comparison with allowing them to proceed downstream on their own volition? Will the system be economically feasible?

It will be several years before a final judgment can be made, but sufficient information is already available for optimism. Theoretically, by reducing losses of young fish, the system has the potential for increasing the number of adult salmon and steelhead to the Columbia River Basin by 60 percent. The degree to which reality can match this potential remains to be seen.

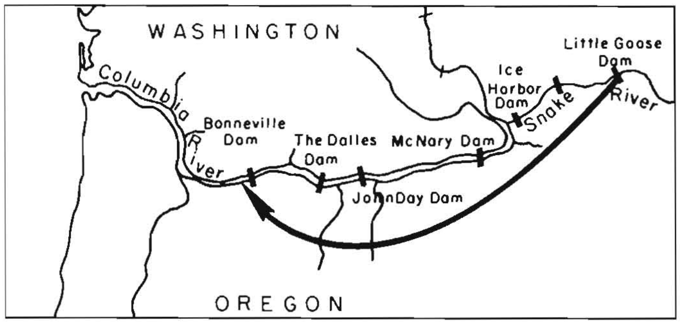

Figure 21.—Transportation route from Little Goose Dam to below Bonneville Dam.

CONCLUSION

Despite the many problems that complicate the maintenance of salmon runs when rivers are interrupted by dams, our runs of salmon can be maintained. Problems of reproduction, passage, temperature, delay, and supersaturation all can be solved if enough effort is made. Even the "impassable" large impoundments can be bypassed. With sufficient determination, there will always be salmon in the "Salmon" River—and all of the other salmon streams of the Northwest.

MFR Paper 1222. From Marine Fisheries Review, *Vol. 38, No. 11, November 1976. Copies of this paper, in limited numbers, are available from D825, Technical Information Division, Environmental Science Information Center, NOAA, Washington, DC 20235. Copies of* Marine Fisheries Review *are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402 for $1.10 each.*

MFR PAPER 1223

Effects of Water Diversions on Fishery Resources of the West Coast, Particularly the Pacific Northwest

Blahm

THEODORE H. BLAHM

Theodore H. Blahm is with the Northwest Fisheries Center, National Marine Fisheries Service, NOAA, 2725 Montlake Blvd. East, Seattle, WA 98112.

INTRODUCTION

Man has found it necessary to divert water from its natural courses to enhance his existence and insure his survival. In the United States, for example, the Rio Grande River no longer flows into the sea, and all water of the Colorado River is being used—except for 1.5 million acre-feet, which is allocated to Mexico. The Missouri and Mississippi rivers have been affected by man's water diversion practices. Another example, which has altered the environment of Delaware Bay, is the diversion of Delaware River water to New York City. In 1922 the total water storage capacity in the United States was 33 million acre-feet; in 1962, it was about 300 million acre-feet; and by the year 2,000, an estimated 600 million acre-feet will be stored. By 1980 approximately 50 percent of our stream and river flow will be diverted. By the year 2000, this will increase to more than 80 percent. As we carry out vast programs of water storage and use, we will greatly curtail river flow into the sea (Stilwell, 1962). Even though less than 1 percent of the world's water supply is now diverted or stored (Armstrong, 1972), the manipulation of this seemingly insignificant portion can have a profound effect on the survival of fish species.

In the United States today, the primary water uses are: 1) electrical power production, 2) irrigation, 3) flood control, 4) navigation, 5) industrial, 6) mining, 7) domestic, and 8) recreation. These uses are not listed in order of importance because any one use on any body of water may take precedence over all others; each plays a part in contributing to water diversion problems.

While there are a multitude of examples to demonstrate the biological consequences of diverting water, this paper will outline only the impact on the fishery resources of the west coast.

MAJOR TYPES OF WATER DIVERSION ACTIVITIES

Irrigation, Flood Control, and Navigation

Irrigation, flood control, and navigation are important west coast water uses that affect fish production. Many dams used solely for these purposes have been built without fishways, and portions of the production of Pacific salmon, *Oncorhynchus* sp., have been eliminated by these obstacles.

