways.
21	Middle S. Fork Toutle River — just below USACE dam.

* Live-box bioassays.

suspended residue was measured. Thirty-percent hydrogen peroxide (3-5 ml) was added to the dried residues. The samples were heated to 50°C for 45 min. in order to digest all the organic components. This method was utilized to minimize breakdown of sediment particles to facilitate further analysis of particle sizes. The filters were weighed again and the difference in weight multiplied by 5 to give the value of the organic component of the sample in mg/l. The turbidity (JTU) of each suspended sediment sample was determined with a Hach DR-EL turbidimeter.

5.2 Instream Bioassays

5.2.1 Juveniles

Between July 8 and October 11, 1980, 96-hr instream live-box bioassays were conducted at twelve locations on the Toutle, Cowlitz, Columbia and Kalama Rivers (Fig. 1). Each test generally consisted of 25 juvenile coho salmon in a cylindrical live-box (45.7 cm long x 35.5 cm diameter) suspended in the river (Fig. 2). The first four bioassays tested juvenile coho salmon from the Lewis River Hatchery, while the last bioassay used Grays River Hatchery coho.

The initial bioassays over the period from July 8-12, 1980 were conducted at six locations (sites 2 [control], 4, 7 W, 9 W, 10 [control] and 11; Fig. 1). The July 22-26 bioassays were expanded to twelve sites (2, 3, 5, 7 E, 7 W, 8, 9 E, 9 W, 10, 11, 13 and 16). The August 12-16 bioassays utilized every site except site 13. The only site of the twelve which could not be utilized during the September 9-13 bioassay was site 9 W. A replicate live-box was used at site 11. The October 7-11 bioassays utilized ten sites because sites 8 and

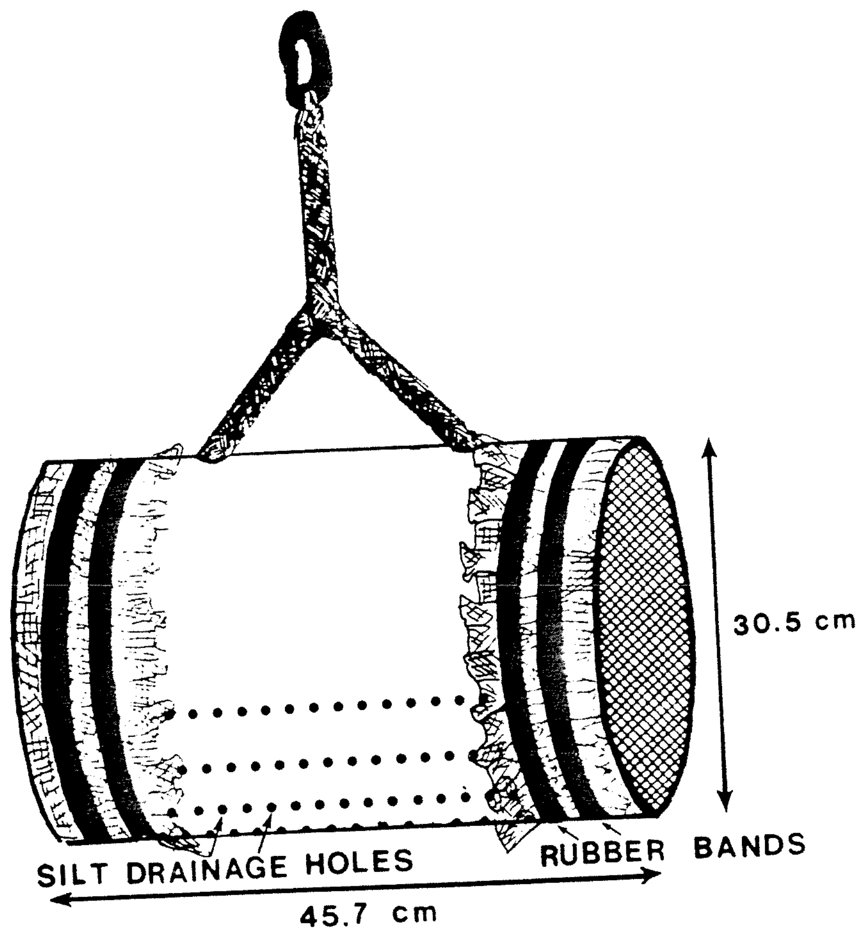

Fig. 2. Live-box used for instream bioassays of juvenile salmon.

9 W were inaccessible. Water quality and velocity measurements were taken each day at each site.

Mortalities were noted at approximately 24-hour intervals. Upstream sites, where mortalities occurred rapidly, were checked at approximately hourly intervals until 100 percent mortality had occurred. The 24-, 48-, and 96-hr LC50 concentrations of suspended sediments were calculated using the BMD03S computer program for probit analysis.

Samples of gill and skin (caudal peduncle) taken from fresh specimens were preserved immediately in Bouin's fixative. Tissue samples were dehydrated in ethanol, cleared in xylene, embedded in paraffin, cut on a microtome to a thickness of four microns, mounted on glass slides, and stained with hematoxoylin and eosin. The histological analyses were conducted by Dr. Marsha Landolt.

5.2.2 Adults

Two instream live-box bioassays were conducted from October 1 through 9 and October 21 through 31, 1980 with adult coho salmon. A large wire mesh pen was placed in the Cowlitz River at Kelso (site 7 W) and at the Cowlitz Salmon Hatchery as a control. Four adult coho were held in each pen during the first bioassay. During the second bioassay four adult coho were held in the control and two steelhead (*Salmo gairdneri*), two chinook (jacks) and four coho in the test pen. Pens were checked daily for mortality and a fish sacrificed from the test pen at 24 hours and at ∿ 48 hours for gill tissue samples. Examination of these tissues remains to be completed.

5.3 Laboratory Bioassays

5.3.1 Juveniles

Six 96-hr bioassays were conducted in 60-liter tanks modified with a steeper 1/16"-thick PVC concave bottom than that described by Smith (1978). The concave bottoms were needed to help keep the sediment in circulation. In each tank the fish were contained in a 1/4" mesh Vexar (TM) pen, and the water was recirculated by a submersible Little Giant (TM) pump to keep the sediment in suspension. The pump intake was positioned at the center of the concave bottom, and the recirculated water was directed in a circular motion in each tank (Fig. 3). Depending on the bioassay, a test used 8 to 16 tanks. All the tanks were placed in large water baths which kept the temperature within 2.3°C of ambient. Airstones were added to all tanks after the third bioassay to ensure saturation of dissolved oxygen.

Mortality and water quality monitoring schedules varied among the bioassays. The typical schedule was to check the tanks at 3, 6, 12, 24, 48, 72 and 96 hours. The 24-, 48-, and 96-hr LC50 concentrations of suspended sediments were calculated using the BMDO3S computer program for probit analysis. Water quality measurements were taken on temperature, pH, dissolved oxygen and conductivity. Turbidity (JTU) readings were taken initially with a Hach turbidimeter and samples were taken for measurements of settleable and suspended solids. Samples were also analyzed for organic/inorganic components.

