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Assessment of Impacts from Water Level Fluctuations on Fish in the Hanford Reach, Columbia River

C. D. Becker
D. H. Fickeisen
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May 1981

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

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ASSESSMENT OF IMPACTS FROM WATER LEVEL FLUCTUATIONS ON FISH IN THE HANFORD REACH, COLUMBIA RIVER

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Pacific Northwest Laboratory
Richland, Washington 99352

SUMMARY

Observations on the effects of water level fluctuations in the Hanford Reach of the Columbia River, Washington, were made in 1976 and 1977. The two years provided contrasting flow regimes: high water and fluctuations of greater magnitude prevailed in 1976; low water and higher temperatures prevailed in 1977. Situations where fish and other aquatic organisms were destroyed by changing water levels were observed and evaluated each year in three study areas: Hanford, F-Area, and White Bluffs sloughs. Losses primarily were due to stranding, entrapment (with or without complete dewatering), and predation. Juvenile fish were more susceptible to entrapment and stranding than were adult fish. Estimates of actual losses were biased and conservative because relatively few fish could be found after each decline of water level and dewatering.

The most valued species of fish affected by water level fluctuations at Hanford were the anadromus fall chinook salmon (*Oncorhynchus tshawytscha*) and the resident smallmouth bass (*Micropterus dolomieui*). Crucial periods for chinook salmon occurred during winter when incubating eggs were in the gravel of the main channel, and before and during seaward migration in the spring when fry were abundant in shoreline zones. The crucial period for smallmouth bass was during spring and early summer when adults were spawning in warmed sloughs and shoreline zones. Chinook salmon and smallmouth bass fry were vulnerable to stranding and entrapment, and smallmouth bass nests were susceptible to exposure and temperature changes resulting from repeated water level fluctuations. Thus, flow manipulation may be crucial to their survival.

The extent to which other species of riverine fish were affected by water level fluctuations depended upon their use of shoreline zones for spawning and rearing young. Few of these relationships are completely known or understood. Most fish fry found stranded or entrapped in 1976 and 1977 consisted of "coarse fish" species, which are abundant and of limited economic value. Loss of young coarse fish from water level fluctuations might not be reflected at the adult

population level. While some invertebrates lost in shoreline zones may be replaced by survivors from deeper water, those removed are no longer available to higher trophic level consumers. The magnitude of fish and invertebrate losses in shoreline zones may be of little importance to overall ecosystem dynamics.

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INTRODUCTION

Many rivers are increasingly regulated for power, irrigation, flood control, and industrial and municipal water supplies. Such regulation changes natural flow regimes. With increased interest in renewable sources of electricity and the use of hydroelectric generation for peaking, acute fluctuations in water level are becoming more severe and more widespread. The situation is exemplified by the Columbia River.

Construction of hydroelectric installations and filling of impoundments in recent decades has transformed the mainstem Columbia River into a series of connected storage reservoirs. The reservoir chain extends from Bonneville Dam near the river's outlet eastward and northward to the Canadian border. Only one area--the Hanford Reach--remains in an unimpounded, free-flowing condition; it extends about 88 km from Richland, Washington, upstream to Priest Rapids Dam (Figure 1).

The Hanford Reach is affected by upstream water storage, hydrogeneration, irrigation, and flood control operations that alter river flows. The Hanford Reach is also subject to flow manipulation at an upriver dam, and its daily flow regimes are highly regulated. Future regulatory control is expected to be as great or greater than at present to maximize use of limited water supplies as societal needs increase.

Water passage through turbines at some hydroelectric dams is managed primarily in response to hourly power demand. Some excess water passes over dam spillways during spring spates, resulting in a normal annual period of high flow. Spring spates, however, are now dampened by upstream storage, and volumes of water stored will become greater in future years as turbines are added and reservoir capacity extended (Parametrics, Chapman and Welsh 1979).

Before extensive impoundment, the Columbia River represented a relatively predictable, stable ecosystem in respect to changing flow. The annual runoff would cause a gradual increase in water level over a period of weeks as the winter snow pack melted in the spring; this was followed by a period of sustained high flow during peak runoff and a gradual return to moderate, sustained

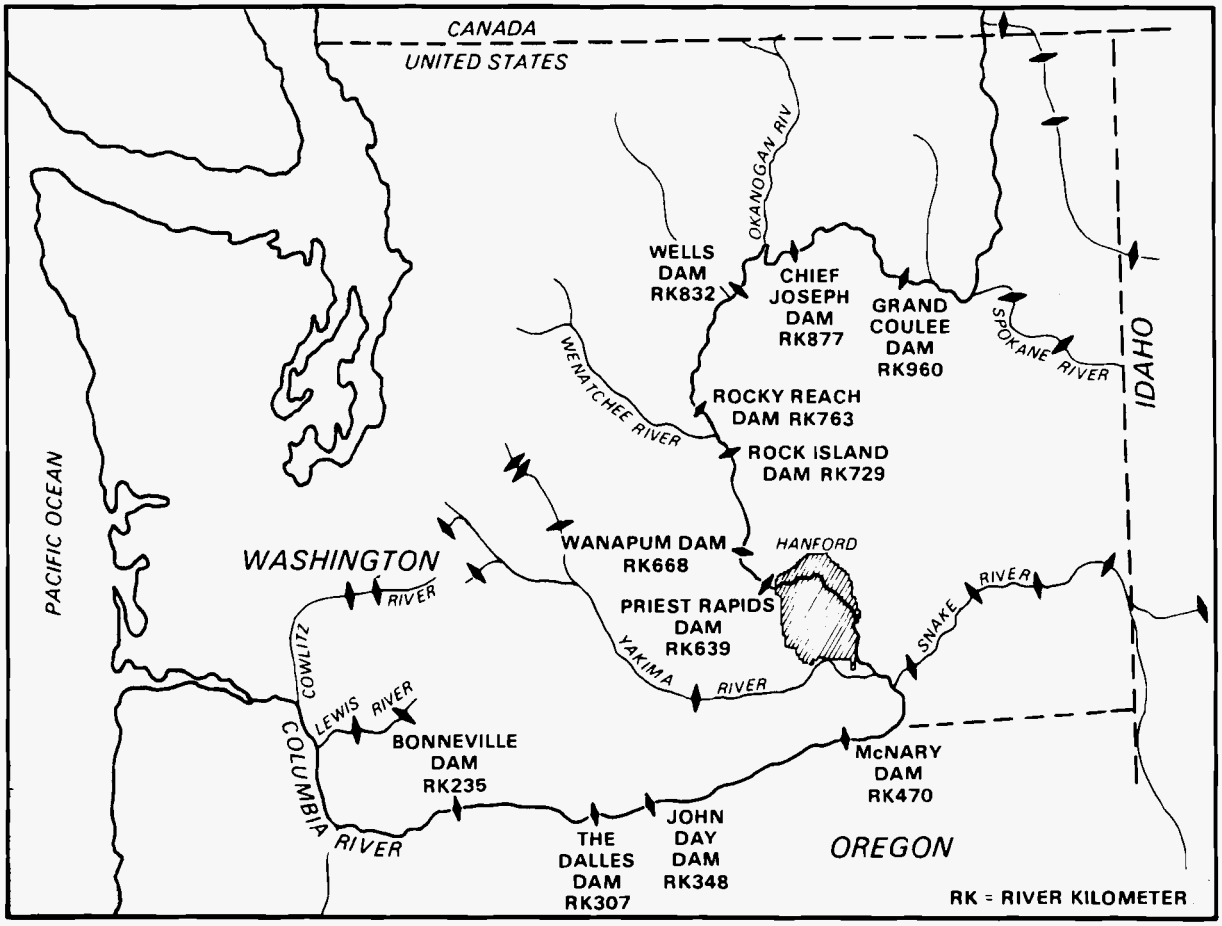


FIGURE 1. The Mainstem Columbia River, Location of Hydroelectric Dams, and Site of the Hanford Reservation Operated by the United States Department of Energy.

flows of summer, fall, and winter. Changes in flow were gradual, with little daily fluctuation in water level. River organisms and riparian plant communities evolved that were adapted to this seasonal change in flow and temperature.

Within the free-flowing Hanford Reach, hydroelectric generation in response to power demand is primarily responsible for rapid changes in water level over a 24-hr period (Figure 2). Such fluctuations may encompass several vertical meters, thereby alternately exposing and inundating large areas of riparian habitat each day. Preliminary observations during the 1970s indicated that aquatic organisms in the Hanford Reach were affected by stranding,

entrapment, and predation as a result of flow manipulation at Priest Rapids Dam. Furthermore, fish were subject to thermal and oxygen stress, and to chronic malnutrition in pools persisting in dewatered areas. These observations occurred during a period when regional power demand approached the limit of existing generating capacity at Columbia River dams. Accordingly, river discharges were being carefully regulated to retain more water in reservoirs when power demand was low and to release more water through turbines when power demand was high.

The observations we now report define several direct impacts on aquatic biota resulting from changes in water level in the Hanford Reach as a result of hydroelectric operation. The observations are more qualitative than quantitative. While the observations reflect impacts on individual organisms or groups of organisms, they do not reflect impacts at the population or ecosystem level. Such effects must be measured quantitatively at considerably higher expenditure of time, manpower, and funds than now available. A complete ecological evaluation must also consider population resiliency and compensation mechanisms inherent in natural populations.

Objectives

The objective of this report is to evaluate how rapid changes in river flow affect aquatic organisms in the Hanford Reach of the Columbia River. Observations are summarized concerning 1) entrapment of fish and invertebrates on April 10 and 11, 1976, a period of minimum low flows; 2) entrapment of fish and invertebrates at White Bluffs, F-Area, and Hanford sloughs during the spring and summers of 1976 and 1977; and 3) movements of tagged smallmouth bass during the summers of 1976 and 1977. Observations and data are interpreted in terms of ecological effects.

Definitions

Dehydration: the disappearance of water from shoreline zones, pools and organisms as a result of dewatering.

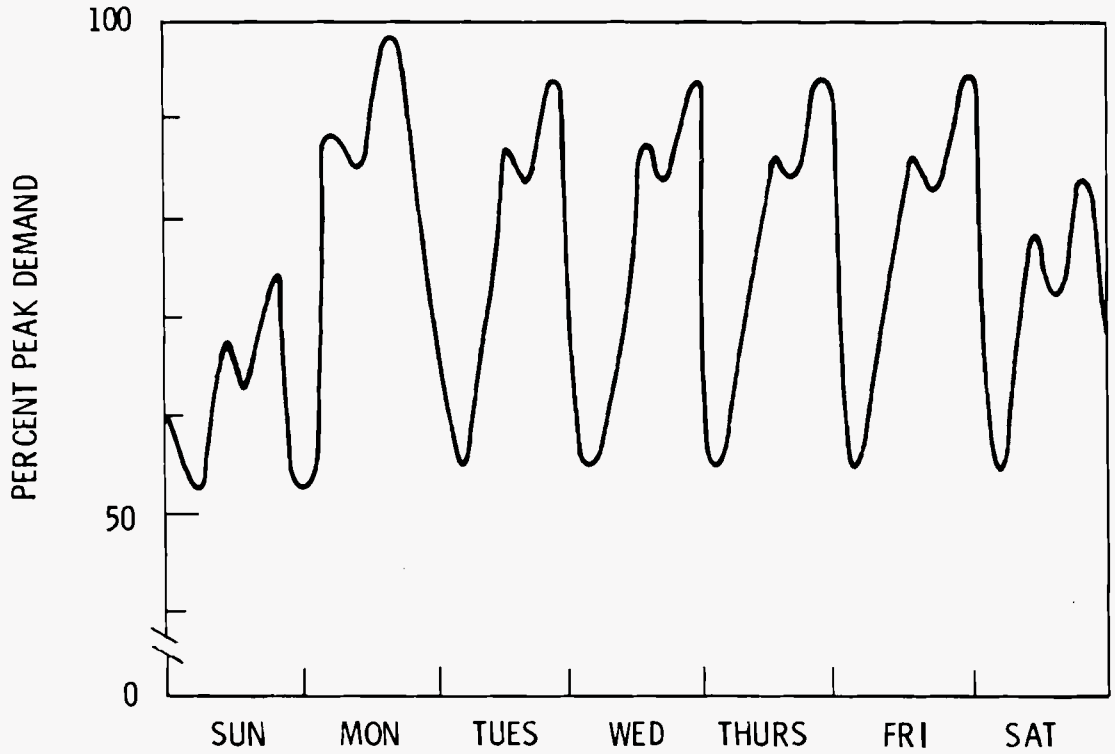


FIGURE 2. Typical Electrical Load Pattern Based on Power Demand During One Winter Week in the Pacific Northwest. (Figure modified from U.S. Army Corps of Engineers 1977.) Note large daily fluctuation during the work week and reduced power demand on weekend.

Dewatering: the disappearance of water from an inundated area, pool, pond, or slough as a result of a declining stream level, surface runoff, subsurface drainage, or other means.

Drawdown: the intentional reduction of water level in a reservoir or stream that exposes shoreline areas or river bottom.

Entrapment: the isolation of fish and other aquatic organisms from the river in shoreline pools or sloughs that may, or may not, eventually dewater.

Predation: the removal of live, entrapped fish and aquatic organisms from pools, ponds and sloughs by terrestrial vertebrate predators.

Scavenging: the removal of stranded fish and aquatic organisms from dewatered areas after their death by terrestrial vertebrate scavengers.

Stranding: the exposure of fish and other aquatic organisms to the atmosphere by the disappearance of water from an inundated area, pool, pond or slough after the river level declines.

Shoreline zone: the river margin between low and high flows that is periodically exposed and flooded by fluctuating water levels.

METHODS

Methods were suitable only for identifying direct impacts and for providing conservative estimates of damage to aquatic organisms. Methods for the Low-Flow Experiment are given by Page (1976).

Walking surveys were initially conducted to identify shoreline areas affected by water level fluctuations on the basis of gradient, conformation, substrate, and presence of potential entrapment areas. Thus, sites were selected to encompass specific terrain features and riparian habitat for impact monitoring. Three sites were selected for study--White Bluffs Slough, F-Area Slough and Hanford Slough (Figure 3). These sites are located on the northeast corner of the U.S. Department of Energy's Hanford Reservation. Human access has been restricted in this area for nearly 40 years. The sites are also recognized spawning sites for smallmouth bass (*Micropterus dolomieui*), a valued resident sport fish. In addition, large numbers of chinook salmon (*Oncorhynchus tshawytscha*) fry and fingerlings temporarily inhabited shoreline zones at the sites annually from mid-March to June after emergence and while migrating seaward.

Mortalities of aquatic organisms were documented photographically. Dewatered areas, entrapment ponds, dehydrated areas, and evidence of predation by birds and mammals were also photographed.