Irrigation

The Columbia River Basin Project, supplied by pumps at Grand Coulee Dam, has hundreds of miles of main irrigation canals which will transport over 4 million acre-feet of water. Although the main canals are screened to the laterals, the intakes of the large pumps are not screened. In the Columbia River drainage, the U.S. Department of Interior's Bureau of Reclamation has pumping plants and irrigation projects that entail more than 40 significant dams. Extensive irrigation systems have been developed in many of the major Columbia River tributary systems, e.g., Yakima, Boise, Payette, John Day, and the Umatilla. There are nearly 70 private storage and diversion structures in the Columbia River system alone. The Bureau of Reclamation owns or supervises approximately 83 projects in the state of California, all creating comparable problems. The U.S. Army Corps of Engineers has numerous projects in Washington, Oregon, and California; although they are primarily hydroelectric projects, the impounded water can be diverted for irrigation.

Screens, or other structures, that remove fish from diverted water can cause fish mortality; however, if the screening structures were not used, more severe loss would probably occur. Fish screening structures are required when taking water from a river system, but irrigation diversions are often unscreened and young fish are diverted into the farmer's field. Even when screens are installed, they are often removed to provide maximum water flow. These problems occur despite laws and regulations pertaining to the installation and operation of fish screens. The Federal government participated with State agencies in the fishery development of the Columbia Basin under a program initiated in 1949. Within this program over 700 fish screens (Fig. 1) have been installed, most of which were in operation during

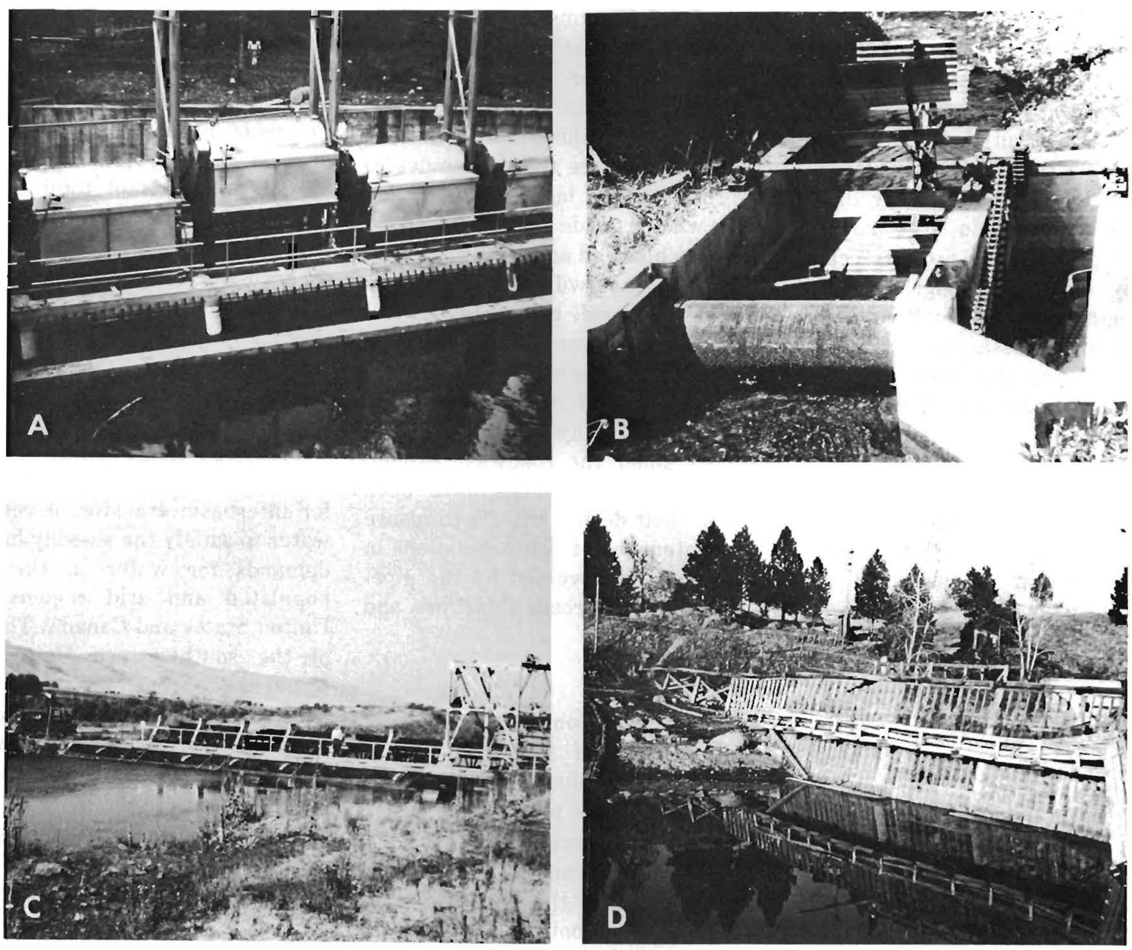

Figure 1.—Fish screening installations in the Columbia River drainage: (A) vertical traveling screens, (B) and (C) two sizes of paddle wheel powered drum screens, and (D) screening weir.