All bioassays except one used air-fall ash from the Green River. This ash was taken from the banks of the Green River above the backup of the north fork Toutle River mudflow. This ash was used as a standard for later comparison

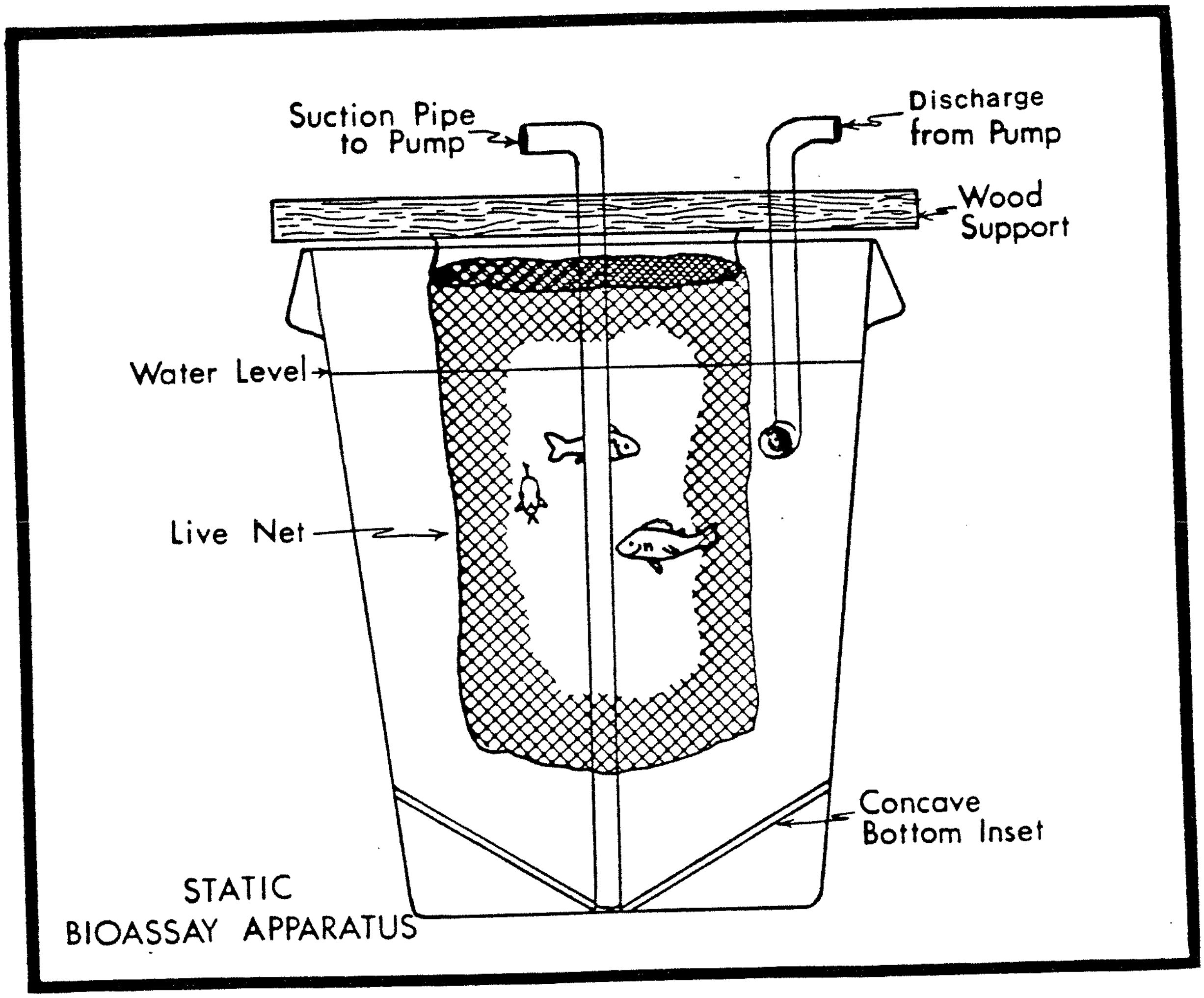

Figure 3. Laboratory bioassay apparatus (after Smith 1978).

with other sediment types generated from the eruption. Both Green River ash and fine mudflow sediment from the south fork of the Toutle River were tested in one side-by-side series of suspended sediment concentrations.

The sediment used in each bioassay was passed through a series of screens to remove particles of sediment and organic detritus larger than 0.105 mm. The concentrations used varied between bioassays, depending in part on the results of the previous tests, but generally had maximum suspended solids concentrations of about 49,500 mg/l (7,000 JTU). The suspended solids concentration in one bioassay (No. 6) was increased to 177,800 mg/l (16,500 JTU) by concentrating the suspended sediments during the screening process.

The initial bioassay used juvenile coho salmon from the Minter Creek Hatchery (average weight ∿ 8 grams) while juvenile coho from the Lewis River Hatchery (average weight 3.5-6.5 grams) were used in all the others. Loading rates varied from 18 to 25 fish per tank and did not exceed 3.3 g fish/l.

5.3.2 Adults

Tests of adults were conducted at the Big Beef Creek Fisheries Research Station in 9.14 m (30') long by 25.4 cm (10") wide by 25.4 cm (10") deep artificial streams (Fig. 4) with ∿ 90 percent recirculating water and suspended sediment. Suspended solids concentrations tested ranged from 57 to 15,000 mg/l and water velocities averaged 17.4 cm/s (0.6 fps). Adult coho salmon from Minter Creek Hatchery were tested in Green River ash between October 13 and November 5, 1980. From November 6 through November 20, 1980, two troughs were used (1 control, 1 with ash) to further test for ash-caused abrasion, and to look for possible indicators of sublethal stress. Fifteen female coho salmon were obtained from Minter Creek Hatchery, and one was

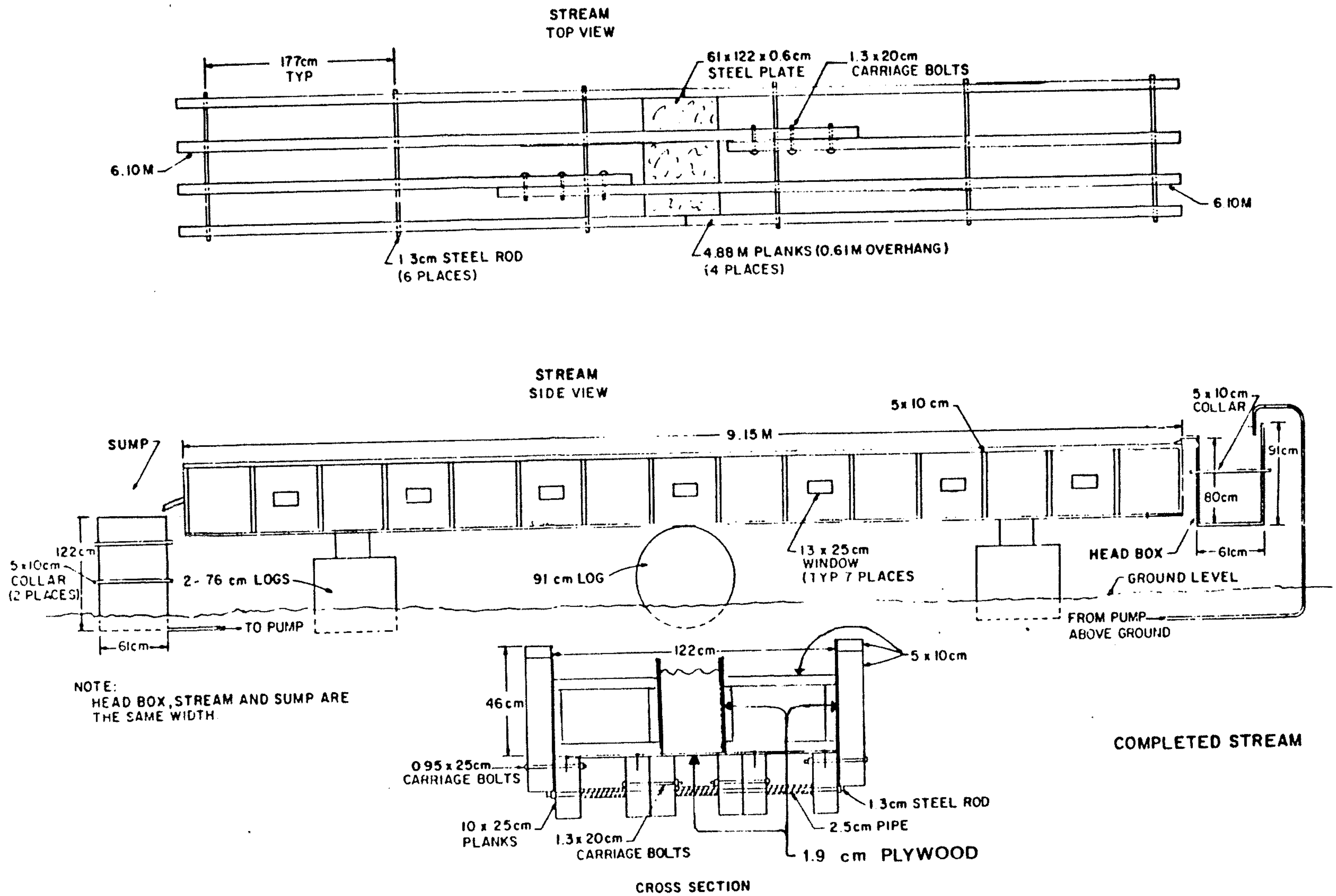

Fig. 4. Plan of experimental stream (modified from Noggle 1978).

sacrificed as a control. Seven fish were placed in each trough, and 1 fish from each trough was sacrificed after 1, 2, 4, 5, 7 and 9 days. Tissue samples including gill, skin and nares were taken from each fish, which remain to be analyzed.