Surveys with electroshockers were conducted to determine the species and number of fish in smaller isolated ponds and pools that later were dewatered by drainage. Organisms in larger entrapment ponds that resisted dewatering were collected by trapnet, beach seine, and crayfish traps. Recently dewatered ponds were examined visually to determine the species and estimate the number of fish lost. Predation was inferred from predator tracks on the margin of isolated pools, and scavenging by tracks in recently dewatered areas.

Movement and behavior of adult smallmouth bass during spring spawning periods were examined by attaching radiotelemetry tags, which were subsequently monitored from a mobile receiving station, and by dart tags. Spawning success, residence time in study areas, entrapment, and escape was recorded in relation to daily, weekly and annual changes in river water level.

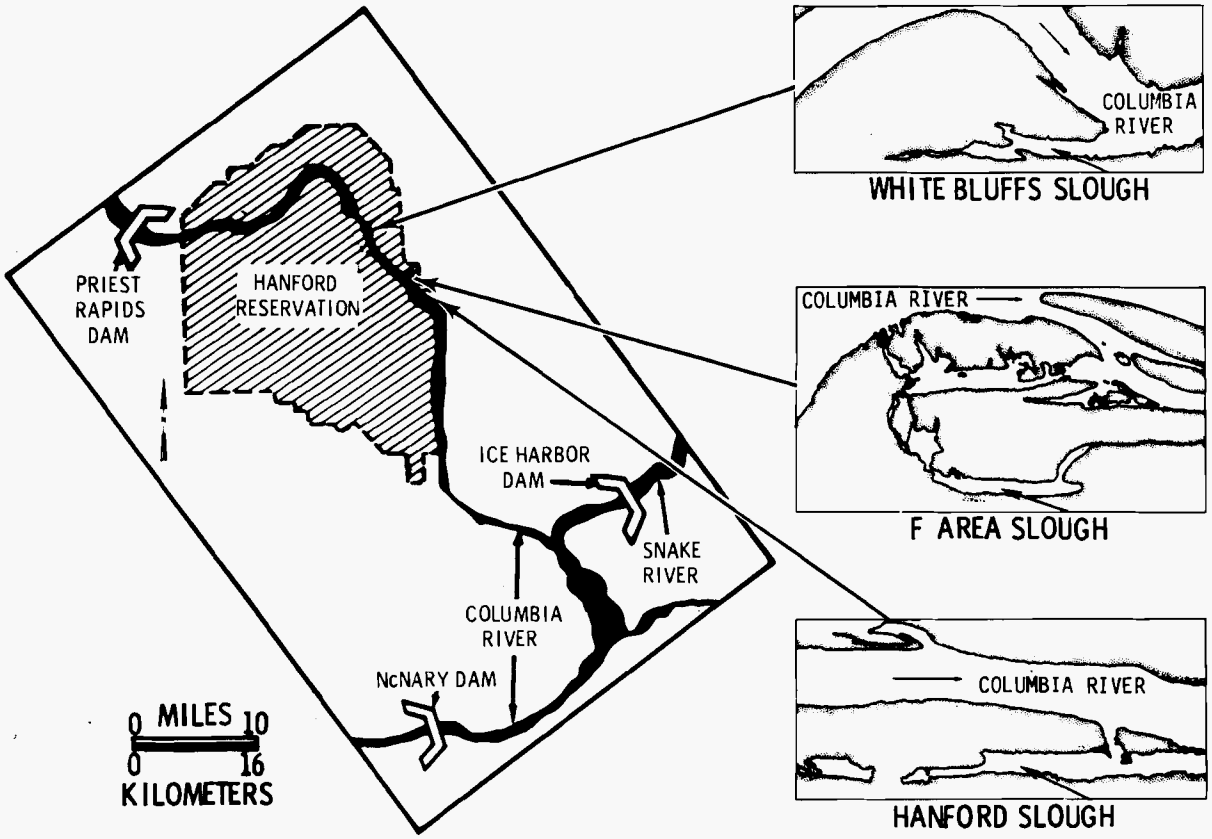


FIGURE 3. Location of Selected Study Areas for Assessment of Impacts from Water Level Fluctuations on The Hanford Reservation, Mid-Columbia River, Washington State.

Radiotelemetry equipment was fabricated by the Bioelectronics Laboratory at the University of Minnesota (Tester and Siniff 1976). The receiver could distinguish among 100 different crystal-tuned radiotags from a frequency of 53.000 to 53.999 MHz. Directional antennas were mounted in the back of a pickup truck and in a boat. Transmitters measured 50.8 mm by 15.0 mm, weighed 19.3 gm when dry, and were encased in epoxy resin with a projecting, 30 mm long teflon-coated antenna. Radiotags were fastened to adult bass by inserting two attachment cables through the dorsal musculature of the fish (Montgomery and Fickeisen 1978; Montgomery, Fickeisen and Becker 1980).

Radiotagged bass were monitored at least twice weekly, and fish location at each "siting" was marked on a map. This allowed calculation of minimum movement between sitings.

Movement of dart-tagged bass was monitored by subsequent recovery of tags from local fishermen. Dart-tagged bass entrapped by falling water levels in ponds were monitored by angling and seining, and released at the capture site.

Common names of aquatic organisms are used in the text; Tables 1 and 2 list the common and scientific names of organisms encountered. Common and scientific names of fish are those recommended by the American Fisheries Society (Robins et al. 1980). Dominant species of phytoplankton, zooplankton, benthic invertebrates, and fish in the Hanford Reach are known and have been characterized in relation to their seasonal abundance (Battelle, Pacific Northwest Laboratories 1976).

TABLE 1. Common and Scientific Names of Fish Entrapped or Stranded in the Hanford Reach by Water Level Fluctuations, 1976 and 1977[a]

Family	Common name	Scientific Name
Salmonidae	coho salmon	Oncorhynchus kisutch (Walbaum)
	chinook salmon	O. tshawytscha (Walbaum)
	**steelhead trout	Salmo gairdneri (Richardson)
	mountain whitefish	Prosopium williamsoni (Girard)
Centrarchidae	*pumpkinseed	Lepomis gibbosus (L.)
	*bluegill	L. macrochirus Raf.
	*smallmouth bass	Micropterus dolomieui L.
	*largemouth bass	M. salmoides (L.)
	*white crappie	Pomoxis annularis Raf.
	black crappie	P. nigromaculatus (Lesueur)
Cyprinidae	chiselmouth	Acrocheilus alutaceus Agassiz and Pickering
	*common carp	Cyprinus carpio L.
	*peamouth	Mylocheilus caurinus (Richardson)
	*northern squawfish	Ptychocheilus oregonensis (Richardson)
	*redside shiner	Richardsonius balteatus (Richardson)
Percidae	yellow perch	Perca flavescens (Mitchill)
	**walleye	Stizostedion vitreum vitreum (Mitchill)
Ictaluridae	*black bullhead	Ictalurus melas (Raf.)
	yellow bullhead	I. natalis (Lesueur)
	brown bullhead	I. nebulosus (Lesueur)
	channel catfish	I. punctatus (Raf.)
Catostomidae	bridgelip sucker	Catostomus columbianus (Eigenmann and Eigenmann)
	*largescale sucker	C. macrocheilus Girard
Cottidae	*prickly sculpin	Cottus asper Richardson
Gasterosteidae	*threespine stickle	Gasterosteus aculeatus L.

[a] Juvenile fish were the primary life stage affected. In some cases, adults were also found entrapped or stranded (*). Two species were found only once (**).

TABLE 2. Aquatic Invertebrate Groups Commonly Entrapped and Dehydrated by Water Level Fluctuations in Shoreline Zones, Hanford Reach, 1976 and 1977[a]

Common Name	Scientific Name or Classification
Crayfish	*Pacifasticus leniusculus*
Freshwater leeches	(Hirudinea)
Freshwater snails	(Gastropoda)
Freshwater clams	(Pelecypoda)
Annelids	(Lumbriculidae)
Mayflies	(Ephemeroptera)
Dragonflies	(Anisoptera)
Damselflies	(Zygoptera)
Water boatmen	(Hemiptera: Corixidae)
Back swimmers	(Hemiptera: Notonectidae)
Giant water bugs	(Hemiptera: Belostomatidae)
Caddisflies	(Trichoptera)
Predaceous water beetles	(Coleoptera: Dytiscidae)
Water scavenge beetles	(Coleoptera: Hydrophilidae)
Midge larvae	(Diptera: Chironomidae)

[a] No detailed survey of stranded invertebrates was made with the aim of producing a complete taxonomic list of organisms. This table lists the general categories of some common macroinvertebrates observed.

LOW-FLOW EXPERIMENT

Effects of a rapid, controlled decline in water level at the three study sites was observed on April 10 and 11, 1976. Washington Public Power Supply System (WPPSS) had arranged for a brief period of the legal minimum flow release from Priest Rapids Dam to examine water levels and current patterns at the intake of a new power plant (WNP-2), then under construction. Observations to detect fish stranding, particularly of juvenile chinook salmon, were made by PNL at other locations in the Hanford Area as water levels declined in a co-operative effort (Page 1976).

Our study on effects of water level fluctuations in the Hanford Reach had entered its initial phase. Observations were made in the three study areas at the time of the low-flow test to identify environmental features associated with an extreme decline in water level. A reduction in flow from about 95,000 to 36,000 cfs (2690 to 1020 m^3/sec) was initiated at Priest Rapids Dam on the midnight of April 9. Falling water levels occurred downstream at the study sites in early morning before daylight on April 10. In an effort to minimize fish stranding and entrapment, the intended drop was not to exceed one vertical foot per hour at Priest Rapids Dam

Results

Hanford Slough

Several shallow ponds appeared at the north end of Hanford Slough (Figure 4) as the water level receded during the morning, April 10. The largest pool (about 1 m deep) continued to drain via a shallow stream during the low-flow period, which indicated bank storage and seepage of water from surrounding areas. Adult fish were trapped in the pool, but the shallow channel prevented escape to the rapidly receding river. Four adult fish (a largemouth bass, a white crappie, a largescale sucker, and a threespine stickleback) attempted to negotiate the channel but stranded and died. Smaller isolated pools contained chinook salmon fry, prickly sculpin and an adult smallmouth bass. The pools drained and decreased in size throughout the day. All fish

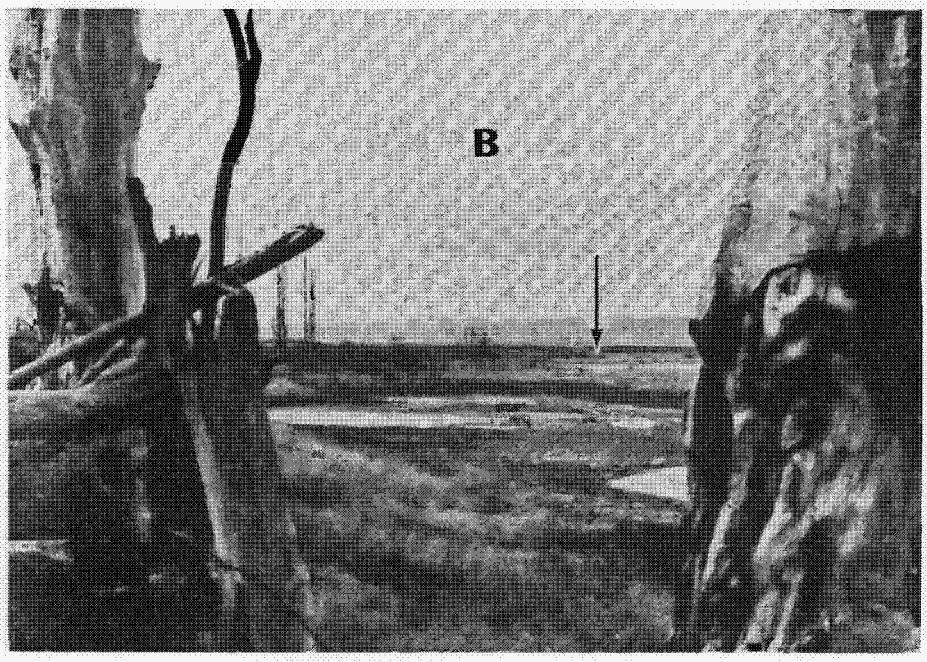


FIGURE 4. North End of Hanford Slough at High Water (A) and Low Water (B) Stages. Note numerous entrapment ponds and puddles. Larger ponds did not completely drain and served as refuges for larger fish. Smaller puddles usually dewatered within 24 hr and trapped fish fry. The large pond (arrow) received river water only during the annual spring spate, but fish were usually entrapped and isolated the rest of the year.

presumably perished either directly from pool dewatering or indirectly from solar warming and predation.

An estimated 1,000 to 2,000 chinook fry were entrapped in several small pools near the upper end of Hanford Slough. All fry presumably perished. The pools completely drained by morning, April 11, but no stranded chinook fry were found. Since animal tracks (coyote, mink, great blue heron, killdeer, and sandpiper) covered the dewatered area, missing fry were presumably either scavenged or hidden in mud and gravel interstices.

Death from thermal and oxygen stress probably occurred for many small fish prior to complete dewatering of pools. Temperatures in shallow ponds increased from the ambient river level of 6°C to 20°-25°C by mid-afternoon, approaching or exceeding the 21.5°C upper thermal tolerance limit of juvenile chinook acclimated at 6°C (Brett 1952). Since ambient air temperatures were relatively cool and skies were partially cloudy, the temperature rise in isolated pools was probably less than would occur on a warm and sunny day.

Crayfish were present in several pools, and some were stranded as water levels dropped. Fate of these organisms is unknown, although predation probably took its toll. Survival of some crayfish may be prolonged by moist conditions beneath rocks and in mud. The crayfish is more resistant to warm water temperatures than are juvenile salmonids, but less resistant than either largemouth bass or brown bullhead (Becker, Genoway and Merrill 1975).

F-Area Slough (North End)

A land bridge connecting the shore to a large island was formed at the upper end of the F-area slough by the afternoon of April 10. The channel became an isolated water body by mid-morning. At normal river flows, the upper and of the channel contains many coves and large ponds with mud and cobblestone substrates. Since the area was rapidly exposed due to the relatively gradual shoreline slope, numerous small puddles resulted that measured about 1 m^2.

Numerous chinook salmon fry, cyprinid fry, crayfish and aquatic insect larvae, and some largemouth bass fry and threespine stickleback, were trapped in the small puddles. By the morning of April 11, most of the ponds had dewatered, and an estimated 90% to 95% of the organisms died. However, only a

few dead organisms were subsequently found. Apparently, many small fish entered moist mud in rock interstices as the water level dropped. Also, tracks indicated that terrestrial scavengers (coyotes, birds, racoons) were active and probably removed many fish.

We estimate that several thousand salmon and cyprinid fry and several hundred crayfish perished in the area adjacent to the slough during the low-flow test. In support of this estimate, 14 salmonid fry, 9 cyprinid fry, and 2 crayfish were later found beneath the edges of one rock measuring about 28 by 30 cm.