1974. Throughout irrigated lands in the western United States and Canada, there are thousands of such structures, large and small. Each screen-effort can have influence on fish survival by contact mortality, by not screening out eggs and larval fish, and by diverting fish into by-pass canals where predation is increased and water quality is not optimum.

Flood Control

A secondary feature of most water diversion projects is flood control. The Truckee River Project along the border of California and Nevada coordinates water use in the interest of flood control, hydroelectric power, and recreation. During the early development of the project no safeguards for fish were included; this has resulted in a reduction of fish populations. It was reported by the U.S. Fish and Wildlife Service (1950) that there would be 42 diversions on the Truckee River, 5 of which would be for electrical power, the others for irrigation and flood control. It is obvious that fish ladders and screens are required to protect some fish. The San Joaquin River Flood Control Project in California, as proposed in 1958, would destroy fishery habitat and result in large animal losses. Flood control projects can specifically eliminate sloughs, affect littoral vegetation, and inundate deep pools which are necessary to carry over the fishery during the summer (U.S. Fish and Wildlife Service, 1958).

Navigation

Navigation uses conflict with fisheries when dam-and-lock structures are built to facilitate transportation. Spawning beds can be damaged by channel improvements or by direct gouging of stream bottoms. Water level fluctuation can occur when water is released to maintain navigable depths.

Mining and Road Construction

Mining and road construction are important activities in some watersheds. Water, which is diverted for processing excavated materials, is returned to the system—polluted chemically and thermally. Gold dredging has gutted streams, blocked fish migration, and resulted in silting many miles of spawning grounds. In California, several tributaries to Shasta and Deswick reservoirs and the upper Sacramento River contribute heavy metal and acid pollutants which accumulate in waters diverted for mining operations. Chinook salmon, *O. tshawytscha*, and steelhead trout, *Salmo gairdneri*, in the Sacramento system support a fishery estimated to have an average annual value of $1,400,000. It is reported that the food supply of these anadromous fish has been adversely affected, and significant numbers of fish have been killed (U.S. Fish and Wildlife Service, 1959).

The easiest route for a road through rugged terrain is adjacent to an existing stream bed, and consequent desecration of the stream's environment (Fig. 2) will affect its fish populations. In most western States, gravel excavating and processing for road construction is a major activity (Boland, 1974; Miller and Peterson, 1974). Small streams are diverted to allow access to the gravel beds and provide water for washing gravel. During construction of the Alaska oil pipeline from Valdez northward to Prudhoe Bay, more than 500 miles of new road will be built and improvements will be made on existing road beds. One hundred and sixty river and stream crossings will be necessary to complete the road; each crossing will divert water in some way. Precautions can be taken, however, to reduce harmful effects of road construction. For example, many streams will be diverted under the roadway through culverts (Fig. 3); studies have been done on their design criteria to insure the maintenance of fish populations in the streams transversed by the pipeline and adjacent roads (MacPhee and Watts, 1973).

Other Activities

The U.S. Soil Conservation Service has thousands of large and small projects in the Columbia River drainage. Many of these projects affect fish survival either directly or indirectly. The list is by no means complete, but it does demonstrate the significance of irrigation, flood control, and soil conservation on fish survival.

Recreational facilities can be created by damning or diverting water. Boating and fishing in lakes or ponds provide the public with many hours of relaxation. However, even these lesser diversions can at times affect fish populations adversely by creating the same conditions that are associated with the diversions outlined previously.