6.0 RESULTS AND DISCUSSION

6.1 Water Quality

6.1.1 Suspended Sediment

The upper Cowlitz River was unaffected by the eruption and represents a baseline condition for suspended sediment (Fig. 5). The lower Cowlitz River affected by mudflow had a slight decline in sediment concentration through mid-August followed by a general increase during the extensive dredging which occurred from late August to early November. Concentrations ranged between 500 and 2500 mg/l. The north fork Toutle River had low suspended sediment concentrations during dry weather in July and early August (range 15 to 815 mg/l), but when the rains started, erosion from the debris in the upper valley increased the sediment loads to very high levels. The north fork of the Toutle River above the dam following a November storm had concentrations over 300,000 mg/l. Large mudflow deposits of sediment along the south fork Toutle River eroded continuously following the May 18 eruption, causing high suspended sediment concentrations during the entire study period. During the beginning of the rainy season the debris dams constructed by the Corps of Engineers reduced the initial suspended sediment loads in both forks of the Toutle River. The Green River drainage was affected only by air-fall ash. Suspended sediment concentrations ranged to 15,891 mg/l following a rain

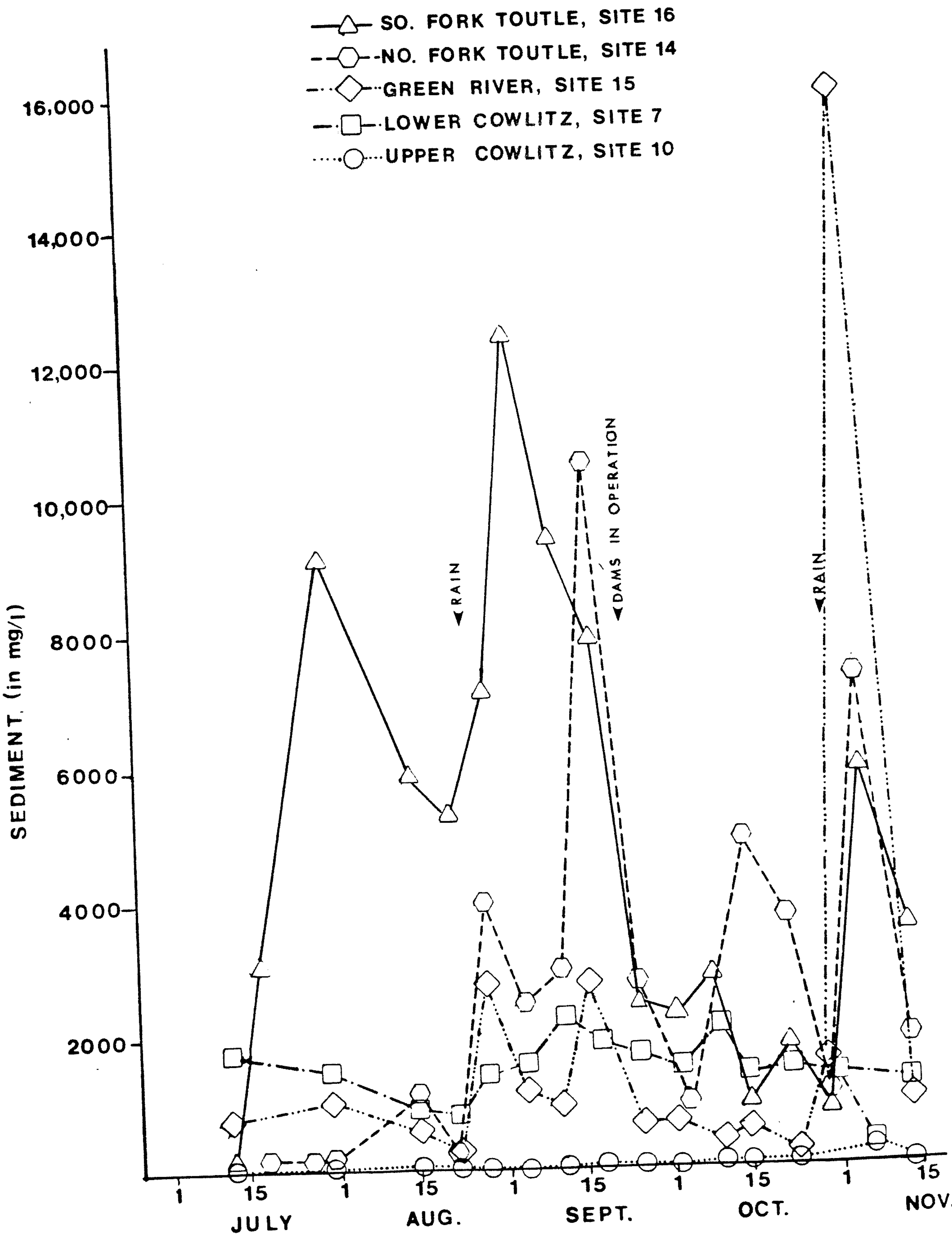

Fig. 5. Suspended sediment samples for five selected sampling sites taken at one-week intervals during the study.

and were similar to those of the other tributaries which received mudflow and blast debris.

6.1.2 Water Temperature

Little difference was apparent in temperatures between upper and lower Cowlitz River sites (Fig. 6). Comparison of the lower Toutle with the Kalama River indicates the Toutle River temperatures ranged to a maximum of 25°C during July 1980 while the Kalama did not exceed 17°C. Water temperatures (23 to 25°C) during the summer were similar on the north and south forks of the Toutle River and in the Green River. Pre-eruption water temperature data at the Toutle Hatchery for the five years preceding indicated average maximum water temperatures less than 19°C. The loss of riparian vegetation along the mudflow-devastated rivers is partly responsible for the increase in summer temperatures. An increase in water temperatures is expected to reduce survival in the presence of other water pollutants.

6.2 Juvenile Coho Bioassays

The log-probit plots of instream and static bioassays are presented for comparative time periods in Figs. 7, 8, and 9. The 24-, 48-, and 96-hr LC50 suspended sediment concentrations determined by instream live-box bioassay were 2,895, 2,124 and 1,217 mg/l, respectively. Static 24-, 48-, and 96-hr LC50 suspended sediment concentrations were 21,842, 18,798 and 17,976 mg/l, respectively. The static laboratory bioassays indicated LC50 concentrations nearly ten times higher than the instream bioassays. The difference between laboratory and instream LC50's was probably due in part to higher water velocities in the field which increased abrasion of the gill tissues and uncontrollable changes in physical water quality parameters. The detection of phenolic compounds by the USGS and COE in the Toutle and Cowlitz Rivers