An estimated 10,000 fry were observed trapped in two larger ponds, each about 50 m^2. The fish were too small and numerous for complete positive field identification, but most were probably mountain whitefish. The ponds were dewatered on the morning of April 11, and no fry were found. This was probably due to bird predation (abundant tracks) and mixing of fish with mud as the last water drained.

One large pond, a backwater area of the main river ($\approx$ 500 m^2 and 1 to 2 m deep), was isolated as water receded. Several adult smallmouth bass were trapped. All fish apparently survived because the pond retained water until flows were increased on the afternoon of April 11. Salmonid, cyprinid, and whitefish fry were seen along the pond's margin, but no estimate of their number was made. Some adult bass probably preyed on the fry.

F-Area Slough (South End)

A large pond in the south end of F-Area Slough was also isolated from the river. It drained slowly via a small stream, but the water level dropped only a few centimeters. Tumbleweeds blown into the pond provided cover for salmonid fry and other small fish. The period of minimal river flow probably had little effect on organisms temporarily retained in the pond.

The drainage channel eventually separated into two branches. One branch dried, isolating several puddles that averaged less than 1 m^2 in area. All were dry by the morning of April 11. Several crayfish, aquatic insects, and ten salmon fry were found dead. Tracks indicated heavy scavenging by mammals and birds. Some small fish were found hidden under rocks.

White Bluffs Slough

Three types of pond entrapment occurred in White Bluffs Slough, depending upon whether the ponds were located at the the north end, the south end, or at the southeast shoreline.

The north end contained a series of ponds measuring 5 to 20 m wide and 30 to 40 cm deep. The ponds were connected by shallow channels about 1 m wide and 20 cm deep. Pond features ranged from mud bottom with steep, grassy edges to river cobble bottom and gently sloping edges. Parts of the ponds and channels were choked with tumbleweeds. Salmonid fry, cyprinid fry, and caddisfly larvae were present. The ponds did not dehydrate on April 10 or 11, and temperatures remained below lethal limits until water levels increased. Consequently, little mortality was observed.

The south end contained a pair of larger, deeper ponds connected by a channel 40 to 50 cm deep and fed by intragravel seepage or springs. These drained via a shallow channel leading to the main slough. Adult carp, smallmouth bass, largemouth bass, largescale and bridgelip suckers, and chinook salmon fry were present. No mortality of adult fish occurred because ample water depth and favorable temperature were maintained. Adult smallmouth bass were observed feeding on salmon fry. Although the drainage channel was too shallow for adult fish to pass, several thousand salmon fry were swimming in or near the channel.

Numerous ponds on the southeast shoreline zone were shallow, had mud and cobble bottoms, and ranged from about one to several m^2 in area. Many ponds contained chinook salmon fry, cyprinid fry, redside shiner and chironomid (midge fly) larvae. By the afternoon of April 10, pond temperatures reached 20°C, approaching the lethal limit for juvenile salmonids.

One pond (15 by 6 m diameter) contained an estimated 1,000 to 2,000 chinook salmon fry. By the morning of April 11, most ponds were dewatered and tracks of mammal and bird predators were abundant. Examination of bottom mud revealed no dead fish, but one dead crayfish was found near an exposed cobblestone (Figure 5).

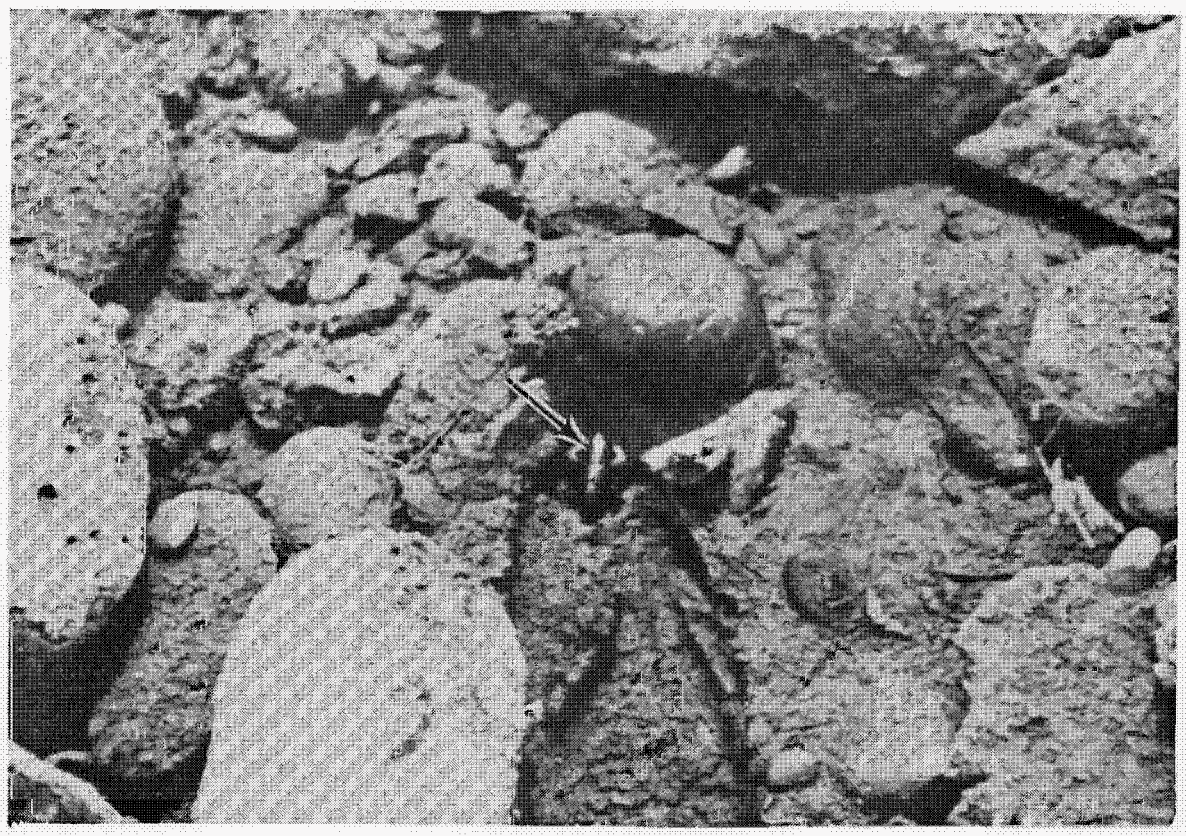


FIGURE 5. A Dead Crayfish Found Under Cobblestone During Pond Dewatering, Low-Flow Experiment, April 10-11, 1976.

Remarks

Shoreline zones in the Hanford Reach are productive ecological areas. They are inhabited during spring by fry of many fish species, including smallmouth bass, largemouth bass, chinook salmon, and numerous species of aquatic invertebrates. The low-flow experiment arranged by WPPSS in April, 1976, caused Columbia River water levels to drop rapidly over a 4-hr period from about 95,000 cfs (2690 m^3/sec) to minimum legal levels of 36,000 cfs (1020 m^3/sec). The water stayed at that stage for about 36 hr, and then increased to near the former flow level. Test conditions were unique. An abrupt decline in water level to minimum levels within a short period of time would occur rarely under normal hydroelectric generating conditions.

Our observations in three selected on-site areas led to the following conclusions:

1) Losses of mobile, aquatic organisms such as fish are related largely to the number, size, substrates, and drainage features of entrapment ponds left by the receding water (i.e., the shoreline zone topography).
2) Adult fish may escape by either following the receding water of the main river channel outward, or by choosing deeper pools that do not drain completely.
3) Juvenile fish are more susceptible to entrapment than are adult fish. Juveniles linger in shallow water areas that first become isolated and then warmed and dewatered.
4) Observations after dewatering do not portray the extent of fish loss because dead individuals cannot be accurately enumerated. They enter mud and penetrate beneath cobblestones as the water recedes, or are taken by predators or scavengers. Since only a few fish are found by observers, estimates of losses are strongly biased and highly conservative.
5) Small, shallow ponds in the Hanford area may drain rapidly because the underlying substrate consists largely of permeable river gravel. Drainage is rapid if the bottom is above the surface of the nearby river.
6) Large, deep ponds usually drain slowly or incompletely because they are supplied by drainage water from bank storage or from springs, their bottom may extend below the surface of the nearby river, and/or the underlying substrate is less permeable.
7) Entrapped fish may be exposed to low oxygen and high temperature stress before complete dewatering of smaller ponds takes place. The fish are also subject to predation or scavenging.
8) Since fry are more susceptible to stranding than are adult fish, the greatest impact from a major decline in river flow would occur when young fish are at peak abundance, usually the spring and summer.

RIVER LEVEL FLUCTUATIONS

High flows characterized the Columbia River during the spring and summer of 1976. Flows did not decline to usual summer levels until late September. In contrast, the Pacific Northwest experienced a drought in 1977, and water entering Columbia River tributaries upstream from Hanford was reduced below typical summer levels. The contrasting flow regimes past Priest Rapids Dam are shown in Figure 6. Low-flow years are accompanied by significant warming of Columbia River water compared to high-flow years (Figure 7).

1976 Results

Planning was the major effort in the initial year. However, ten walking surveys to define impacts from water level fluctuations were conducted between April and October 5 at Hanford, F-Area, and White Bluffs sloughs. Water level fluctuations were well defined despite the relatively high discharges and spills at Priest Rapids Dam. In fact, water level fluctuations proved to be more abrupt and of greater magnitude in 1976, as in 1977, a low-flow year. (Figure 8). A number of impacts on aquatic organisms in shoreline areas were identified in association with fluctuating changes in river flow.

Since the three study sites were known spawning areas for smallmouth bass, we hypothesized that spawning and incubation of smallmouth bass eggs would be affected by fluctuating water levels. Seven adult smallmouth bass were radio-tagged at White Bluffs Slough by late June. Subsequent monitoring showed that the use of radiotags to locate spawning smallmouth bass was feasible. Monitoring also provided information on bass entrapment in large ponds, bass nesting sites, and smallmouth bass residence-time in ponds and sloughs.

Hanford Slough

Water levels fell in August 1976 after the peak summer flows. A large pond was disconnected at the northern end of the main slough on September 15. Yearling largemouth bass, bluegill, threespine stickleback, black crappie, yellow bullhead and carp were trapped in a 30 by 0.5 m-area connecting the slough and pond. The area completely dried by October 5.

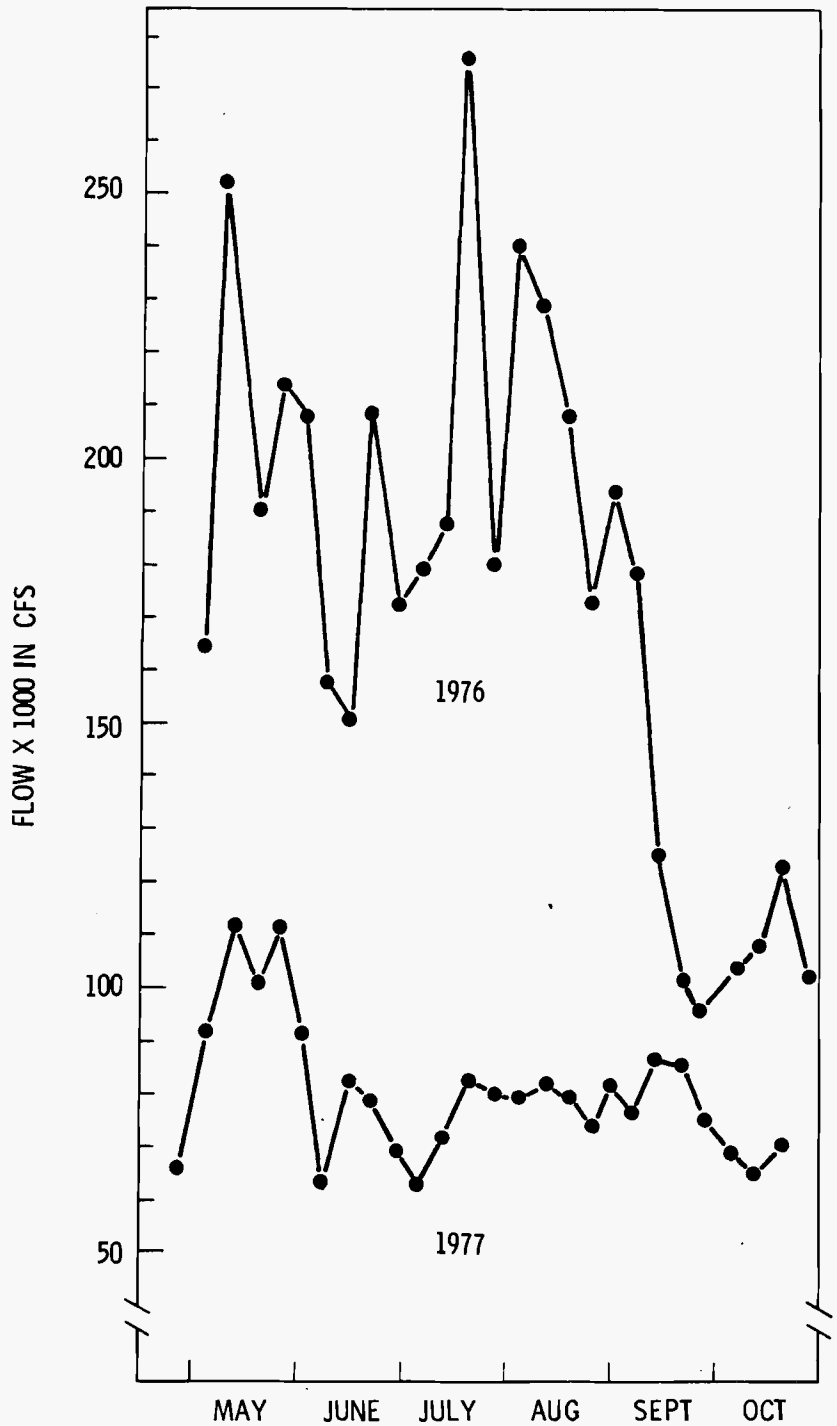


FIGURE 6. Average Weekly Columbia River Flows (Spill Plus Discharge) at Priest Rapids Dam from May Through October, 1976 and 1977. (Compiled from unpublished data of the U.S. Army Corps of Engineers). See Figure 8 for interweekly flow variations. To convert cfs to m^3/sec, multiply by 0.0283.