Industrial Water Supply Systems

Industry diverts large quantities of water from both saltwater and freshwater systems. This water, diverted for industrial purposes, can be altered physically, chemically, and thermally. The accumulation of heat and toxic pollutants which are related to industrial and domestic uses can directly, or indirectly through synergism, adversely affect the survival of fish populations. There are many major industrial intakes and outfalls on the Columbia River between Bonneville Dam and Astoria, Oreg.; the chemical input includes organic and inorganic solids, mercury, phenolic compounds, cyanides, fluorides, chlorine, sulfates, thiosulfates, organic phosphates, and acrolein (a slime controlling agent). Estimates of pollutants that enter the Columbia River from industrial and domestic diversion include some 1,800,000 pounds of total solids, including 20,000 pounds of fluorides and 25 pounds of mercury per day. The thermal input from these sources is estimated at 37,660 million Btu (British thermal units) per day during the summer months.[1]

DEVELOPMENT OF FUTURE WATER DIVERSIONS

Various proposals have been made for interbasin transfer of continental water to satisfy the steadily increasing demands for water in the densely populated and arid regions of the United States and Canada. The people of the southwestern United States would like to transfer water southward from the Columbia and Snake rivers of the Pacific Northwest. California has a program for moving water from three northern areas to the more arid south. The United Western Investigation, a project completed by the Bureau of Reclamation in 1951, proposed more

[1]Fulton, L. A. 1971. A preliminary report on types and locations of pollution outfalls on the lower Columbia River. Unpubl. manuscr., 22 p. Natl. Mar. Fish. Serv., NOAA, Seattle, Wash.