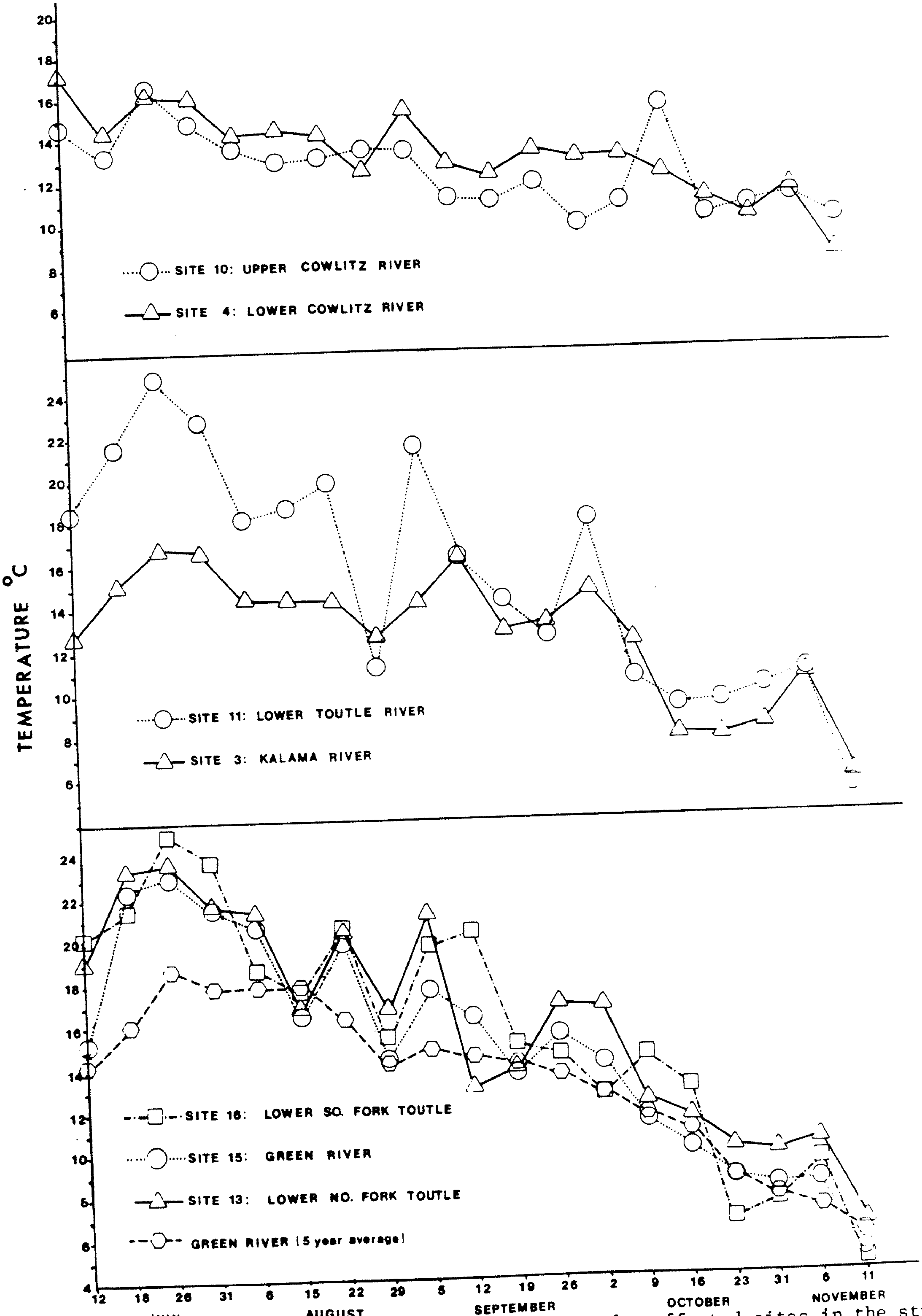

Fig. 6. Water temperatures comparing affected and unaffected sites in the study area. The average temperatures reported for the Green River cover the period 1975-79 at the Toutle River Hatchery (WDF data).

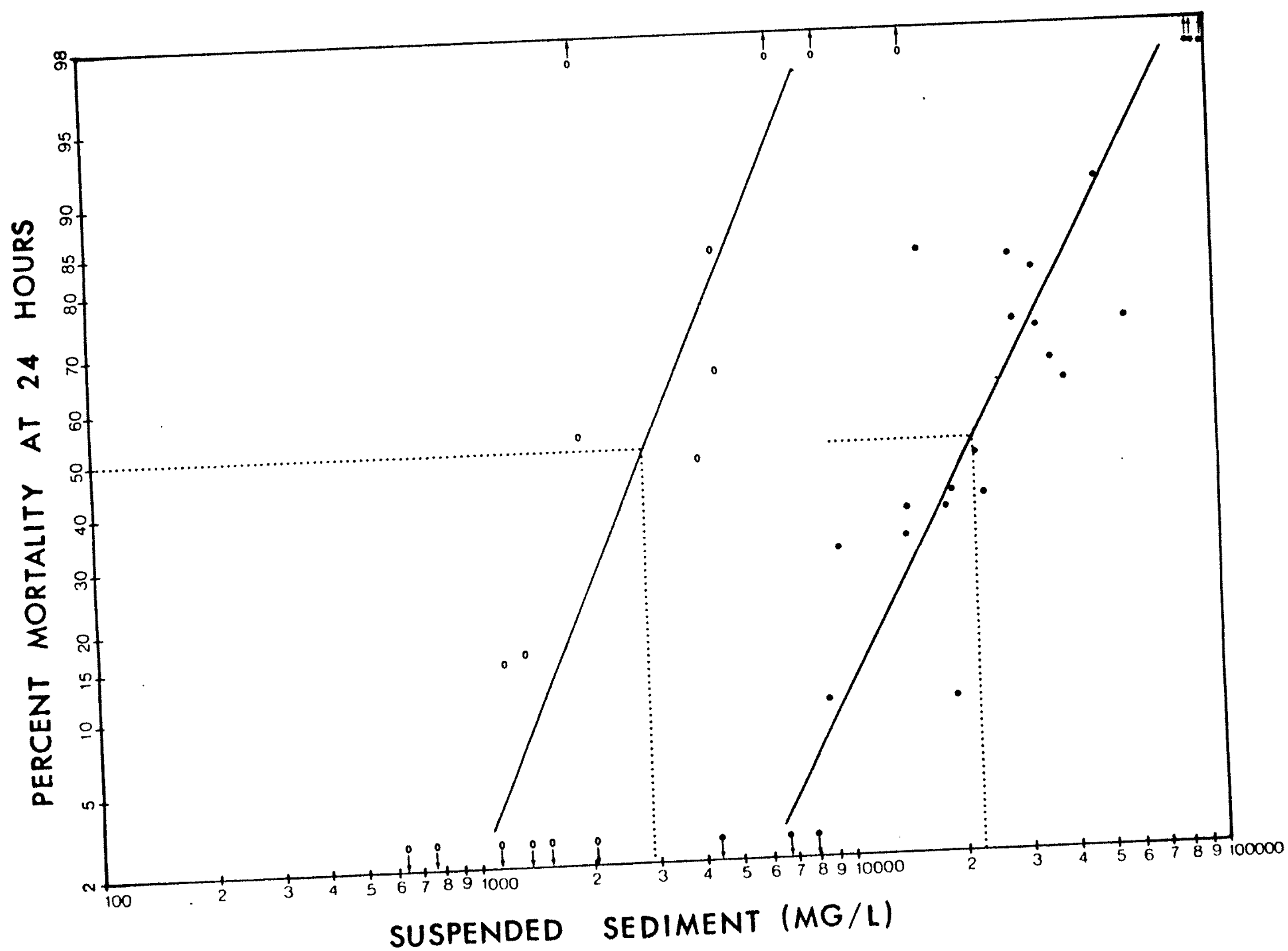

Fig. 7. Log-probit (percent) plots of 24-hr instream live-box (0) and static laboratory (●) bioassays indicating respective LC50 values.