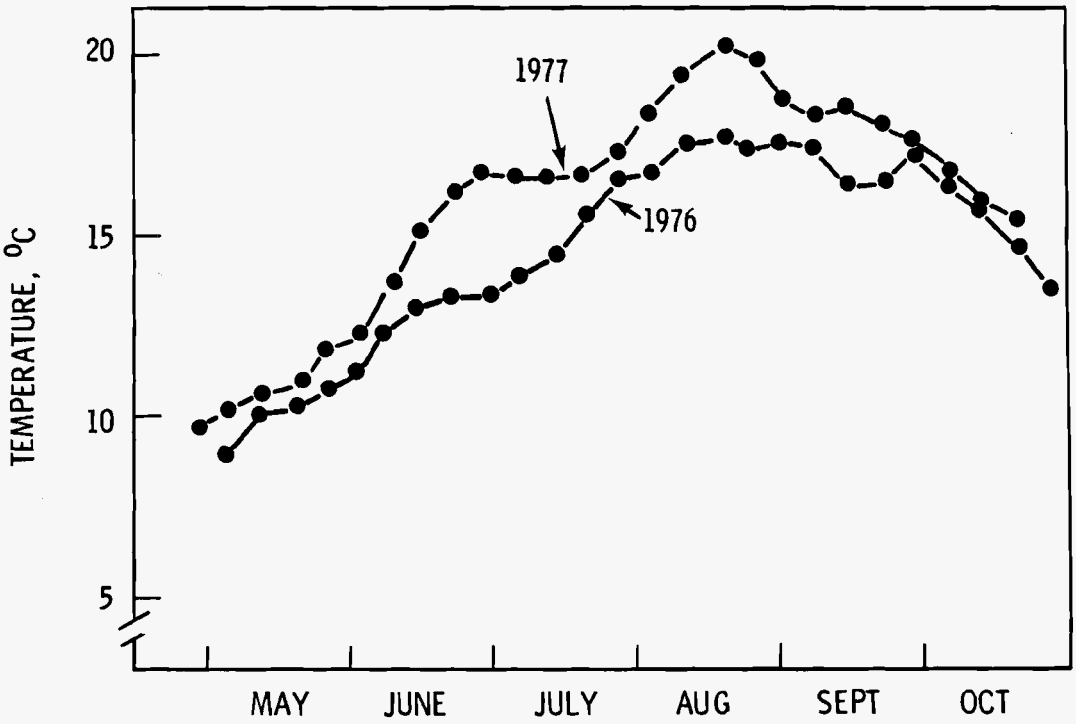


FIGURE 7. Average Weekly Columbia River Temperatures at Priest Rapids Dam from May Through October, 1976 and 1977. (Compiled from unpublished data of the U.S. Army Corps of Engineers). Water temperatures are warmer during summer in low-flow years in the Hanford Reach because solar radiation is more effective.

An entrapment area also occurred on the west side of Hanford Slough that was connected by a series of channels at high water stages. This area contained about 45 pools and 300 puddles with various types of substrates (Figure 9). Those with permeable mud or sand substrate drained in 0.5 to 48 hr by subsurface drainage. Larger pools with less permeable cobble and mud substrate required at least three weeks to dewater from slow drainage and evaporation. On September 15, 400 to 600 northern squawfish fry, 5 yearling black crappie, and 14 adult carp were observed isolated from the main slough in the area. Dewatering was complete by October 15.

Smaller pools commonly contain quantities of aquatic insects. Damselfly and dragonfly nymphs (Odonata) and water beetles (Coloptera, Dytiscidae) were large forms easily seen under dewatering conditions (e.g. mud or cobblestone substrate and warm temperatures) in field situations.

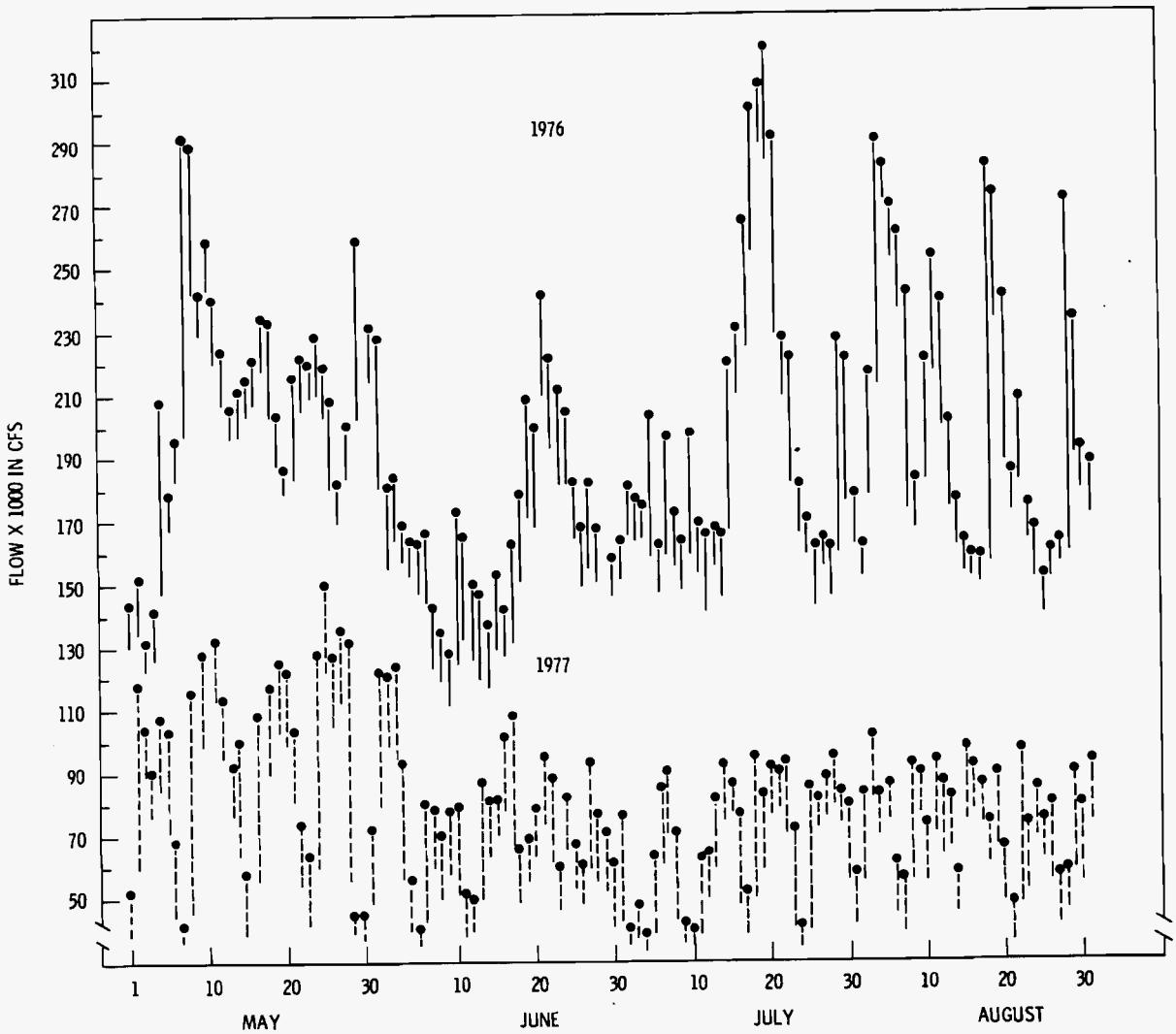


FIGURE 8. Daily Columbia River Flow Patterns (Spill Plus Turbine Discharge) at Priest Rapids Dam from May Through August 1976 and 1977. (Compiled from unpublished data of the U.S. Army Corps of Engineers). Daily and weekly flow variations result from power peaking in response to consumer demand. To convert cfs to m^3/sec, multiply by 0.0283.

F-Area Slough (North End)

Six surveys were made in F-Area Slough between July 12 and August 5. Each survey concentrated on one section of the slough, either the north or south end, to provide adequate observation of dewatered areas.

High water flooded the peninsula at the upper end of F-Area Slough (Figure 10) in mid-summer 1976, forming a channel about 2.6 km long connecting the river and slough. Ponds formed and drained in the channel periodically as water levels fluctuated in July and August. The ponds would receive an influx of freshwater every 3 or 4 days. As river flows declined in mid-August, passage of water through the channel ceased and seven larger ponds remained. These ponds warmed and drained completely by September 16.

The north end of the slough contained many small pools and large ponds as the water receded in August 1976,. These ponds ranged from less than 1 m^2 (2 cm deep) to 30 m^2 (1 to 2 m deep). Dewatering time varied with the amount of groundwater and type of substrate. Small pools with sandy substrate dewatered within 1 hr, whereas others took several months to dry.

One pool left by receding water was about 5 cm deep and contained about 150 largescale sucker, carp, redside shiner and peamouth fry. The fish apparently died from thermal and oxygen stress as the shallow water was heated by exposure to the sun. Another pool measuring 0.5 by 0.3 m contained 100 dead redside shiner fry. Two larger ponds contained about 800 fish including 150 largemouth bass, 175 smallmouth bass, 175 carp, 130 pumpkinseed, 125 bluegill, 36 black bullhead, and four prickly sculpin. This pond did not dry completely until 1977 (see 1977 results).

Another pond about 100 by 800 m and 2 m deep contained about 35 adult, 75 yearling, and 3 fry smallmouth bass. In addition, it contained adult and juvenile squawfish, carp, peamouth, redside shiner, and largescale sucker. Only two puddles remained on September 15; they contained about 2,500 dead and dying 0-age fry (a mix of the above species). The puddles dried the next day. Seagulls, starlings and blackbirds scavenged the area. Since no adult fish were found, they were presumably removed earlier by scavengers such as coyotes (Springer 1977). A conservative estimate of loss in this pond was 10,000 adult and juvenile fish.

Several thousand small fish representing the above species and three yearling largemouth bass were found when six other ponds in the vicinity dried earlier. Nymphs and larvae of aquatic insects, primarily dragonflies, damselflies, mayflies, caddisflies, water boatmen, and nonbiting midge larvae, were commonly found desiccated in various pond basins.

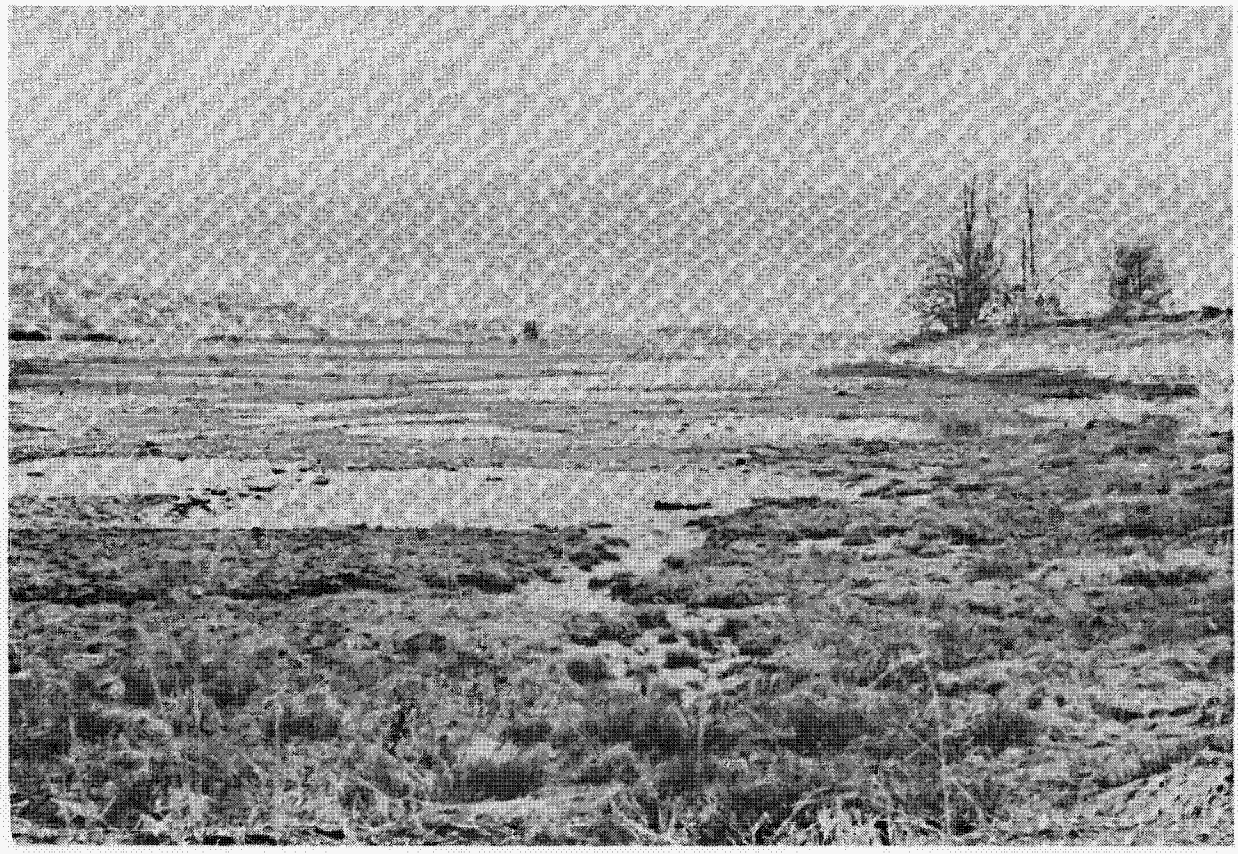


FIGURE 9. The North End of Hanford Slough Facing South During A Low Water Stage. High water inundated the area 24 hr previously. Each pond and puddle represents an effective entrapment area for fish. Repeated flooding and dewatering multiplies entrapment impact.