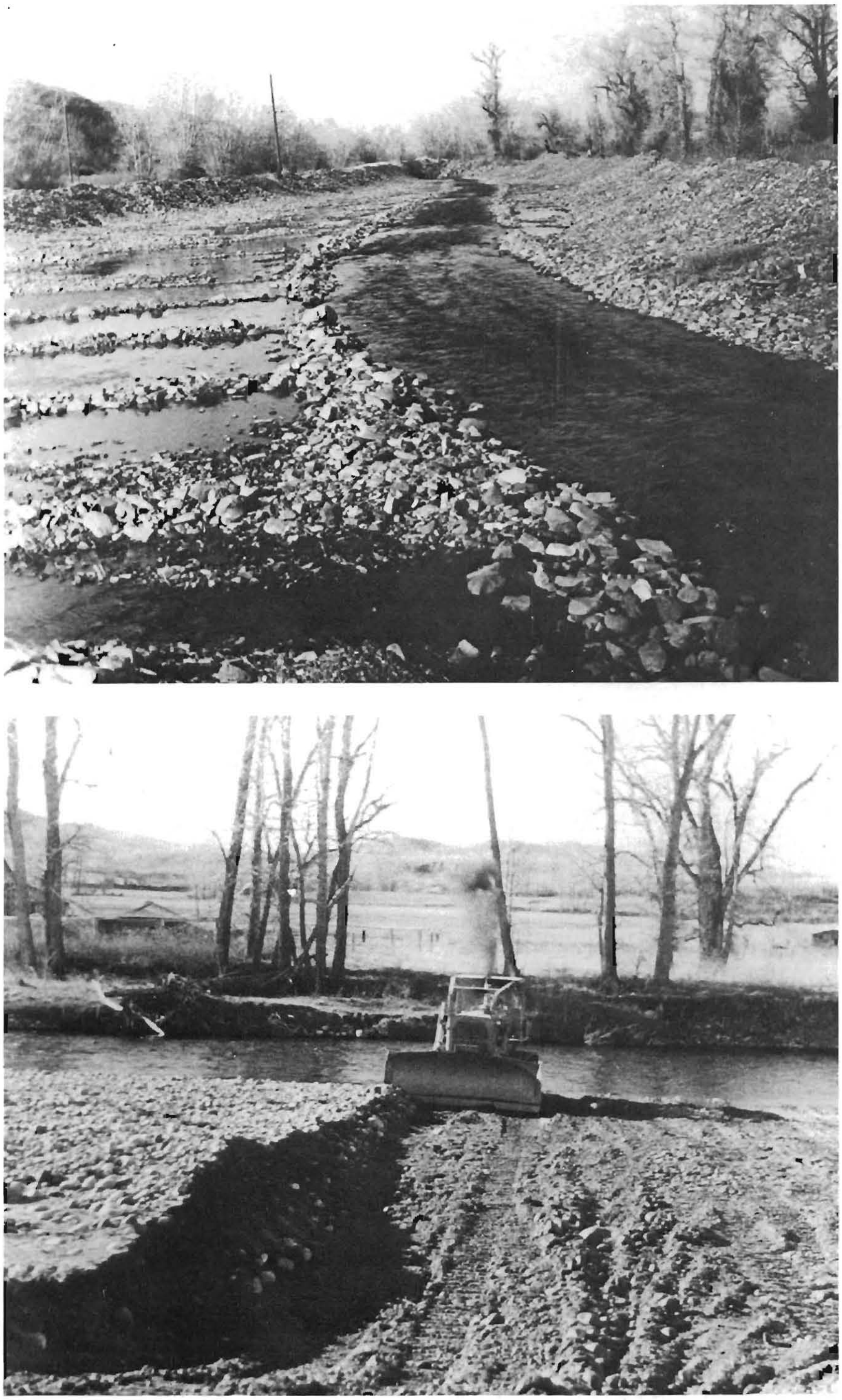

Figure 2.—Desecration of a stream bed associated with road construction.

than 30 different possibilities for diverting Pacific Northwest waters to the Southwest. More recently there has been a proposal which dwarfs those mentioned. This plan, the North American Water and Power Alliance (NAWAPA), or the "Parsons Plan," would cost $60-100 billion and take more than 30 years to complete (Parsons, 1964). It would bring water from the Yukon, MacKenzie, and other rivers of Canada and Alaska and carry it throughout the western states of the United States and provinces of Canada, providing vast regions with an abundance of water. It would even provide the northern provinces of Mexico with a water supply. It would connect the Peace and Fraser Rivers in British Columbia with the Great Lakes, and canals would be dug through the western provinces of Canada through which deep draft vessels might travel from ocean to ocean. Most concervationists have adopted the view that the transfer of water from northwestern North America would adversely affect fish populations in the area.

IMPACT OF WATER DIVERSION ACTIVITIES

Freshwater and Anadromous Fishes

Commercial and Recreational Fishery Resources

The impact of water diversions on local fishery resources has varied widely on the west coast. Generally, major water diversions are detrimental to native populations of fish, but some fishermen have benefitted by the construction of dams and the formation of reservoirs in areas that had little, if any, fishery resources. Weighing fishery losses against fishery gains, it is apparent that the losses in the Pacific Northwest have been much greater than the gains; valuable commercial and recreational fisheries for salmon and steelhead trout, for example, have been detrimentally affected in the Columbia River system by water diversions. In the arid Southwest, on the other hand, there has been a considerable increase in fish habitat and recreational fishery resources because of water-storage reservoirs.

In the Columbia River, estimates of mortality of juvenile salmon and steelhead trout in any one year are as high as 70-90 percent during their seaward migration (Cleaver, 1969; Pacific Northwest River Basins Commission, 1974). Most of this mortality could be directly or indirectly related to man's diversion of the river system. We have tried to compensate for these losses by hatchery production, but hatchery reared fish are subjected to the same detrimental conditions as are the naturally spawned individuals. Approximately 500,000,000 juvenile salmon and trout migrate seaward in the

Columbia River each year, more than half of which are hatchery reared. Water which is diverted from a stream or river to supply a fish hatchery can be returned to the system with detrimentally altered water quality, thus adding to the complexity of the overall problem.

Rare and Endangered Species

It has been established that there is an adverse effect on some fish populations caused, in part, by large and small water diversions. It is virtually impossible to quantify the losses; as the population increases, the problem will become more severe. Already we have several groups of fishes on the Rare and Endangered Species List of the U.S. Fish and Wildlife Service (1973) as a direct and indirect result of water diversion. While most of the fish on the list are not important in commercial or recreational fisheries, we may one day find important species included.