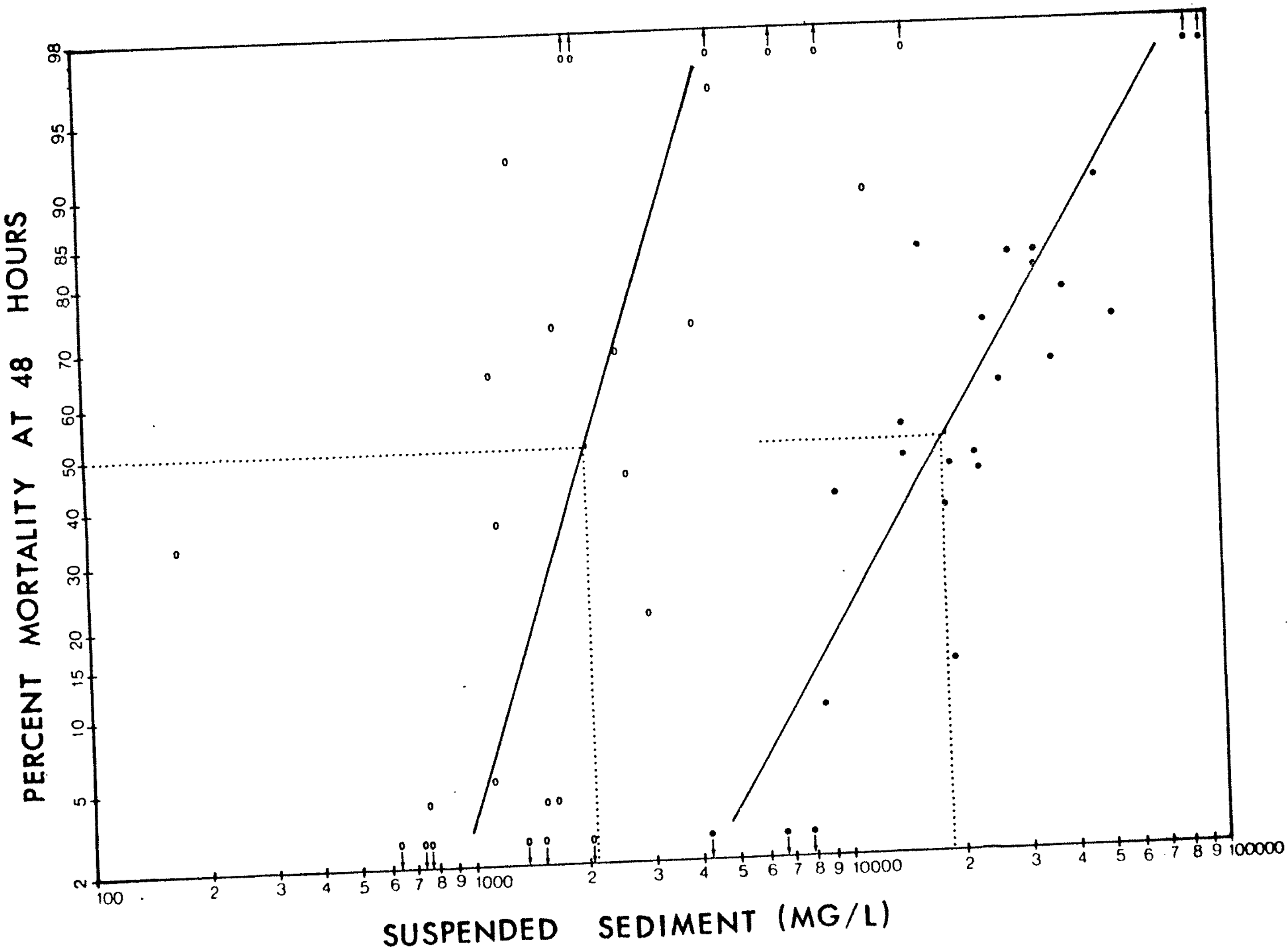

Fig. 8. Log-probit (percent) plots of 48-hr instream live-box (0) and static laboratory (●) bioassays indicating respective LC50 values.

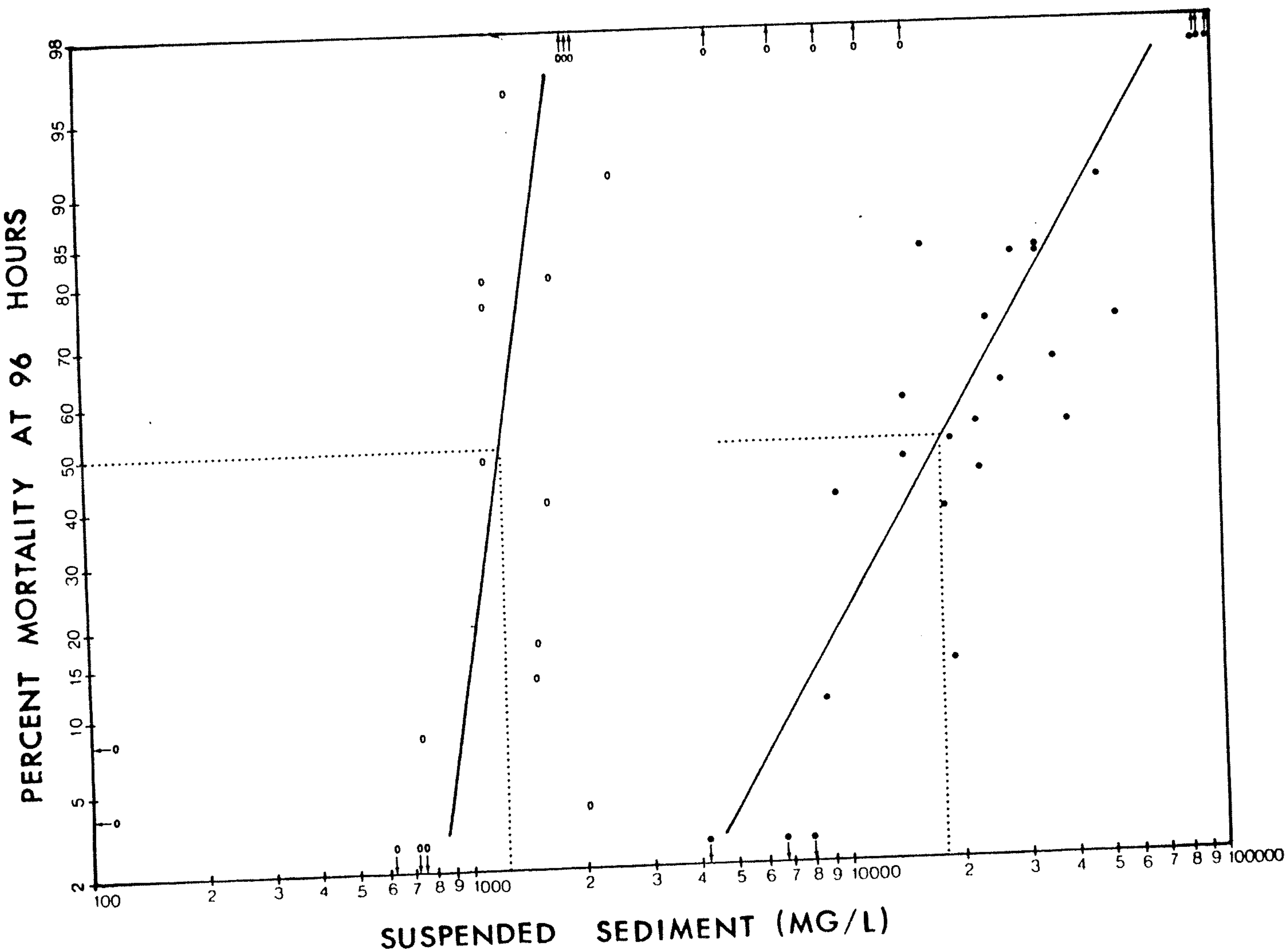

Fig. 9. Log-probit (percent) plots of 96-hr instream live-box (0) and static laboratory (●) bioassays indicating respective LC50 values.

following the eruption may also be a contributing factor. The occurrence of phenols from the blast debris did not become known until after these field studies had been completed. The instream live-box bioassays were considered to provide the most conservative estimates of the LC50 and were used in the following comparisons and predictions.