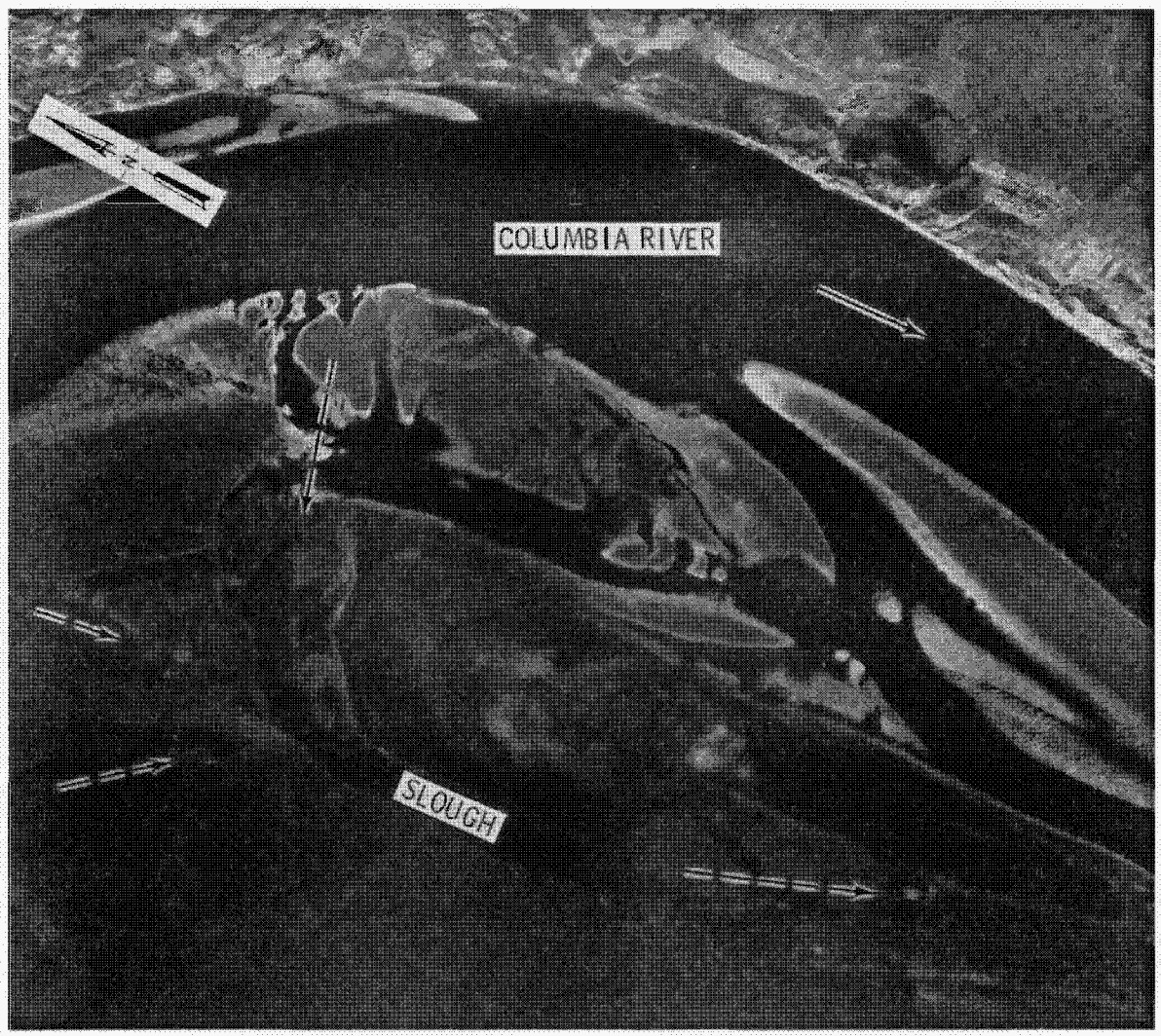


FIGURE 10. F-Area Slough and Environs During a Summer Period of Low Flow. Columbia River Water enters the north end of the slough during high stages (dashed arrows), usually the annual spring spate, and leaves by the south end. The main slough is enclosed during low water stages. Terrain features at the north and northeast ends create numerous areas that entrap fish as high water levels drop.

F-Area Slough (South End)

The south end of F-Area Slough was bisected by a bank that retained water in the main slough. The bank extended into a large, shallow area covering about 400 by 200 m. Largescale sucker and squawfish fry, and 0-age smallmouth bass utilized shoreline cover in this area when it flooded in late August 1976. During intermittent high flows, water entered through two lower portions of the bank and created 125 to 150 pools of various size. Fry entered and dispersed in flooded, grassy areas behind the bank. Receding water then isolated the pools, which usually dried in 24 hr. An estimated 200 smallmouth bass, 800 northern squawfish and 1,000 largescale sucker fry were lost in one such occurrence.

White Bluffs Slough

Chinook salmon fry commence seaward migration during April and May, and were present during most of the summer high-flow period. Corresponding with the migration, temporary pools that formed at the head of White Bluffs Slough contained juvenile salmonids. In one area, nine ponds contained 50 to 100 chinook fry each. Although all ponds eventually dewatered, some fish may have escaped because the ponds periodically filled and drained as water levels changed. Scrutiny of incompletely dried pools on later dates revealed some dead salmon fry, which apparently succumbed to high thermal and low dissolved oxygen stress. No dead salmon fry were found in completely dewatered pools, but signs of terrestrial predators and scavengers were abundant. Coyotes were seen preying on entrapped adult carp, and tracks indicated similar predation on at least three carp and four largescale sucker carcasses.

Because temperatures in the various Hanford sloughs are often warmer than the river, they are selected by smallmouth bass for spawning, primarily when temperatures in early spring reach 12.8° to 15.6°C (Henderson and Foster 1956). Data from other areas indicate that smallmouth bass generally move to spawning areas at rising temperatures extending from 4.4°to 15.6°C; while spawning begins at 14.4° to 21.1°C, a drop to lower temperatures will cause spawning to cease (Emig 1966).

Five nests constructed by smallmouth bass were located at White Bluffs Slough and observed through egg incubation until the fry dispersed. Eggs hatched in only two of the five nests, each of which produced less than 50 fry. A smallmouth bass nest normally produces about 2,000 fry (Scott and Crossman 1973), but egg deposition may reach 8 to 9 thousand (Carlander 1977), depending on geographical region and type of habitat. Temperature declines associated with water level fluctuations may impact bass spawning and egg survival.

Male smallmouth bass guarded nests in the slough until mid-July, and gravid females were collected until mid-August. No nesting was detected after the end of July when spawning areas were exposed to high river flows entering the upper end of White Bluffs Slough (Figure 6).

Seven adult bass carrying radiotags remained in the slough until late August, but then returned to the mainstem Columbia River. Departure corresponded with the decline from high to low flow (Figure 6).

1977 Results

Because of limited water supplies in upstream watersheds and storage reservoirs, overall Columbia River flow through the Hanford area was reduced (Figure 6). There was little excess spill at Priest Rapids Dam to dampen flow variations resulting from power generation. Consequently, response to peak power demands resulted in considerable daily and weekly variation in flow regimes (Figure 8). Greatly reduced flows occurred on weekends when industrial electrical consumption was reduced, and vast stretches of shoreline zone were periodically exposed to dehydration.

Hanford Slough

Chinook salmon fry were first detected in Hanford Slough on March 22. Changes in Columbia River water levels from flow regulation intensified toward the end of March as water shortages were predicted for the pending summer. Three stranded salmonid fry were found in one small pond (3 by 2 m) and two were found in another pond (3 by 3 m). Birds were actively foraging in the area. Hence, most dead fish probably were removed before survey.

The large pond at the northern end of Hanford Slough (Figure 4A), which was isolated during falling water levels in mid-September 1976, contained the following surviving fish: adult largemouth and smallmouth bass, crappie, bluegill, pumpkinseed, three species of bullhead, and adult carp. Weight-length condition factors indicated that the adult bass were at normal weights after overwintering (7.5 mo entrapment), but smaller bass (25.6 to 30.7 cm total length) were more robust than the larger ones. Forage species utilized by bass were either large or absent, presumably because feeding bass removed smaller individuals selectively.

Sampling in November 1977 indicated that the abundance of fish in the pond was reduced, and that forage fish suitable for predator fish consumption were absent. Bass condition factors indicated chronic malnutrition. Intensive sampling in February 1978 produced only 11 emaciated carp, which apparently survived because of their ability to utilize algae and substrate detritus as food.

F-Area Slough

High water from the Columbia River flooded F-Area Slough through its northeastern end for 2 to 6 days in early April and permitted fish to enter. The receding water trapped all fish in the slough until early March, 1978. The enclosed water body was sufficiently large and deep that it remained suitable fish habitat through the summer and fall.

Some chinook salmon fry entered F-Area Slough during the high-water period in April. These fish could not complete their spring seaward migration and were exposed to predator fish the rest of the year.

Falling water levels after the April flow eventually isolated several areas that contained fish (Figures 11, 12). Two dead chinook salmon fry were found in a small dehydrated pool (0.5 m^2) situated in a channel between the river and the slough. A pond measuring 7 by 3 meters (0.35 m deep) in another channel contained about 80 yearling smallmouth and largemouth bass, 30 adult bluegill, and 8 adult carp. These fish survived the summer but were lost during winter to terrestrial predators and freezing.

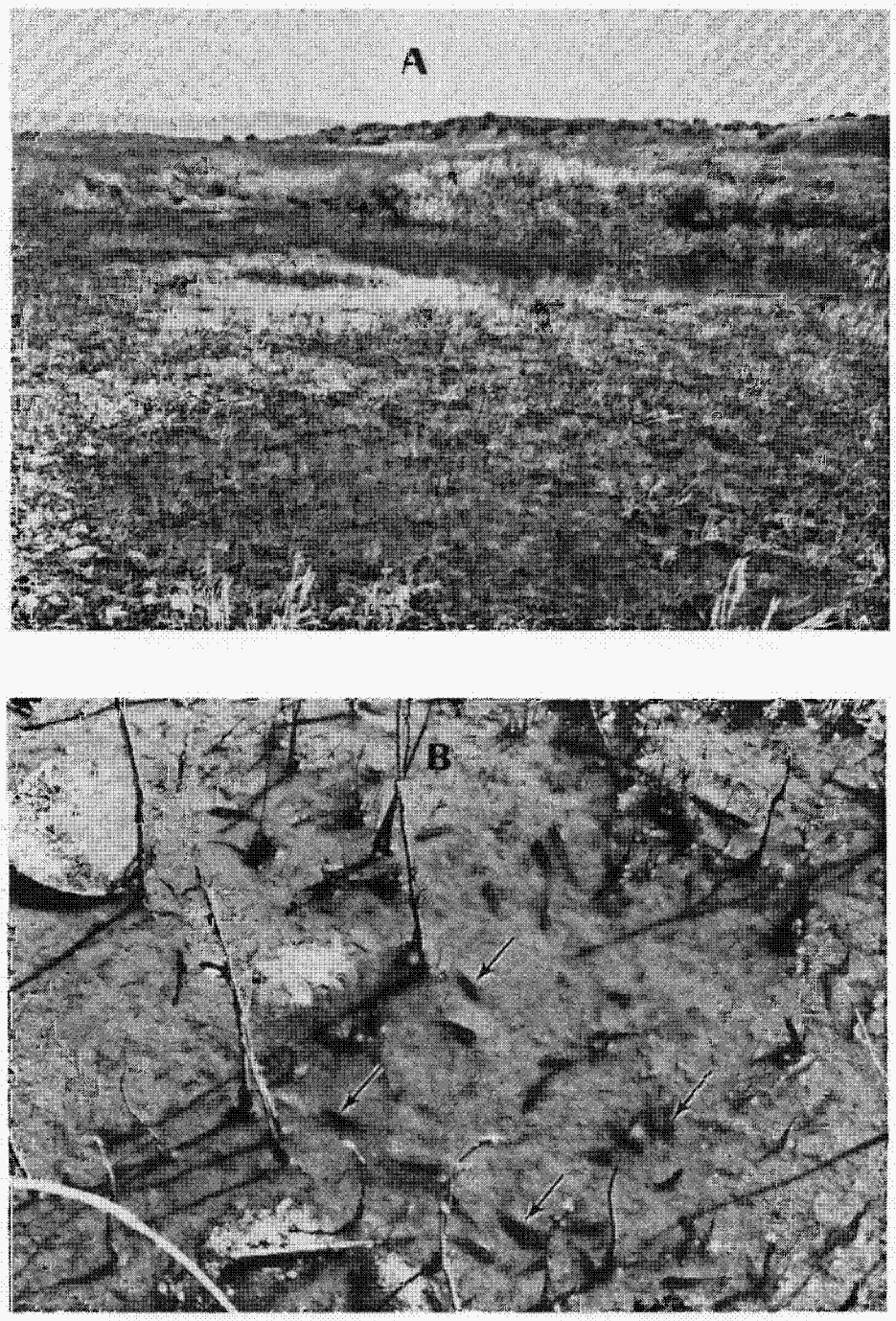
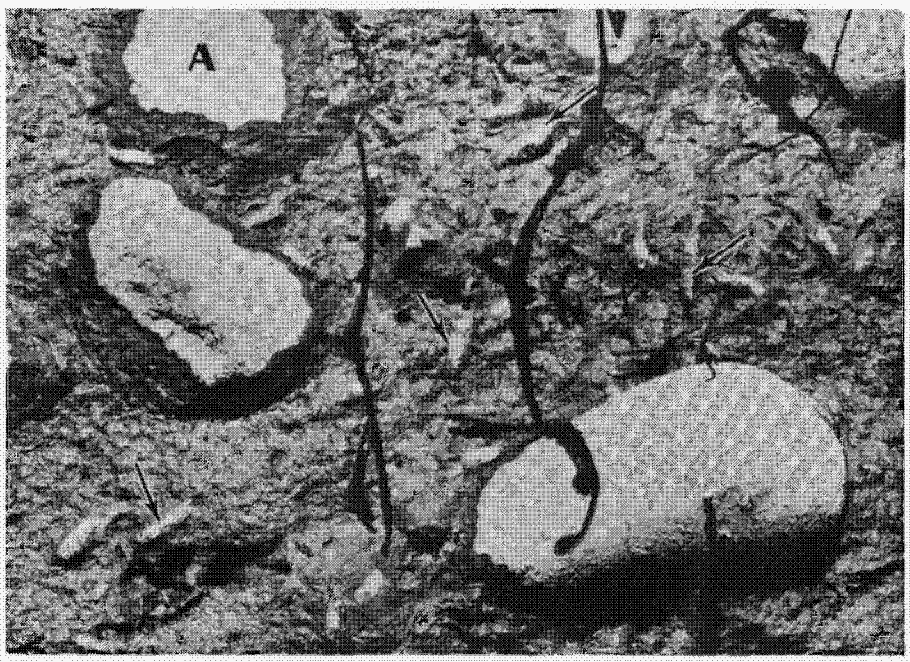


FIGURE 11. A Flooded Grassy Area at the Head of F-Area Slough After the April 1977 Spate (A). Numerous chinook salmon fry were isolated as water levels fell (B) and eventually perished as the area dewatered. Grassy areas were particularly attractive to fish fry because they provided cover as well as food.



