THE APPLICATION OF SNOWMELT FORECASTING TO COMBAT COLUMBIA RIVER NITROGEN SUPERSATURATION PROBLEMS [1/]

By

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Introduction

The Columbia River, perhaps the greatest example of the utilization of snow resources in water resources development, is now threatened with perhaps its most serious environmental problem. Fisheries agencies discovered within only the last few years that at times water in the lower reaches of the Columbia and Snake Rivers contained supersaturated concentrations of dissolved nitrogen, and that such concentrations can be lethal to fish life. It was found that the supersaturated concentrations of gases were created when excess river flow was passed over spillways of dams which have been constructed to provide navigation and power for the Pacific Northwest. The full realization of the magnitude of the problem was not known until 1970, when studies conducted by the National Marine Fisheries Service (NMFS) indicated that large percentages of the migrating fish may have been lost due to their prolonged exposure to high levels of supersaturated nitrogen. The NMFS report triggered reactions of concern from environmental agencies and the news media, reactions which might be considered to be of hysterical proportions in some quarters. Although there are some encouraging signs that the mortality rate may not be as high as that suggested by the NMFS, the Corps of Engineers has taken the position that the nitrogen supersaturation problem is indeed serious, and they have instituted what can be called an emergency program of remedial measures. To date some 15 million dollars has been allocated for data collection and research of the nitrogen supersaturation problem, for transporting fish around areas with high concentrations of dissolved nitrogen, and for the construction of structural devices to reduce gas entrainment. Although no one solution can, from presently known methods, completely eliminate the effects of nitrogen supersaturation, a combination of all feasible measures will hopefully lead to mitigation of the problem to tolerable levels. This report describes how reservoir regulation techniques are and will be applied to combating the nitrogen supersaturation problem, and how snowmelt forecasting is used to guide that operation.

Cause and Effects of Nitrogen Supersaturation

Nitrogen supersaturation problems occur primarily at the lower river dams when excess water must be passed over spillways, rather than through the powerhouses to generate power. The amount of water spilled at any project is dependent upon the hydraulic capacity of the powerhouse, the system power load, and the magnitude of the runoff. Spilling occurs primarily during the period April through July, during which the winter's accumulation of snow is melted. The magnitude of this runoff varies markedly from year to year, depending on the amount of snow available and the temperature sequence experienced during the spring. Large capacity reservoirs located on upper reaches of the Columbia River have significantly reduced the spring runoff magnitudes over what they would have been without regulation; however, significant spilling will continue to occur during large magnitude floods. A hydrograph of the 1971 flood as measured at The Dalles, Oregon, is shown on Figure 1. This flood, which resulted in substantial spill as shown, has a recurrence interval of approximately once in 10 years.

The relationship between nitrogen supersaturation and the occurrence of spillway flows is explained by the fact that the spillway-stilling basin action results in air-entrained water being plunged to considerable depths (up to 60 feet) in the stilling basin. The solubility of gas in water is dependent primarily upon two factors, pressure and temperature. At the depths to which the spillway flow is plunged, pressures greater than the atmospheric pressure force the gases contained in air (78 percent N_2, 21 percent O_2) into

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2/ Hydraulic Engineer, U. S. Army Engineer Division, North Pacific, Portland, Oregon solution in quantities exceeding 100 percent saturation relative to surface pressure. Should this supersaturated water become subjected to lower pressures or higher temperatures, the dissolved gases will revert to a gaseous state and the saturation level of the water will be lowered. In natural streams shallow, turbulent water permits supersaturated gases to be released relatively rapidly. In the Lower Columbia River, however, the nitrogen level does not equilibrate, or return to 100 percent saturation because of the lack of turbulent water between the series of dams located there. Some reduction does take place, but the level is again increased at the next downstream dam. Figure 2 shows a profile of dissolved nitrogen levels observed on the Lower Columbia River in 1971.

Fish in their natural respiratory process extract dissolved gases from the water in their gill structures. These dissolved gases generally remain in the dissolved form in the blood which is supplied to all the body tissues so long as the fish remains under the same pressure and temperature conditions. However, if fish in such a condition move to shallower or warmer areas some of the dissolved gases will return to the gaseous state, thus forming lethal or damaging gas emboli (bubbles) in the circulatory system or tissue. There is also evidence that fish held in supersaturated surface waters readily develop symptoms of gas bubble disease with no change in pressure or temperature. The degree to which the nitorgen supersaturated environment becomes damaging to fish life depends upon the concentration and duration of exposure. At 125 percent saturation, about a week of exposure is lethal to migratory size juvenile salmon. At concentrations of 135-140 percent much less time exposure is required. Unfortunately, the greatest number of adult and juvenile fish migrate during the spring, when dissolved nitrogen levels are at their highest.