The instream 96-hr LC50 suspended sediment concentrations by general location are plotted in Fig. 10. Mortalities at the control sites were less than 10 percent and were greater than 90 percent at all the Toutle River sites. Partial mortalities occurred in the lower Cowlitz River following 96-hr exposures to suspended sediment concentrations ranging between 500 and 2000 mg/l. The lower Cowlitz River is the only avenue for fish passage between the Cowlitz Hatchery and the ocean.

Fish mortality in live-boxes placed in the lower main Toutle River increased to 100 percent in 3 hr at mean suspended sediment concentrations of 2,022 mg/l. Complete mortality occurred in about 30 min at south fork Toutle sites where suspended sediment concentrations averaged 11,429 mg/l.

6.3 Histological Examinations

The histological examinations completed to date on juvenile coho salmon gill tissue are presented in Table 3. Pathologic effects on the gills generally increased with increase in suspended sediments. The damage observed in specimen (No. 17) from the Columbia River at the Kalama control site was probably artifactual due to incomplete fixation. The occurrence of histological damage at suspended sediment concentrations below the 96-hr LC50 may represent a threat during passage and rearing which may ultimately affect

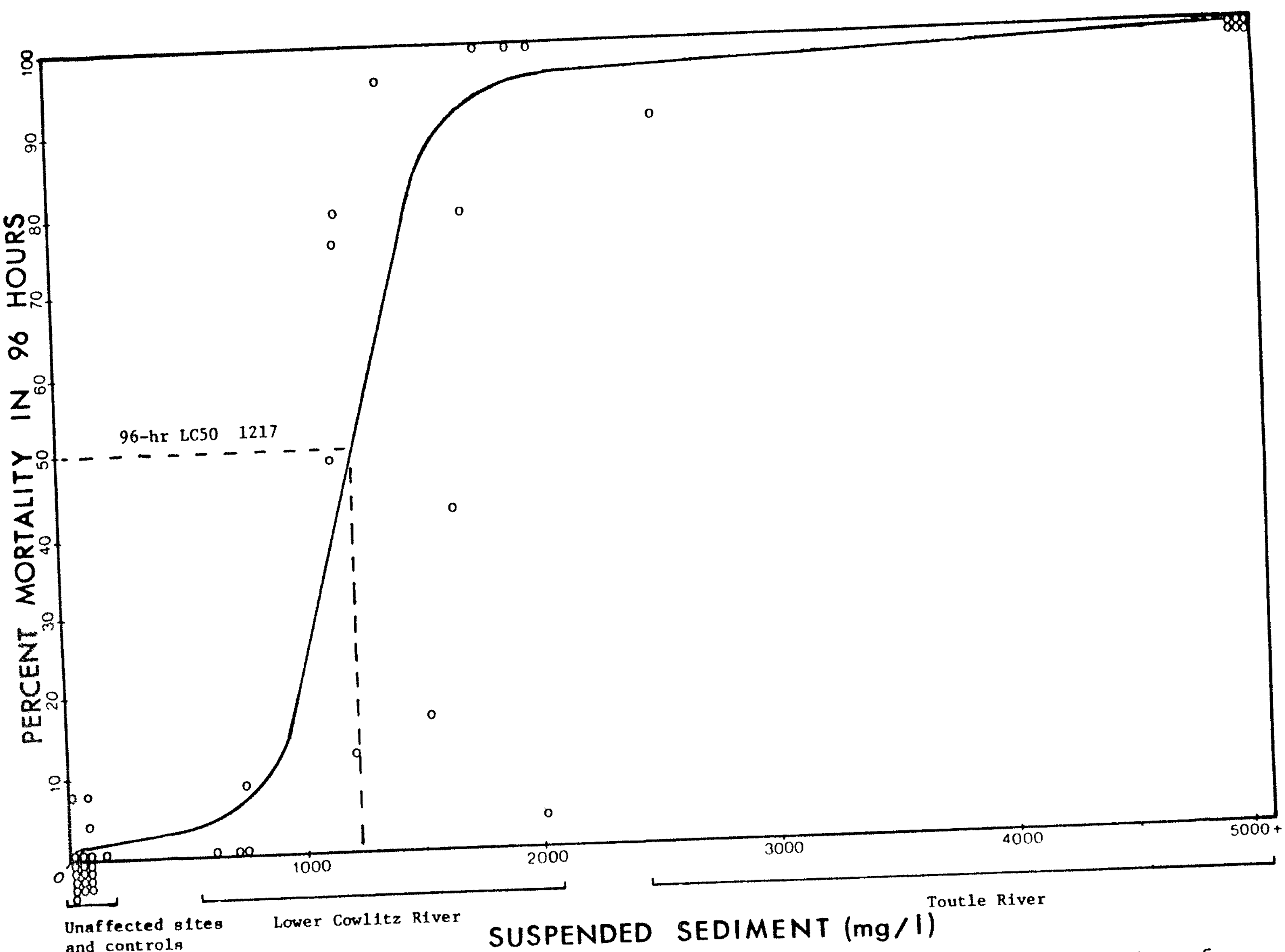

Fig. 10. Instream live-box 96-hr bioassay responses showing the general location of occurrence.

Table 3. **Summary** of preliminary results of histopathology examinations of juvenile coho gills from instream bioassays.

Site	Live fish at end of 96 hours			
	Specimen No.	Average velocity (fps)	Average suspended sediment (mg/l)	Comment*
Cowlitz R. (control)	15	—	7.3	Normal
Cowlitz R. (control)	9	0.49	9.5	Generally normal, slight inflammation
Kalama R. (control)	12	0.86	21.8	Normal
Kalama R. (control)	25	0.89	14.9	Healthy
Columbia R. (control) at Kalama	17	0.32	28.9	Extensive epithelial degeneration and sloughing (possible post-mortem change)
Kalama R. (control)	19	—	13.48	Normal
Columbia R. (control)	32	0.04	18.9	Normal
Cowlitz R. at Castle Rock (west)	11	0.37	83.9	Some epithelial hypertrophy
Cowlitz R. at Kelso	20	1.58	754.7	Minor epithelial hypertrophy
Cowlitz R. at Castle Rock	22	0.45	759.4	Normal
Cowlitz R. at Kelso	18	—	629.0	Some epithelial hypertrophy
Cowlitz R. at Kelso	42	—	1,200.4	Some epithelial hypertrophy
Kalama Falls fish hatchery stock	50	—	28.1	Normal, but with large amount of particulate matter in branchial cavity

Table 3. (continued)

Site	Specimen No.	Average velocity (fps)	Average suspended sediment (mg/1)	Comment*
Gill histopathology of freshly killed coho				
South fork Toutle R. (LT50 < 30 min)	8	0.54	10,588.4	Moderate inflammation, abundant particulate matter in gill lamelli
Main Toutle R. (∿ 3 hr)	16	—		Extensive epithelial sloughing — possible post-mortem change
Histopathology of coho body cross-sections from live fish (96 hr)				
Kalama R. (control)	26	0.89	27.14	Healthy
Cowlitz R. at Castle Rock	23	0.45	759.4	Normal
Cowlitz R. at Lexington	31	1.03	1,732.9	Diffuse granulomatous inflammation among pyloric caeca. Proteinaceous exudate in body cavity
Cowlitz R. at Kelso (east)	45	—	2,020.5	Proteinaceous exudate in body cavity

* This column is a brief summary of Dr. Landolt's comments. It should be emphasized that the conditions (other than normal) described in this column reflect only minor changes for the most part — not gross lesions.

smolt survival during transition into sea water. Future effort will be focused on definition of the sublethal effects of suspended volcanic sediments.

6.4 Adult Coho Bioassays

In the adult coho instream live-box bioassays in the Cowlitz River at Kelso (Station 7 W) one mortality occurred after four days exposure and another after six days. Two remaining fish died on the eighth day, the final day of the test. The suspended sediment concentrations averaged about 1,600 mg/l. The last individuals showed evidence of scale loss and abrasion from battering the sides of the live-box. The second bioassay with four adult coho salmon, two chinook (jacks) and two steelhead received less attention; however, one fish (ripe coho female) died on the second day and another coho succumbed after the ninth day. Suspended sediment concentrations remained at 1,429 mg/l. Control fish did not die in either experiment.