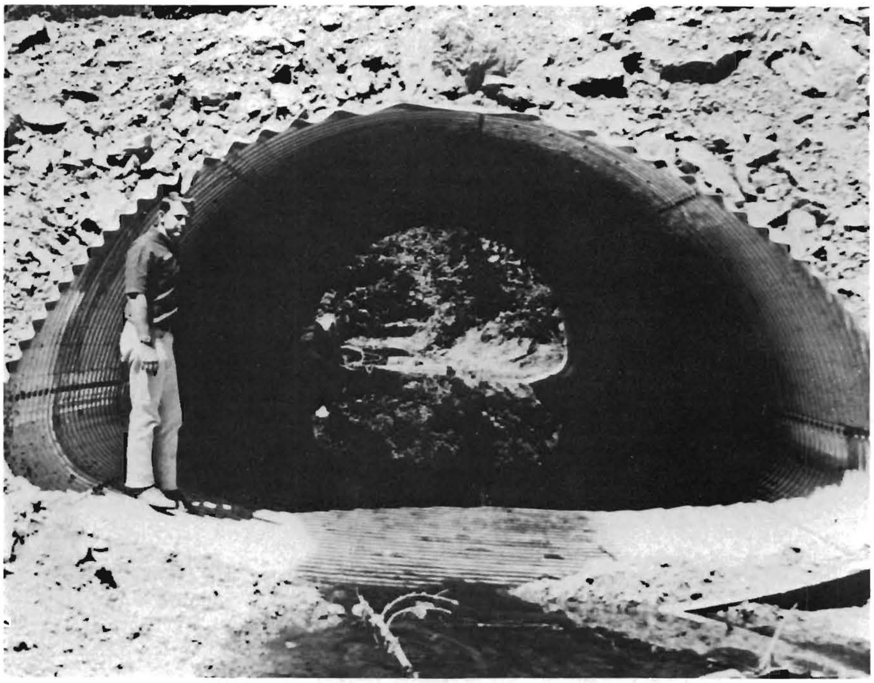

Figure 3.—A type of under-road culvert used extensively during construction of the Alaska oil pipeline.

Marine Fishes and the Marine Environment

To this point, we have discussed the impact of water diversion on freshwater and anadromous species rather than on marine fishes. Marine species that inhabit the estuary during all or a part of their life cycles can also be adversely affected by changes in that environment. Water quality and physical conditions can be altered by water diversions in rivers and streams flowing into the estuary. An obvious interaction between diversion structures and the estuary is an overall reduction in quantity and cycles of flow. For example, water impoundment in some rivers has virtually eliminated spring runoffs, while later summer low flows have altered natural physical and chemical patterns in the estuaries. Small diversion structures, such as dams, dikes, weirs, and locks, appear innocuous. Yet even one of these structures on a stream tributary to an estuary can have profound effects on salinity levels and current patterns. These types of changes can upset the ecological balance of an area far out of proportion to the size of the diversion structure. Though these small structures (along with their large counterparts, the high dams and large impoundments) can be above tide water, their influence is as important as that of structures within the estuarine or coastal zones themselves (DeGuerrero, 1970).

Estuarine fish populations (and secondary food organisms) are affected by the discharges of industrial and domestic diversions which are returned to the system untreated. Studies have shown that sulfite pulp-mill wastes are harmful in several ways: 1) they may be injurious to migrating salmon and steelhead trout, 2) they may suppress phytoplankton and zooplankton activity in the harbor, 3) they may inflict direct damage to eggs and larvae of marine species, and 4) they may create sludge deposits which are detrimental to bottom organisms on which fish rely for food. The pulp and paper industry has many water diversions that return sulfite wastes to the estuary of Washington's Puget Sound—which covers about 883 square miles and supports many populations of anadromous and marine species. In San Francisco Bay, the estuarine communities have not only been reduced in species composition but also in number of individuals, presumably through the effect of toxic wastes (Warren, 1971).

LITERATURE CITED

Armstrong, E. L. 1972. Water for survival. *In* Water-a Continental Resource: proceedings of a conference held at Wenatchee, Washington, June 15, 1972, p. 5. Wenatchee World, Wenatchee.

Boland, R. W. 1974. Was your stream gone when you got there? Mont. Outdoors 5(1):2-5.

Cleaver, F. C. 1969. Effects of ocean fishing on 1961-brood fall chinook salmon from Columbia River hatcheries. Fish Comm. Oreg., Res. Rep. 1(1):76.

deGuerrero, L. C. 1970. Problems of data gathering for coastal zone management. *In* Proceedings, Northwest Estuarine and Coastal Zone Symposium, p. 170-189. Bonneville Power Admin., Portland, Oreg.

Macphee, C., and F. J. Watts. 1973. Swimming performance and migratory behavior of arctic grayling (*Thymallus arcticus*), Alaska. Prog. Rep. Bur. Sport Fish. Wildl., Spec. Stud., 8130 Street, Anchorage, 71 p.