Structural Solutions

Since the nitrogen supersaturation problem first came to light the Corps of Engineers has studied, tested, and instituted several structural modifications to lower river dams to reduce the occurrence of gas-entraining spill. They include the following:

1. Skeleton bay diversion. The three dams on the Lower Snake River contain partially completed powerhouse structures where additional generating units can be installed in the future. By installing, in these structures, a bulkhead containing many orifices (Figure 3) enough energy can be dissipated to pass water safely through the skeleton bay instead of over the spillway. About the same amount of water can be passed through the skeleton bay as would flow through an installed turbine. Tests have shown that there is no increase in nitrogen supersaturation when flow is passed through the skeleton bays. These bulkheads have now been installed in the Lower Snake River dams, and this additional diversion capacity will be available for the spring runoff in 1972. The skeleton bay diversion scheme should reduce the days of spillway release on the Snake River from about 80 to less than two weeks, in an average flood.

2. Energy dissipators in existing units. Tests are now underway to evaluate the feasibility of installing similar slotted bulkheads in the turbine intakes of existing units. These would permit the dams to pass flow through the turbines at nearly the maximum hydraulic capacity and yet produce only a small amount of power. Full use of the powerhouse in the spring and summer is normally not possible because power loads in the northwest are lowest at this time.

3. Spillway deflectors. This scheme employs the use of structures on the spillway that will direct low to moderate flows downstream on the surface rather than permitting the flow to plunge deep into the stilling basin (Figure 4). Prototype tests are now being conducted at Bonneville and Lower Monumental Dams.

Operational Solutions

As shown on Figure 1, substantial reduction of the natural runoff is attained by the normal process of flood control storage which takes place in upstream reservoirs during the spring. The over-all reduction that results is of course beneficial to the nitrogen supersaturation problem; however, in some cases special storage regulation can also be instituted which will further modify the river flow downstream to the benefit of the fisheries resources. The achievement of a regulated runoff pattern that will benefit nitrogen supersaturation control, and yet not compromise the objective of flood control and power production, requires careful operation of the system of reservoirs in the Columbia Basin. Such operation relies heavily on streamflow forecasts to establish reservoir evacuation requirements prior to the flood, and to guide the rate and timing of reservoir releases during the flood runoff period. The following describes the two fundamental types of snowmelt forecasts that are used in the Columbia Basin system regulation, and gives examples of how they have been applied in combating the nitrogen supersaturation problem.

Long-Term Volumetric Forecasts. Forecasts of spring runoff volume are made for various points within the Columbia River Basin as soon as the first snow survey data are available each year, about January first. Standard techniques of multiple correlation analysis are used which relate runoff to such independent variables as snow water content and precipitation. Many of these techniques have been described in past Snow Conference Proceedings. Forecasts are made each month as new snow survey data become available. Since the flow in the Lower Columbia River is affected by upstream reservoirs the spring runoff forecasts must be corrected by the total storage space anticipated to be available in these reservoirs. The corrected volume forecasts can be used to obtain the probable range of the spring peak flow, through the use of established peak-to-volume relationships.

The volumetric forecasts are applied in the system operation to limit nitrogen supersaturation two ways. First, through the establishment of the general flood magnitude, the plan for combating the spring nitrogen problem can be instituted as early as January first. This includes the establishment of interagency task forces, the early coordination between fish agencies and operating agencies, and the establishment of construction schedules for needed structural work. The second application of volumetric forecasts involves their use in determining the magnitude and timing of the drawdown of storage reservoirs to provide space for spring flood control. This can best be illustrated by this year's regulation of Grand Coulee Project. As with all storage reservoirs in the Columbia Basin, there has been established at Grand Coulee criteria which sets forth specific minimum reservoir levels throughout the winter to insure that optimum space is available for the control of the forecasted spring flood. Figure 5 shows the flood control regulation diagram for Grand Coulee Dam. When early winter forecasts indicated that the 1972 spring runoff would be a major flood, steps were taken to modify the drawdown of Grand Coulee to lessen the extent of spill in April of 1972. The drawdown curve finally agreed to by the Corps, Bureau of Reclamation, and Bonneville Power Administration is also shown on Figure 5. It is estimated that regulation in accordance with this curve will decrease the flow in the Lower Columbia in early April by approximately 40,000 cfs, thereby reducing the chance of spill during this period of high fish migration.