These bioassays support the observations made on adult chinook and coho salmon in the field. Some adult salmon avoided the affected rivers and migrated to hatcheries on adjacent streams. The extent of these dislocations will be assessed in the evaluation of tagged fish released from the Toutle Hatchery which returned to the Kalama Falls and Cowlitz Hatcheries. Some returning salmon were found dead or dying in the lower Cowlitz River. These individuals presumably could not tolerate the suspended sediment concentrations encountered in the lower Cowlitz River and did not elect to avoid the passage-way. Small numbers of both live and dead coho and chinook were observed in the north and south forks of the Toutle River. Natural production from any fish which did spawn in the Toutle River was very unlikely; however, most individuals died unspawned. Histological examination of gills from some of the returning adults will be made in an effort to determine the probable causes of death.

Bioassays conducted in the laboratory stream channels did not result in mortality to the adult coho tested. Test fish were sacrificed over time to examine histological changes in gills and nares. Some fish were found to have the nares occluded with sediment and others were observed with nares bleeding. Analyses of the laboratory tests on adults remain to be completed.

6.5 Smolt Passage Survival 1981

Large numbers of chinook (spring and fall) and coho smolts are released each spring from the Cowlitz River Hatchery. The following evaluation is intended to aid in decision-making regarding the release, passage and probable survival of the smolts through the lower 22 miles of the Cowlitz River.

Suspended sediment measurements taken by the USGS from May 25 to December 27, 1980 at Highway 99 (Station 14 2427 00, mile 0.3) on the Toutle River were expressed in tons of suspended sediment per day at each discharge measured, but were taken predominantly at at discharge of < 1000 cfs. Most instream bioassays were conducted when the discharge was < 1000 cfs.

The USGS suspended sediment data (personal communication Randy Dienhart) were converted to concentration by the following procedure:

$$Q_{\ell/d} = 86{,}400 \text{ ft}^3/\text{d} \times 28.31 \ \ell/\text{ft}^3$$

$$= 2{,}446 \times 10^6 \ \ell/\text{d}$$

where one cubic foot per second = 86,400 ft^3/day.

Suspended sediment was converted from tons/day to mg/day by

$$SS_{mg}/d = 908{,}000 \text{ g/d} \times 1000 \text{ mg/g}$$
$$= 9.08 \times 10^{8} \text{ mg/d}$$

where one ton per day = 908,000 g/day.

The concentration represented by each point estimate was then obtained by

$$SS_{conc}\text{mg}/\ell = \frac{SS_{mg}/d}{Q_{\ell/d}}$$

The semi-log curve developed by least squares regression on the data is plotted in Fig. 11 and provides the basis for further assessment of the suspended sediment concentrations with discharge.

The 10-year (1970-79) monthly average discharges for March, April, May and June for the Toutle, Cowlitz and Columbia Rivers are summarized in Table 4 (USGS Water Resources Data for Washington 1970-79). The average discharge values for the Toutle River were utilized to estimate the expected suspended sediment concentrations in the spring of 1981 (Fig. 11). These points are located on the regression line and predict suspended sediment concentrations of 24,701, 21,882, 21,099 and 17,503 mg/1 in March, April, May and June, respectively. These estimates assume that the runoff from the Toutle River drainage will not differ substantially from that observed prior to the eruption which, of course, is not likely. The large loss of forest cover in the watershed will very likely result in higher river discharge than in the past. The estimated suspended sediment concentrations are therefore considered conservative.

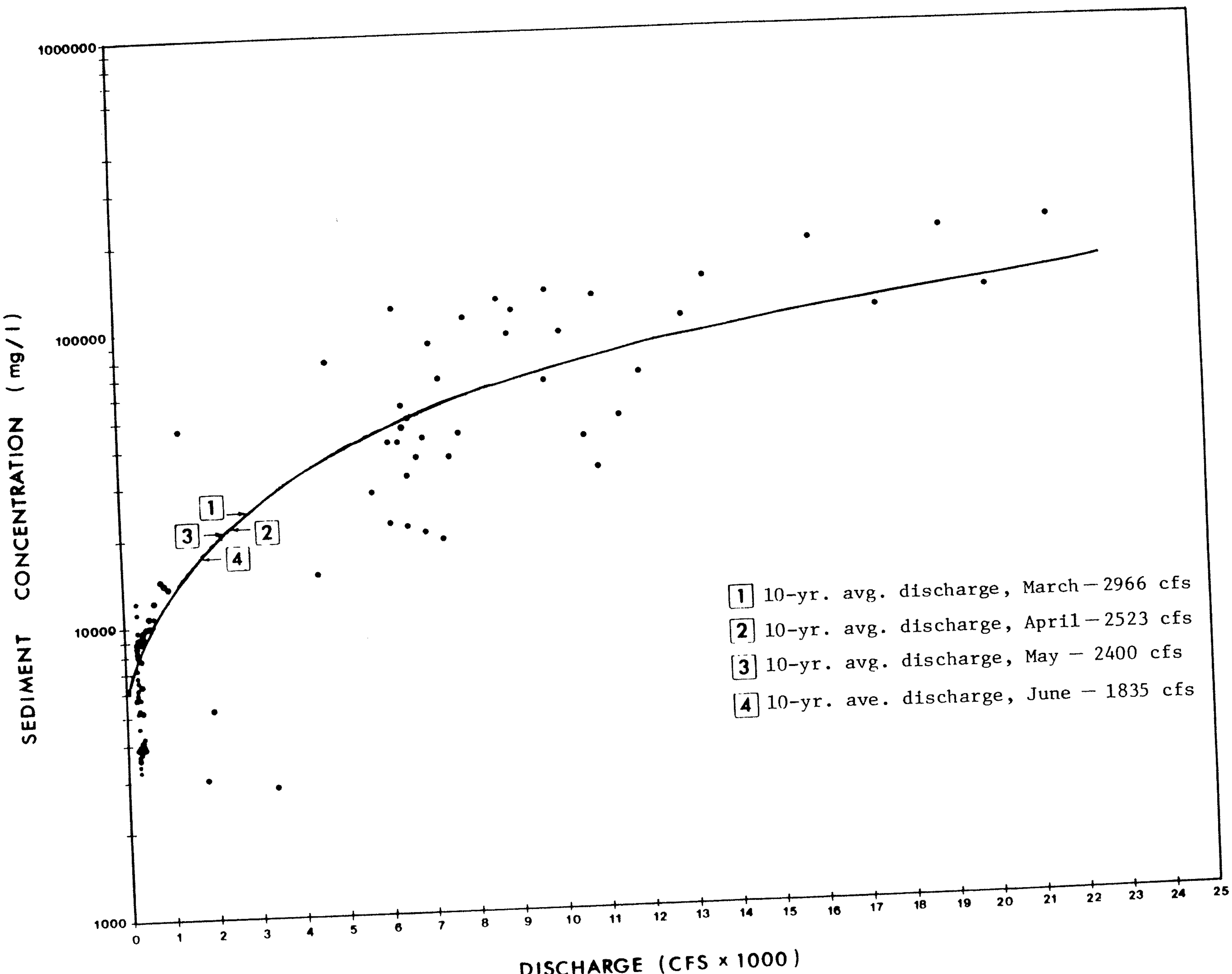

Fig. 11. Sediment concentration vs. discharge for the Toutle River, measured near the mouth (USGS site 14 2427 00, mile 0.3). Adapted from USGS unpublished sediment load-discharge curve for the period 10/1 through 12/27, 1980.

Table 4. Average, high and low discharges (cfs) for the Toutle, Cowlitz and Columbia rivers (USGS Water Resources Data for Washington, 1970-79).