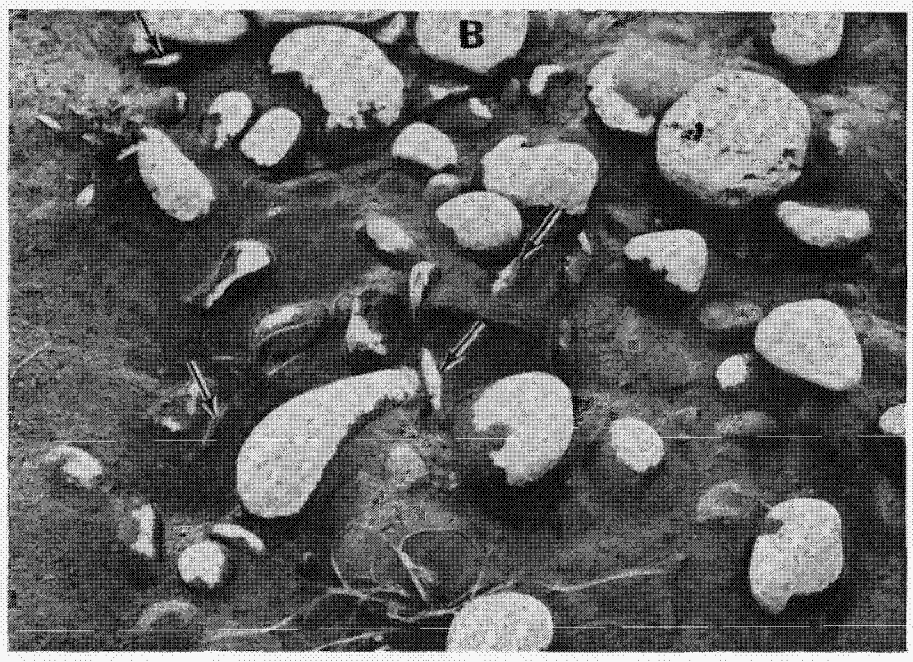


FIGURE 12. Chinook Salmon Fry (arrows) in Mud and Cobblestone Bottom of Dewatered Ponds. Fish were covered with mud in their final struggles (A) or worked their way to gravel interstiches (B), while others were removed by predators or scavengers. Enumeration of stranded fry provides only conservative estimates of actual losses.

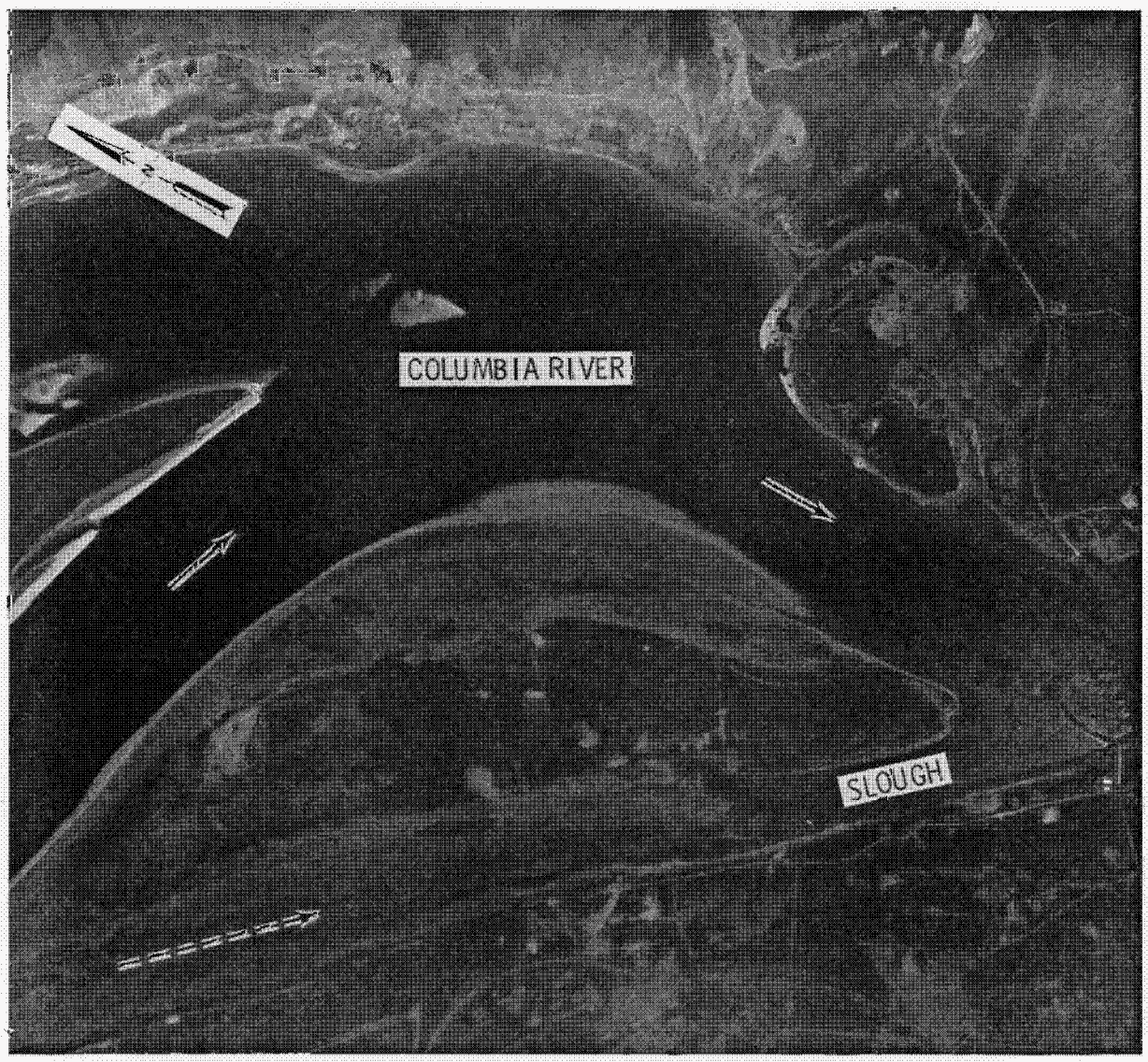


FIGURE 13. White Bluffs Slough and Environs During a Summer Period of Low Flow. The Columbia River enters the northwest end of the slough during high stages (dashed arrow). The main slough is open at the lower end even during low-water stages. Hence, water level rises and falls daily in response to upstream discharges. Ponds form at the head of the slough, and smallmouth bass spawn in the narrow channel.

A small but deep circular pond (3 m diameter, 2 m deep) was isolated west of the main F-Area Slough in September 1976. Sampling at that time indicated that 100 smallmouth and largemouth bass, 100 pumpkinseed, 50 bluegill, 35 black bullhead and several carp were confined in the pond. Sampling in late May, 1977, revealed no bass, bullhead, or carp. The pond had decreased to about one-fourth of its original size with a maximum depth less than 0.5 m. However, the bluegill and pumpkinseed had apparently spawned, increasing their number to about 1,000 small fish. The pond drained completely by late July 1977.

White Bluffs Slough

The slough (Figure 13) remained generally at low water stages throughout the summer due to low Columbia River flows in 1977 (Figure 6). Adult fish were trapped almost daily in the narrow channel leading from the northwestern end as water levels fluctuated in response to daily power demand. However, periodic inundation allowed the adult fish to enter or leave. Adult fish generally inhabit deeper pools, particularly as water levels drop, and avoid shallow areas that drain and dehydrate rapidly.

One isolated pool (3 m diameter and 0.5 m deep) at the north end of White Bluffs Slough was sampled by electroshocker in mid-May. One adult smallmouth bass (gravid female), 130 chinook salmon fry, 5 adult carp, 2 threespine stickleback, 1 redside shiner and 1 squawfish fry were recovered. About 80 to 100 chinook salmon fry escaped capture but were seen. The adult smallmouth was released in the slough and the other fish were returned to the pool, which then dried in 24 hr. Scrutiny the next day revealed only 8 dehydrated chinook salmon fry under cobbles. Tracks indicated scavenging by a coyote, a racoon, seagulls, and blackbirds. Further examination revealed that 2 crayfish, 4 leeches, and about 400 dragonfly nymphs, caddisfly larvae and snails were dead beneath substrate cobbles.

Another pond further north contained an estimated 2,000 chinook salmon fry and 5 adult carp. The fate of these fish was not determined. However, pond temperature was 20.5°C and approaching the 25°C lethal limit (Brett 1952) for juvenile salmon.

Remarks

Observations on the effects of water level fluctuations in the Hanford Reach extend observations made during the Low-Flow Experiment in regard to entrapment of fish. However, the effects noted were more characteristic of present-day flow regulation at Priest Rapids Dam during high-water (1976) and low-water (1977) years. Under present hydroelectric operations, daily water level fluctuations during high-water years may be more extreme than during low-water years (Figure 8).

Priest Rapids Dam was operational, and the first flow records were available, in 1960. Most water during the annual spring spate in 1960 was passed over the dam with little day-to-day fluctuation, and the spate lasted until late July (Figure 14). In 1970, ten years later, a reduction was evident in the annual spate due to filling of upstream reservoirs.

The Columbia River has historically experienced variable high spring flows that subsequently recede to relatively stable flows of late summer and fall. Endemic species of river fish evolved in harmony with this cycle. Juvenile fall chinook salmon, originating from eggs deposited by adults in October and November, move seaward during the annual spate. Largemouth and smallmouth bass, both introduced species, survive in the mid-Columbia River by spawning in warmed inshore areas and sloughs during April, May, and June. Although the spring spate impacts smallmouth bass spawning activity and influences reproductive success each year, populations of adult smallmouth bass remain sufficiently large to support a local sport fishery.

The Columbia River's spring spate is a natural phenomenon, whereas water level changes imposed by power generation are not. Historical water level changes imposed by a spate cover a wide range, upward and downward, over a period of a few months. Water level changes from power generation result in more abrupt and frequent changes, but these are usually of a lesser overall magnitude than occur in an unregulated spate. Man-induced fluctuations from power generation will prevail most of the year as long as water resources in upriver reservoirs are insufficient to meet all competing demands.

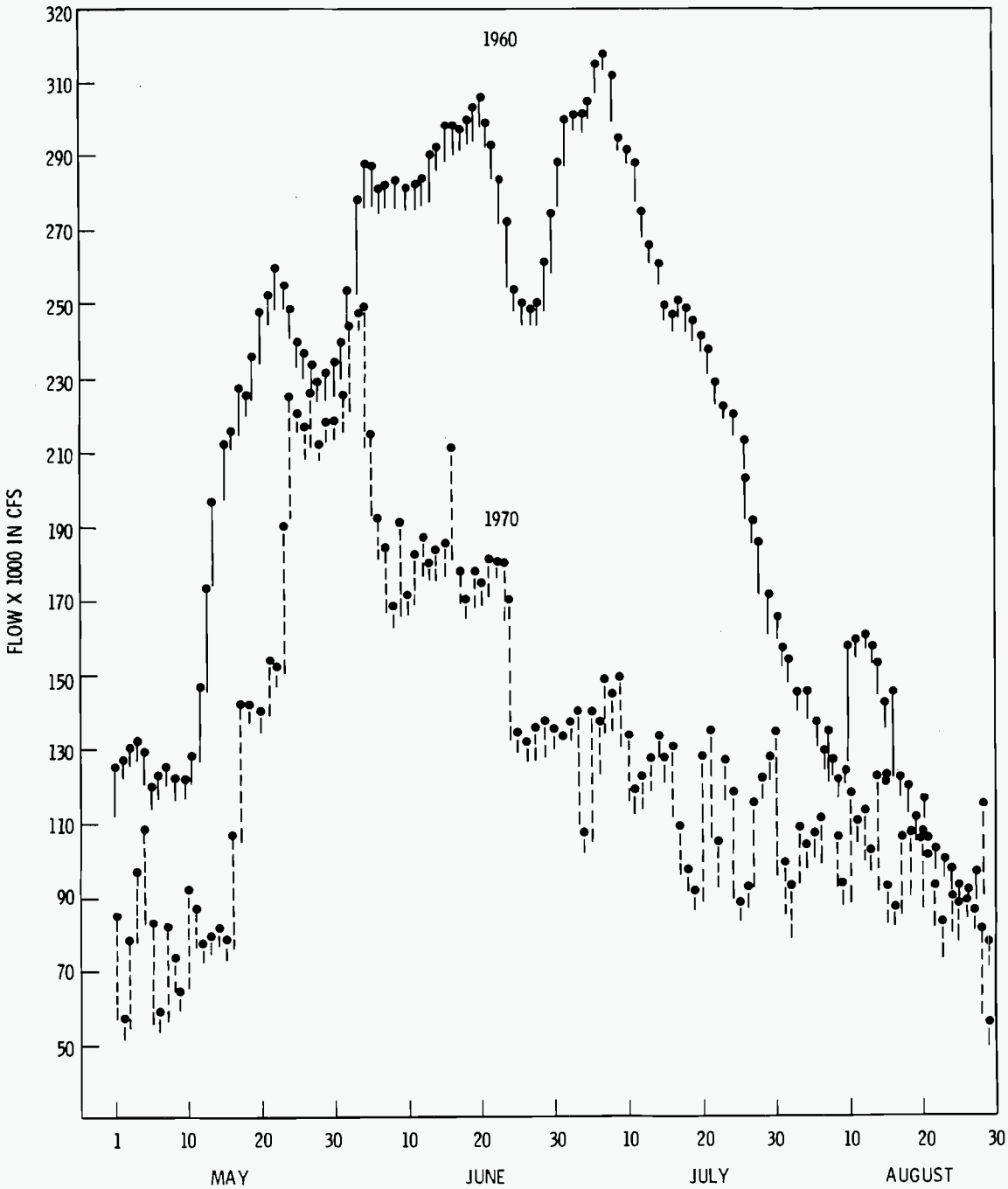


FIGURE 14. Daily Columbia River Flow Patterns at Priest Rapids Dam During the Spring and Summer of 1960 and 1970. Priest Rapids was completed in 1959 and the first flows over the dam occurred in 1960. Compare with Figure 8 for recent flow regimes. To convert cfs to m^3/sec, multiply by 0.0283.

The effects of water level fluctuations in shoreline zones depends not only upon the vertical range of the fluctuation but upon shoreline topography. Generally, the more irregular and gentle the slope and the more depressions it contains, the greater is its potential for entrapment of fish species. Most of the river margin in the Hanford Reach of the Columbia River is limited in vegetation and is composed of gravel and cobblestone with an underlying layer of packed sand or silt. The vegetative zone lies above the water level fluctuations of the main reach most of the year, but may become flooded during periods of maximum runoff (e.g., the spring spate). Pools and sloughs existing in shoreline areas vary in entrapment potential depending upon their size, elevation, depth, substrate, vegetative cover, and other features.

Less area is exposed to water level changes on steep slopes than on gradual slopes (Figure 15A). Thus, a steep shoreline zone has less potential for entrapment of fish. Furthermore, a gradual slope usually contains more shallow depressions that create temporary pools for entrapment of fish fry. Larger depressions in the area covered by fluctuating water levels (fluctuation zone) are periodically filled when water levels rise and become pools as water levels recede. Pools with permeable bottom substrates remaining above the minimum prevailing water level drain relatively rapidly (Pool A, Figure 15B). However, they may not drain completely between each successive withdrawal because of variations in extent and duration of low flows. Pools with impermeable bottom substrates or those reaching below the fluctuation zone (Pool B, Figure 15C) normally remain filled during extended periods of low flows. River water enters during peak flow periods and fish move in and out. Such pools become semi-permanent and may persist for months during extended low-flow periods.