Daily Forecasting by Streamflow Synthesis. Although the volumetric forecasts just described provide the basis for long-range decision-making regarding the nitrogen supersaturation problem, it is the daily, time dependent, forecasts of streamflow which guide the final regulation process. The mainstay of this forecasting process is the Streamflow Synthesis and Reservoir Regulation (SSARR) computer model which has been developed by the North Pacific Division, Corps of Engineers and adapted for operational forecasting by the Portland River Forecast Center, National Weather Service. The SSARR model has been described in numerous publications (1, 2, 3, and 4). The streamflow forecasts are made by the Columbia River Forecasting Service, which is made up of personnel from the Portland River Forecast Center and the North Pacific Division Office of the Corps of Engineers. Streamflow forecasts are made daily beginning about April first, and are continued throughout the spring runoff period.

The SSARR model is made up of three basic elements: a generalized hydrologic watershed model for synthesizing runoff from snowmelt, rainfall, or a combination of the two; a river stream model for routing streamflows from upstream to downstream points in a generalized manner for the representation of any desired river configuration; and a reservoir regulation model in which predetermined or synthesized reservoir inflows can be operated upon in accordance with several modes of reservoir regulation, within given constraints and specified reservoir characteristics. The combination of these three modes for forecasting on the Columbia River involve 67 subbasin watersheds or local inflow catchments, 47 channel reaches, 28 reservoirs, and 68 downstream control points. The SSARR program is written in FORTRAN IV and is operating on the IBM 360/50 computer system. A modified version is also available for use on an IBM 1130 computer.

Input into the forecasting model consists of fixed data describing the characteristics of the model; initial conditions data which initialize basin, channel, and reservoir conditions; and time-variable input such as precipitation, temperatures for data stations, and streamflow data. Although the SSARR model has the capability of simulating snowmelt runoff by the energy-budget approach, air temperature index procedures are found to be entirely satisfactory for operational usage. On each day during the spring runoff, forecasts are made for the succeeding 30-day period. The temperature sequence utilized combines forecasted temperatures with a sequence of hypothetical temperatures based on predetermined departures from normal (5). The hypothetical pattern is constructed to provide a period of high temperatures with which the model can be used to simulate streamflow that would occur under high melt-rate conditions. The pattern is balanced by periods of negative departure so that the total heat supply is nearly normal. The model automatically depletes the snow pack according to specified depletion relationships and at a rate dependent upon the runoff generated.

Forecasting by streamflow synthesis finds considerable application throughout the entire spring runoff period, as it forms the basis for decisions regarding the rate at which water should be stored in flood control reservoirs to provide the best downstream regulation. The most effective use of flood control storage results in the lowest controlled flow; in general, therefore, this tends to be beneficial to nitrogen supersaturation problems. Streamflow synthesis becomes particularly useful in special short-term operation, however. For instance, in 1971 a special plan was instituted to curtail spill for one week while state and Federal hatcheries made their annual releases of about 40 million young fish. Streamflow forecasts aided in executing the plan, which included power transfers, selected turbine loading, and storage of water at Grand Coulee Dam. This regulation, which resulted in much improved conditions through which the fish migrated to the estuary, is also planned for 1972. A hydrograph of streamflow at The Dalles, Oregon, during this period is shown on Figure 6. This chart also shows the forecasts that were made at that time.

Conclusion

The nitrogen supersaturation problem that now plagues the water resource operating agencies in the Columbia River Basin has probably reached its peak this year. By next year, significant additions to upstream storage and further structural modifications to lower-river dams will have lessened the probability of harmful spill. Continued research and construction will take place in the future, not without considerable expense, so that some day this problem will be associated with only the rarest of floods. Streamflow forecasting, however, will always play an important role in combating nitrogen supersaturation on the Columbia River, for it is the accurate forecasting of runoff that provides efficient regulation of upstream flood control reservoirs to bring about substantial reduction in the over-all magnitude of the spring flood, and to provide special regulation as needed to benefit the fisheries resource of the river.