A. Daily discharge*: Toutle River mouth (USGS Site 14 2425 00, values + 5%**).

	March	April	May	June
High	14,879	7,056	5,645	8,798
Average	2,966	2,523	2,400	1,835
Low	1,289	1,135	1,334	838

B. Daily discharge*: Cowlitz at Castle Rock (USGS Site 14 2430 00).

	March	April	May	June
High	44,100	21,600	23,100	27,600
Average	11,653	9,349	10,590	9,896
Low	4,680	3,550	3,630	2,730

Average monthly discharge*: Columbia at Longview (USGS Site 14 2453 00).

	March	April	May	June
High	534,500	410,600	475,500	627,200
Average	279,392	273,792	346,192	397,046
Low	179,000	141,300	175,600	155,400

* All data: 10 years, 1970-1979.

** 5% has been added to all values taken at USGS Site 14 2425 00 (Silver Lake) to estimate discharge at the Toutle River mouth.

The dilution of the suspended sediment concentrations flowing from the Toutle River into the Cowlitz River and later into the Columbia River is presented in Table 5. The average discharge for each river during the same time period (Table 4) was used to calculate the suspended sediment concentrations. The concentrations in the lower Cowlitz River at Castle Rock will decline to 6,299, 5,908, 4,789 and 3,238 mg/l and decrease further to 272, 197, 148 and 88 mg/l in the Columbia River at Longview (Table 5) during the months of March, April, May and June, respectively.

The passage time of juvenile downstream-migrant salmon may be generally related to the velocity of flowing water. The water velocities were generated by a USGS computer model for a range of discharges at three different cross-sections of the Cowlitz River (Table 6) from Castle Rock to the Columbia River. The three cross-sections cover the 22 miles of the Cowlitz River affected by mudflow. The velocities in feet per second were converted to miles per hour and the time required for water to pass the intervening distance for each river reach over a range of discharges was calculated (Table 6). The travel time from the upper extent of the mudflow was based on the Castle Rock cross-section. The time needed for water to pass through each reach was added to obtain the total travel time through the 22 miles of affected river. The time required for water to pass the lower 22 miles of the Cowlitz River at an average discharge of 10,000 cfs was estimated at 10.5 hours.

This evaluation found the 24-hr LC50 suspended sediment concentration was 2,895 mg/l in the lower Cowlitz River. The suspended sediment concentrations were conservatively estimated to range from 6,299 to 3,238 mg/l from

Table 5. **Expected spring 1981 sediment loads in the Toutle, lower Cowlitz and Columbia rivers.** Sediment source: Toutle River only.

	March	April	May	June
Toutle River suspended sediment conc. (mg/1)				
Average	24,701	21,882	21,099	17,503
Drought conditions	14,028	13,048	14,315	11,158
Toutle — average % of Cowlitz*	25.5	27.0	22.7	18.5
average % of Cowlitz (drought conditions)	11.1	12.1	12.6	8.5
Cowlitz River suspended sediment conc. (mg/1)				
Average	6,299	5,908	4,789	3,288
Drought conditions	1,557	1,579	1,804	948
Toutle — average % of Columbia**	1.1	0.9	0.7	0.5
average % of Columbia (drought conditions)	0.5	0.4	0.4	0.2
Columbia River suspended sediment conc. (mg/1)				
Average	272	197	148	88
Drought conditions	70	52	57	22

* At Castle Rock.

** At Longview.

Table 6. **Water velocities**, and time necessary for water to pass through the 22 miles of the lower Cowlitz River affected by the Toutle River mudflow. From USGS computer model based cross sections of the Cowlitz River on 11/8/80.

Cowlitz River Location of cross section	River mile	Miles to next station	Discharge (cfs)	Average velocity (fps)	Average velocity (mph)	Time to next station (hours)
Upper end of mudflow*	22	4.7	5,000	2.5	1.7	2.8
			10,000	3.08	2.09	2.2
			15,000	3.75	2.55	1.8
			20,000	4.25	2.89	1.6
			25,000	4.70	3.20	1.5
			30,000	5.10	3.47	1.4
			50,000	6.30	4.28	1.1
Castle Rock	17.3	12.4	5,000	2.5	1.7	7.3
			10,000	3.08	2.09	5.9
			15,000	3.75	2.55	4.9
			20,000	4.25	2.89	4.3
			25,000	4.70	3.20	3.9
			30,000	5.10	3.47	3.6
			50,000	6.30	4.28	2.9
Kelso	4.9	4.2	5,000	3.15	2.14	2.0
			10,000	3.75	2.55	1.6
			15,000	4.18	2.84	1.5
			20,000	4.65	3.16	1.3
			25,000	5.05	3.43	1.2
			30,000	5.35	3.64	1.2
			50,000	5.95	4.05	1.0
0.7 mi. from Columbia**	0.7	0.7	5,000	.75	.51	1.4
			10,000	1.25	.85	.8
			15,000	1.73	1.18	.6
			20,000	2.20	1.50	.5
			25,000	2.65	1.80	.4
			30,000	3.10	2.11	.3
			50,000	4.20	2.86	.2
Total time in affected area (2.0 miles above Toutle, to Columbia: 22.0 miles)	0-22	—	5,000			13.5
			10,000			10.5
			15,000			8.8
			20,000			7.7
			25,000			7.0
			30,000			6.5
			50,000			5.2

* Based on cross section at Castle Rock.

** "Next station" is mouth of Cowlitz — no cross section.

Note: All underlined data are the average for March-June.

March to June. It is apparent that the suspended sediment concentrations will remain above the 24-hr LC50. Barring an extreme drought this spring, the suspended sediment concentrations carried by the Toutle River into the lower Cowlitz River are likely to be significantly higher than predicted by using historical surface discharge records.

The data suggests that if downstream migrant salmon move with the speed of the current through the lower 22 miles of the Cowlitz River, the Columbia River could be reached in 10.5 hours. The rate of emigration for fall chinook salmon smolts is unknown but could be expected to be the most rapid of the three species considered. Spring chinook smolts are known to rear over a period ranging from days to weeks during passage. Coho smolts, completing a rearing period of at least one year, would take several days or a few weeks for passage. Even though the travel time of the water is about one-half the 24-hr LC50 exposure time we cannot be certain that survival will be sufficiently high to sustain the runs. In addition, the behavior of juvenile salmon under the passage conditions presently existing in the lower Cowlitz River is unknown. Whether high suspended sediment concentrations in the possible presence of phenolic compounds will stimulate a more rapid emigration rate via a mild stimulatory mechanism or a slower rate due to the effects of multiple toxicants will require further research. It is probable that passage conditions could remain very poor if the runoff approaches normal levels in 1981.

Since the winter of 1981 has thus far resulted in a very low snow pack, the estimated suspended sediment concentrations were based on the historical minimum of the Toutle River discharge (Table 5). The Cowlitz River is regulated by hydroelectric facilities, which are presently operating with full reservoirs, so average discharges (Table 5) were utilized in the estimates for the Cowlitz and Columbia rivers. This increases the dilution. The predicted suspended sediment concentrations in the Toutle River (Fig. 11) are 14,028, 13,048, 14,315 and 11,158 mg/l for March, April, May and June, respectively. These concentrations should decrease to 1,557, 1,579, 1,804 and 948 mg/l in March, April, May and June, respectively, in the lower Cowlitz River. These estimates are the "best cases" and approximate the 96-hr LC50. These conditions are better than those estimated for average flows, but still may cause mortality if the emigration time is 96 hrs or more. Dilution in the Columbia River should result in relatively harmless concentrations of 70, 52, 57 and 22 mg/l for March, April, May and June, respectively. Although much improved over the Toutle River the "base case" is still marginal for maximum smolt survival in the lower Cowlitz River.

The resuspension of suspended solids by the extensive dredge operations in the lower Cowlitz River have not been included in this analysis, but the operations no doubt cause increases. If the natural suspended sediment concentrations decline substantially due to drought conditions, the effects of continued dredging will become more significant. In addition, the fate of smolts which survive passage to the Columbia River but receive sublethal stresses is unknown. If gill damage occurs during passage the ability to adapt to sea water may be severely limited.

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