The typical slough is open at one location and river water enters during high-flow periods. Some small, shallow sloughs fill and drain with each rise and fall of the river's water level (Figure 16A). Larger and deeper sloughs retain water and become temporarily isolated pools as water levels recede (Figure 16B). Such isolation may persist for months during extended periods of low flows. River water may enter at the head of a slough during peak flow periods, and a series of connected pools remain that retain water as flows decline (Figure 16C). When river level fluctuations become cyclic on a daily

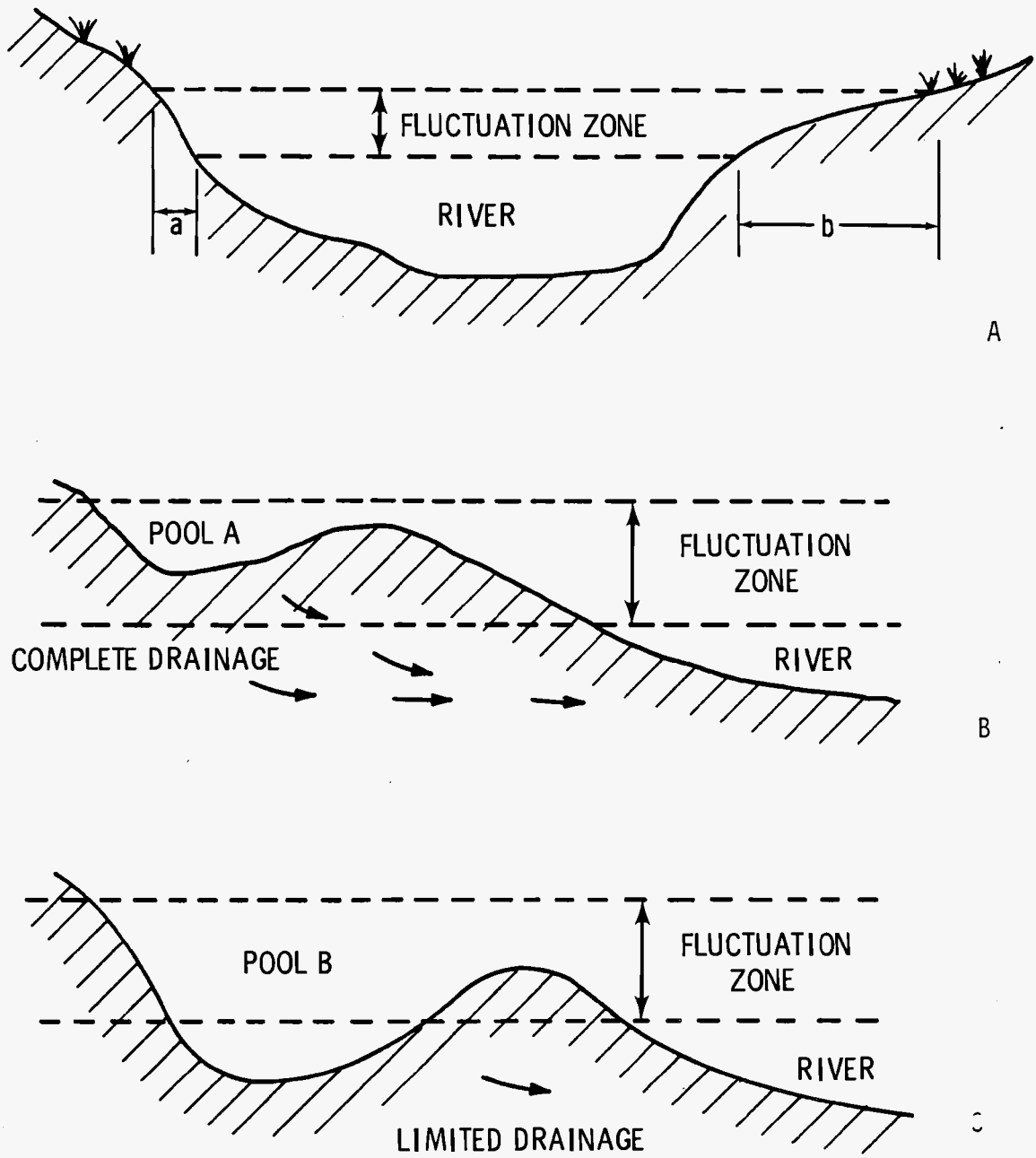


FIGURE 15. Typical Situations Existing in Pools Subject to Filling During River Level Fluctuations in the Hanford Reach

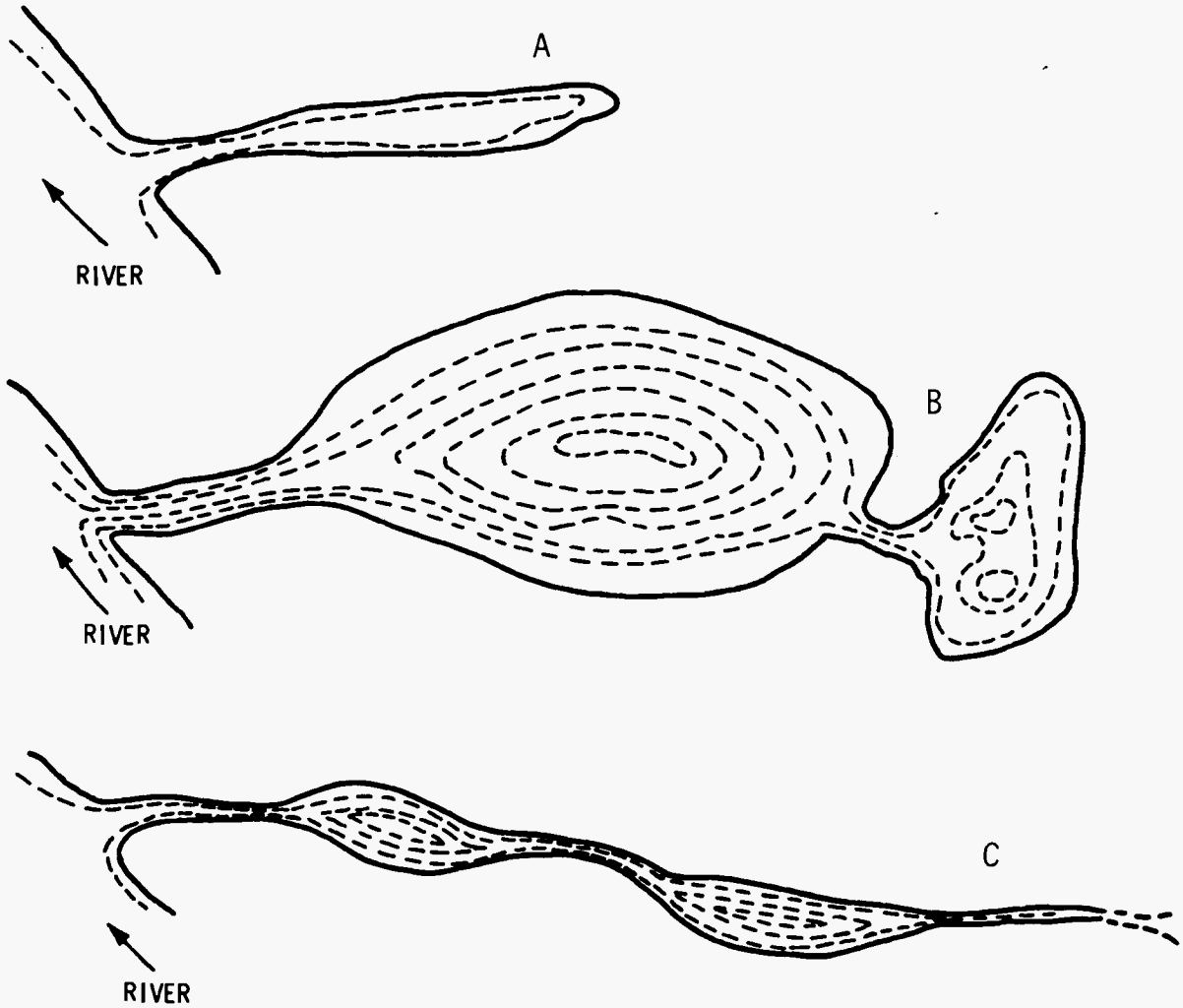


FIGURE 16. Typical Situations Existing in Sloughs Subject to Filling During River Level Fluctuations in the Hanford Reach

and weekly basis, water may enter only at the "outlet" of a slough, extending inward only as far as the rise permits (Figure 16C). Temperatures in pool and slough areas are subject to abrupt changes whenever river water enters.

Conclusions based on 1976 and 1977 field observations are:

1) Water level fluctuations from power generation should be minimized from late March through June, because this period corresponds to: 1) the emergence of juvenile fall chinook salmon that often feed in shoreline zones prior to or during seaward emigration, and 2) the spring spawning period of adult smallmouth and largemouth bass.

2) Many fish larvae affected by receding water are those of the so-called "coarse" species (suckers, sculpins, cyprinids) with limited economic value. These fish exist in abundance, and unoccupied habitats are soon replenished by fish migration (short term) and reproduction (long term).

3) Bird "predation" on stranded fish, in both pools and in completely dewatered areas, often involves scavenging. The Great Blue Heron is, perhaps, the main avian predator. Scavengers include seagulls, redwing blackbirds, species in the "sandpiper" group, killdeers, crows, ravens, starlings, coyotes, and mink.

4) Loss of aquatic invertebrates (aquatic insects, crayfish, oligochaetes, leeches, plankton, copepods) from dewatering of shoreline areas probably effects only a small portion of available populations. Many destroyed organisms are eventually replaced by natural dispersal and reproduction processes from populations existing in deeper water.

5) Invertebrate population densities in shoreline zones periodically exposed and flooded will be lower than those in unaffected areas.

6) Losses of fish from water level fluctuations can be quantified by an extensive monitoring and sampling program. However, such losses may not be reflected at existing adult population levels. Possible exceptions are chinook salmon and smallmouth bass, which are limited in number, seasonally vulnerable to flow changes, and directly harvested (cropped) by man.

BASS TAGGING STUDIES

Radio-Tagged Fish

Radio transmitters were placed on seven adult smallmouth bass at White Bluffs Slough in 1976. Fish residence was monitored from mid-March until late August, the annual spring spawning period. Fish remained in or near the slough and were temporarily trapped several times in deep pools as water levels fluctuated. However, water levels remained relatively high until the spawning period passed (Figure 6). All fish survived and returned to the main Columbia River as water levels declined in late August and September 1976. Spawning success of smallmouth bass in White Bluffs Slough was low (see preceding section).

Forty adult smallmouth bass (37.2 $\pm$ 2.5 cm standard length) were tagged with radio transmitters at White Bluffs (15 fish), F-Area (15) and Hanford (10) sloughs during 1977. An additional 120 adult bass were marked with dart tags at the three sites. Spawing activities of radiotagged bass began in late April, and egg hatch was complete by mid-June.

Smallmouth bass radiotagged at White Bluffs Slough remained in the area until late June, and were periodically isolated in deep pools during that time. However, 13 of the 15 tagged fish returned to the main Columbia River when spawning was complete in 1977. The other two fish were trapped in pools at the northern end of the slough and remained there until tag-battery failure in September 1977. Contrasting high and low flows in 1976 and 1977 (Figure 6) had little apparent affect on the survival of adult smallmouth bass in White Bluff Slough during the spawning period. Even though water levels varied daily, the adult fish avoided entrapment situations that might lead to direct mortality as they attempted to spawn.

Adult smallmouth bass entered F-Area Slough during April 1977 when high flows connected the slough to the Columbia River for a few days. The fish were probably seeking warm-water areas to spawn. Radio-tagged fish were trapped as the river receded to summer low-flow regime. With no new flow influx, slough volume gradually declined throughout the summer. Three large

ponds separated by sand and gravel bars eventually formed. Radio-tagged fish remained trapped in these areas until a spate in March 1978. All movement was confined to the ponds.

Adult smallmouth bass in Hanford Slough area were radio-tagged March 22 1977. Some bass were trapped periodically in the northern end of the slough as river levels fluctuated. However, these fish escaped and returned to the Columbia River in late June. Smallmouth bass avoided entrapment by moving into deeper water of the Columbia River near the open end of the slough when water levels decreased, and returning to the slough when water levels increased.

After leaving spawning areas in White Bluffs and Hanford sloughs, radio-tagged smallmouth bass remained near the slough outlets for 1 to 2 weeks (Montgomery and Fickeisen 1978). Bass at White Bluffs Slough remained in a pool adjacent to the mouth and favored deeper water at depths of 6 to 16.5 m (Figure 17B); during observation, mean distance moved downstream was 1.8 km. Bass at Hanford tended to move further downstream (Figure 17A), but movements were largely random. One bass moved 61 km downstream, but mean distance moved by all bass recovered was 15.1 km (Montgomery, Fickeisen and Becker 1980). Figure 17 shows typical movements of adult smallmouth bass at White Bluffs (tag 250) and Hanford (tag 750) sloughs. Movement within sloughs open to the river is partially due to changing river flows. Fish move to deeper water near the slough outlets as water levels decline and return to shallower water as water levels increase.

Dart-Tagged Fish

Dart-tagged smallmouth bass trapped in F-Area Slough and recaptured during October 1976 and March 1977 had relatively lower condition factors based on fish weight in relation to length. These data were compared with smallmouth bass taken in another area open to the Columbia River 30 m north of the study site. The diminished supply of forage organisms in F-Area Slough apparently restricted bass growth.