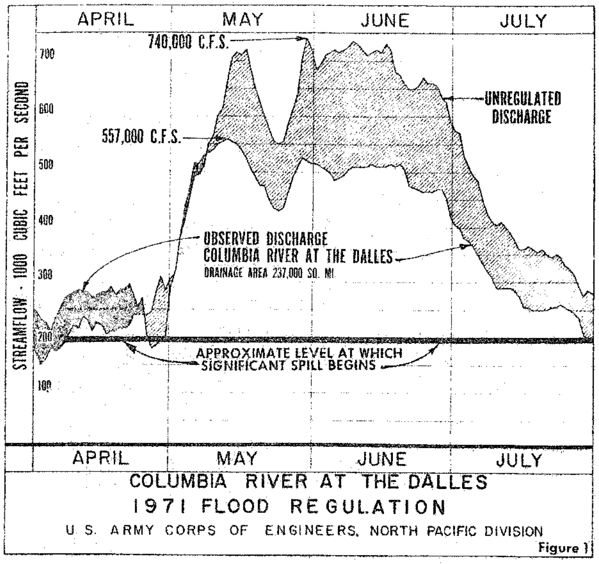

Figure 1. Streamflow hydrograph of the 1971 flood, at The Dalles, Oregon

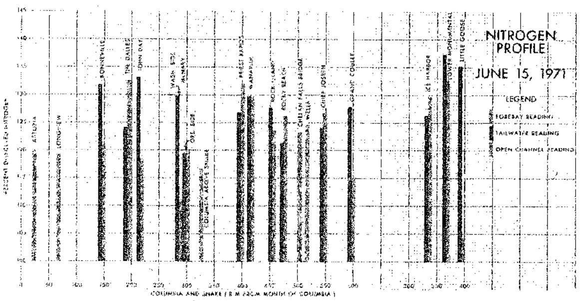

Figure 2. Dissolved nitrogen profile on lower Snake and Columbia Rivers, June 15, 1971

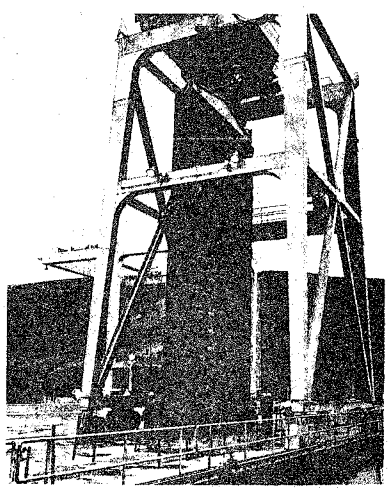

Figure 3. Slotted orifice gate being installed in one of the skeleton bays at Little Goose Dam

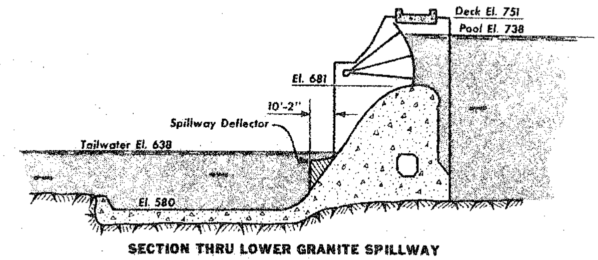

Figure 4. Proposed configuration of spillway deflector (Lower Granite Spillway)

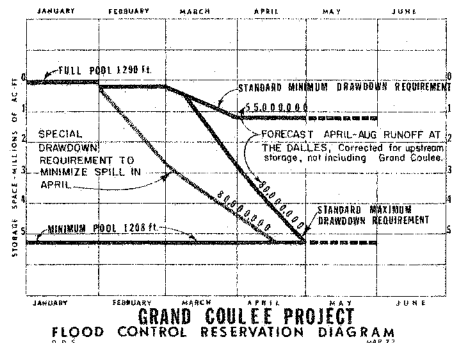

Figure 5. Comparison of standard flood control drawdown requirement for Grand Coulee project with special requirement adapted in 1972 for nitrogen supersaturation control

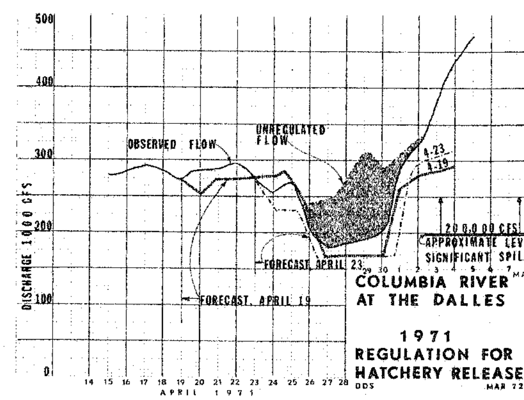

Figure 6. Detail of 1971 regulation for release of hatchery fish, showing comparison of observed and forecast flow.

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