Miller, W., and N. Peterson. 1974. We're losing our streams. Mont. Outdoors 5(1):6-10.

Pacific Northwest River Basins Commission. 1974. Second status report on anadromous fish runs of the Columbia River. Pac. Northwest River Basins Comm., Vancouver, Wash., 24 p.

Parsons, R. M. 1964. North American Water and Power Alliance - water for the next one

hundred years. Ralph M. Parsons Inc., Los Angeles, Calif., 22 p.
Stilwell, H. 1962. What happens when the rivers stop flowing? Field Stream 66(10):29, 65, 125-129.
U.S. Fish and Wildlife Service. 1950. A preliminary evaluation report on the fish and wildlife resources affected by the proposed Truckee River Project, California and Nevada. U.S. Fish Wildl. Serv., Portland, Oreg., 31 p.
_________. 1958. A preliminary report on fish and wildlife resources affected by San Joaquin River Flood Control Project, California. U.S. Fish Wildl. Serv., Portland, Oreg., 23 p.
_________. 1959. Effects of mine-waste pollution on anadromous and resident fish in upper Sacramento River, Shasta County, California. U.S. Fish Wildl. Serv., Portland, Oreg., 14 p.
_________. 1973. Threatened wildlife of the United States. U.S. Fish Wildl. Serv., Wash., D.C. Resour. Publ. 114.
Warren, C. E. 1971. Biology and water pollution control. W. B. Saunders Co., Philadelphia, Pa., 434 p.

MFR Paper 1223. From Marine Fisheries Review, *Vol. 38, No. 11, November 1976. Copies of this paper, in limited numbers, are available from D825, Technical Information Division, Environmental Science Information Center, NOAA, Washington, DC 20235. Copies of* Marine Fisheries Review *are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402 for $1.10 each.*

MFR PAPER 1224

Concluding Remarks

MAURICE E. STANSBY

Many types of situations adversely affecting aquatic biota in the region bordering the northeastern Pacific Ocean may already be of a serious nature, if not in the future. In considering these matters here in a preliminary way, we can divide such problems into two categories: 1) those based upon physical changes; and 2) those arising as a result of chemical action.

Under physical types of activities causing potential problems are two industrial activities of great importance to the region under consideration. Diversion of waters has already been carried out to a greater extent here than in any other part of the country. We can certainly see that such activity has, even during the past several decades, resulted in very serious inroads into anadromous species of fish, especially salmon. A second physical type of alteration is the change in water temperature brought about by using water as a means for cooling in industrial operations. Such a change is, of course, of greatest concern for installations located either on rivers and streams or on enclosed marine bodies of water. Where volumes of water available to serve as the coolant are restricted, a considerable rise in temperature of water can occur. The use of water as a coolant will, in all probability, increase tremendously in the next few decades in connection with the installation of thermonuclear electrical generating plants. With a preponderance of electrical power having been generated in northwestern North America by hydroelectric means in the past, the problems connected with raising water temperatures from electric power developments have been of less significance in this region than elsewhere in the country. They will, however, certainly become a major consideration in the near future.

Maurice E. Stansby is with the Northwest Fisheries Center, National Marine Fisheries Service, NOAA, 2725 Montlake Blvd. East, Seattle, WA 98112.

Potential problems based upon chemical activity of pollutants entering waters can stem from a variety of sources including discharge of effluents from chemical manufacturing operations, uses of chemicals which may get into waters either from general industrial or agricultural and lumbering operations, discharge of raw or partially processed municipal sewage into waters, and accidental spillage of raw materials or chemicals during transport. These are the chief ways in which this class of pollutant can become problematical.

In the past, because the regions bordering the northeastern Pacific Ocean have had much lower population and less industrial and agricultural activity than most other areas of the country, these types of problems have, for the most part, been much less severe. In the future, buildup of populations and industry in the northwestern part of North America will increase such hazards. Especially, changing patterns in certain industrial operations such as the recent petroleum operations in Alaska could intensify these problems very rapidly in the near future.

MFR Paper 1224. From Marine Fisheries Review, *Vol. 38, No. 11, November 1976. Copies of this paper, in limited numbers, are available from D825, Technical Information Division, Environmental Science Information Center, NOAA, Washington, DC 20235. Copies of* Marine Fisheries Review *are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402 for $1.10 each.*