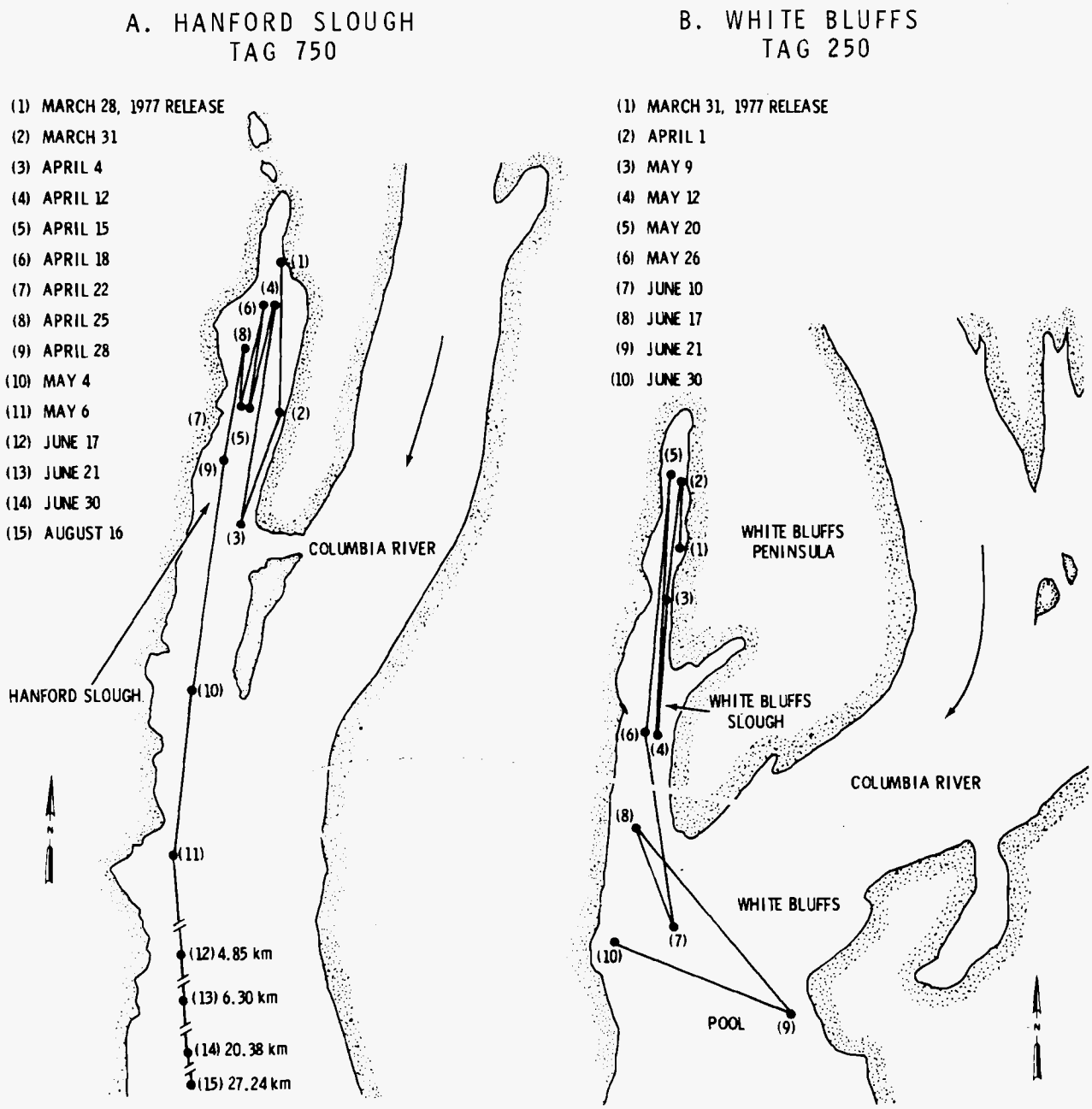


FIGURE 17. Movement of Radio-Tagged Smallmouth Bass at Hanford and White Bluffs Sloughs (from Montgomery and Fickeisen 1978)

Recaptures of dart-tagged bass after the March 1978 spate revealed that some bass stayed in the F-Area Slough even though high water permitted their departure.

Some smallmouth bass with dart tags moved between study sites. One adult male tagged at Hanford Slough on March 22, 1977, was recaptured May 17, 1978, guarding a nest at F-Area Slough. One adult female tagged at White Bluffs Slough May 12, 1977, was recaptured in gravid condition on June 28, 1978, at Hanford Slough.

Based on reports received from sport fisherman, smallmouth bass with dart tags that subsequently were recovered from the main Columbia River also showed a general downstream movement. One bass tagged on April 28, 1978, at White Bluffs Slough moved 62.5 km downstream before recapture about two weeks later. Another bass was recovered 63 km downstream after a longer release period.

Remarks

Radio tags provide daily information on fish movement. Dart tags provide information only when labeled fish are recovered and interim movement is unknown. In either case, movement can be affected initially by stress from capture and tagging, and subsequently by the burden of a tag carried by individual fish. Within these limits, data on movement of tagged smallmouth bass provide a basis for evaluating possible effects from seasonal, weekly, and daily changes in river flows at Hanford. It is not always possible to distinguish between natural seasonal movement and movements influenced by river level fluctuations. But entrapment of tagged bass can be easily determined.

Tagging indicated that adult smallmouth bass were present at the study sites in late March. Many bass returned to the mainstem Columbia River after the spawning period in August 1976 and late June 1977. Early movement to inshore areas such as sloughs may reflect 1) increased fish activity as river temperatures increase in the spring, and 2) early selection by fish of future spawning areas based on slight but measureable warming of water compared to water passing downstream in the main channel. Warming of inshore areas is greatly influenced by mass water movement that, in turn, is influenced by water level fluctuations.

Conclusions resulting from smallmouth bass tagging studies at Hanford are:

1) Adult bass may be entrapped for various times by fluctuating water levels during the spring spawning period. Most adult fish survive by entering deeper pools on the river margin that do not dewater or become excessively warmed.

2) Adult bass trapped in larger, deeper pools can survive for several months or more if the water does not drain. Eventually, however, forage organisms (prey) may be reduced so that bass (predators) suffer from malnutrition and may eventually starve.

3) Water level fluctuations can affect bass reproductive success by flooding nests with cooler water, depositing silt, driving away adult bass guarding nests, exposing bass eggs to desiccation, and stranding the recently emerged fry.

4) Movement of adult bass leaving spawning areas in late summer appears to be primarily downstream. This may be an experimental artifact in relation to dart-tagged fish because sport fishing pressure, and hence recovery, is more intense below the study area than above. Yet radiotelemetry showed a similar trend.

ENVIRONMENTAL IMPLICATIONS

The Columbia River now represents a "regulated stream" (Ward and Stanford 1979) in the sense that man controls flow by an intricate system of dams and diversions. Many reservoirs in major U.S. rivers are operated so that flow downstream becomes more consistent, eliminating large spates or severe droughts. The relatively steady flow in such streams is one factor leading to a relatively stable shoreline zone and increased primary production. Other dams and reservoirs, particularly those used extensively for power production and irrigation, impart relatively immense and rapid changes in flow levels. This adversely impacts both primary production and secondary production of aquatic plants and animals in shoreline zones.

The Columbia River at Hanford experiences rapidly fluctuating water levels. Daily and weekly variations due to power production and flow regulation at an upstream dam are imposed upon seasonal changes from annual runoff patterns, as modified by operation of upstream storage reservoirs.

The faunal region most sensitive to water level fluctuations is the shoreline or eulittoral zone. Benthic fauna with limited mobility can be stranded by receding water and subject to entrapment, desiccation, oxygen and thermal stress, or predation. Changes in water level can also alter the physical nature of the river bottom and result in loss of shoreline macrovegetation (Hunt and Jones 1972). A number of potential environmental impacts from water fluctuations below hydroelectric dams, based largely on a literature survey, have been identified (e.g., Hildebrand 1980). Furthermore, water level changes in the littoral zone can be expected to impact fish populations indirectly (Estes 1972).

The most valued fish species affected by water level fluctuation in the Hanford Reach are fall chinook salmon (a sport, commercial, and Indian subsistent and ceremonial species) and smallmouth bass (a sport species). The chinook salmon is an obligatory riverine form that requires flowing water for existence. The smallmouth bass is not obligatory riverine, but can exist as well in lentic environments such as lakes and ponds. Other species of fish inhabiting the Columbia River (Gray and Dauble 1977) may fit into either

category. Generally, the native fish are riverine while the introduced forms are both riverine and lentic. Their welfare in the free-flowing Hanford Reach is related, in part, to the extent that critical life stages depend on shoreline zones for feeding and protection.

Two critical periods for chinook salmon in the Hanford Reach occur when eggs are intergravel during winter and when fry are emerging during spring. Considerable effort has been made to determine relationships between minimum low flows and salmonid reproduction success (Bauersfield 1978, Stillwell et al. 1977, Witty and Thompson 1974). The drawdown of the Columbia River below Priest Rapids Dam on April 10 and 11, 1976, to 36,000 cfs (1020 m^3/sec) resulted in an estimated kill of 834,000 chinook salmon fry still intergravel in redds (Bauersfeld 1978). River flows below 18,000 cfs (510 m^3/sec) on the Snake River above Lewiston, Idaho, also expose fall chinook salmon redds (Witty and Thompson 1974). In both cases, the losses occurred within legal flow guidelines established by the Federal Power Commission. However, low flows in most rivers supporting anadromous salmon in population in the Pacific Northwest are usually maintained above minimum permissable levels.

Stranding of chinook salmon fry on shores and gravel bars after emergence is not necessarily related to minimum flow levels, but to daily changes of lesser magnitude that often occur at frequent, repetitive intervals. Observations at Hanford confirm that young salmon are susceptible to stranding and related impacts from late March through July when these fish are present in inshore areas. During this period, young salmonids are also susceptible to impingement on intake screens of water diversions (Scriber et al. 1974; Page, Gray and Neitzel 1977; Page, Neitzel and Gray 1978). Impingement is also influenced by intake flow velocities and, hence, by the prevailing Columbia River water level.

The extent of young salmonid stranding may be related to different site features. For example, stranding on the Skagit River in northwestern Washington State is related to species, seasonal availability of fry, tributary inflow, time of day flows are reduced, sequence of peaking flow followed by low flow release, duration of low flow, and topography of the river channel (Thompson 1970; Phinney 1974). Such factors appear to be both

site specific and generic (e.g., related to the Hanford area) as follows: 1) less fish are stranded if rapid decreases in water flow occur in daylight hours (fish escape more readily); 2) a high discharge prior to a reduction in flow increases the potential for fish stranding (by flooding inshore areas that fish enter); 3) a rapid flow reduction after a peak discharge causes the greatest problem (fish have less time to escape); 4) the lower the flow, the greater the stranding problem (more depressions and potholes in the river bottom entrap more fish); and 5) more fish are lost as the low-flow period lengthens (depression and potholes become warmed and drain, and trapped fish are exposed to predation).

It is difficult to quantify the true extent of juvenile fish loss from stranding due to water level fluctuations in the Hanford Reach. One factor is logistical--there are constraints on available funds, time, and manpower. A second factor is the variable rate and frequency of water level changes. Still another factor is rapid disappearance of entrapped fish. Observations demonstrate that only a fraction of the small fish estimated in pools before dewatering can be accounted for one day afterward. Some fish are removed by predators and scavengers. Others work into mud and gravel substrate before they die, or penetrate beneath larger cobblestones where they cannot be detected during walking surveys. Thus, estimates of number of salmonid fry lost during specific dewatering experiments in various northwest streams (Thompson 1970; Page 1976; Witty and Thompson 1974; Stilwell et al. 1977) are probably conservative.

The movement of adult smallmouth bass into our study sites in the spring for spawning, and their dispersion in late summer after spawning, indicates that the Hanford section of the Columbia River is important in sustaining local bass population levels. The full extent of this contribution is unknown. Other sites in the Hanford Reach, as well as locations above and below, may also be used by smallmouth bass for spawning. However, the Hanford Sloughs historically have been recognized by sport fishermen as gathering spots for smallmouth bass (Henderson and Foster 1956), and they may represent the most important spawning sites in the area.

Annual spawning success of adult smallmouth bass at Hanford appears to be related to seasonal high or low flow and to the extent of water level fluctuations in spawning areas during the spring and summer (Montgomery, Fickeisen and Becker 1980). Poor spawning success in 1976 was related to cold water temperatures in slough areas, a result of high river flows. This may explain the extended residence time of smallmouth bass and delayed spawning. In addition, weekly and daily changes in river flow caused abrupt temperature changes at nesting locations. High flows entering the sloughs imparted cooler water, while low flows allowed the confined water to warm. The cycle was repeated as water levels fluctuated. Moreover, fry were vulnerable to entrapment and desiccation in flooded, usually grassy, shoreline areas.

Smallmouth bass spawning in 1977 appeared to be more successful than in 1976. The generally low river level allowed water in spawning areas to warm and stabilize. Thus, adult bass matured sexually and spawned on schedule. Subsequently, less severe inundation of slough areas apparently accounted for greater egg hatch and fry survival. The enclosed F-Area Slough, where no fluctuations in water level occurred during the spring, produced the largest number of schooling bass fry. Fry of White Bluff and Hanford sloughs were also more numerous than in 1976 and were less affected after hatching by abrupt changes in water level.

The extent to which fish species other than chinook salmon and smallmouth bass are affected by water level fluctuations is related to their use of shoreline zones for spawning and rearing young. Not all of these relationships are known or understood. Largemouth bass also spawn in the study sloughs, but are less abundant than smallmouth bass. Whitefish fry are vulnerable to water level changes and stranding, and apparently were stranded more than any other species during the low-flow experiment on April 10 and 11, 1976, (Page 1976). Our observations show that the young of many Columbia River fish inhabit shoreline zones for feeding and protection, and that they enter flooded, grassy areas during high flow periods. Most other fry species found stranded or isolated in pools during 1976 and 1977 consisted of "coarse fish" of little economic value, which generally exist in biological surplus. Such species include carp, bridgelip and largescale sucker, redside shiner, squawfish, chiselmouth, peamouth, threespine stickleback, sculpins and dace.

Loss of benthic invertebrate fauna from water level fluctuations can be extensive. Particularly noticeable in dehydrated pools and depressions in the study areas were caddisfly and chironomid larvae, mayfly and dragonfly nymphs, and various water beetles. Crayfish were often entrapped or desiccated, but, like fish fry, the portion detected was probably a fraction of the actual loss. For example, few stranded crayfish were counted during the April 10 and 11, 1976, low-flow experiment (Page 1976, this report). Two weeks prior to the test, only two crayfish appeared on the intake screens of the Hanford Generating Plant, but 59 dead crayfish appeared on these screens the week following (Page, Gray and Neitzel 1977).

Loss of benthic invertebrates is probably related to the sequence of water level fluctuations that expose shoreline zones. A period of sustained high flow is required for most invertebrates to colonize a previously exposed shoreline. A slow decline in flow permits some of the mobile invertebrates to accompany the receding water, while a rapid decline causes more stranding. In either case, substrate depressions such as pools and puddles provide temporary refuges that may become death traps. Space formerly occupied by lost organisms may be refilled with survivors from deeper water after flows increase, but total numbers of invertebrates in the ecosystem are temporarily reduced. Hence, missing forage organisms are not available to consumers at higher trophic levels. Effects of water drawdowns on aquatic invertebrates in riparian habitats are detailed in other publications (Fisher and LaVoy 1972; Kroger 1973; Brusven, MacPhee and Biggam 1974; Brusven and MacPhee 1976; Ward 1976; Brusven and Trichey 1978; Haber, Moore and Hicks 1978; Trotzky and Gregory 1974). In shorelines where water levels fluctuate irregularly, the main effect is usually a reduction of primary and secondary productivity.

The effects of water fluctuations on fish and invertebrate populations in the Hanford Reach of the Columbia River may never be fully quantified. Impacts on important fish species such as fall chinook salmon and smallmouth bass may be reflected at the adult population level because sensitive life stages of these species are affected directly. Thus, water level fluctuations can be crucial to their continued survival. Most other species of Columbia River fish, especially the arbitrary "coarse fish" species, apparently exist in

abundance and replenish depleted areas rapidly. Loss of fish and invertebrates by water level fluctuations may be of little importance to overall ecosystem dynamics.

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