Reservoirs: Problems and Conflicts

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Preface

There has been a need throughout history for some means of ensuring an adequate and controllable water supply for power, irrigation, municipal use, recreation, and flood control. In recent times, the need has reflected a combination of these factors. Since man cannot control the time or volume of precipitation, he has devised reservoirs to fill the requirement for water storage. The practice goes back to Egypt where as early as 2000 B.C. the "basin system" was employed to provide water for irrigation.

However, the current storage situation is not quite as simple as in the days of the Pharaohs. There are complex problems to be considered before arriving at a decision to construct a dam and create a reservoir. Completion of the reservoir helps with some of the basic water resource difficulties but other perplexing conflicts may be created.

In an effort to explore some of the facets of reservoir construction and use, a series of weekly seminars was organized during Fall Quarter 1968 on the Oregon State University campus. Speakers included representatives from federal and state agencies, academic personnel, and private individuals. The discussions were open to the general public. On the following pages appear the texts of papers delivered by the guest lecturers.

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Corvallis, Oregon
January 1969
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The Basis for Conflict

The subject of conflicts and benefits is particularly fitting at this time. The extreme pressures being placed on uses of our natural land and water resources are growing and changing with the increasing population and affluence of our society. The current consideration before the Federal Power Commission as to who should build and what resource facilities should be constructed on the Middle Snake River further emphasize this. These alternate projects, Appaloosa, High Mountain Sheep, or Pleasant Valley, have all the problems associated with the development of a major reservoir, including competition for its construction.

This highlights the various uses of a reservoir—its benefits and detriments. You are probably more or less familiar with this instance. We should, however, develop more of the fundamental concepts of multipurpose resource developments, their uses, benefits, and conflicts before delving into this specific instance, which we will to some extent later.

I will, therefore, devote some time to the more general uses and conflict of uses of the Pacific Northwest's water resources. These are representative of the problems that occur wherever resource developments are taking place. Our discussions with engineers from throughout the world indicate that almost invariably as far as river systems and storage developments are concerned, the same general broad concepts have been universally adopted. This does not mean that conflicts do not exist. In fact, particularly in the United States, the mere mention of a proposed reservoir development seems to stimulate debate and discussion.

Marble Canyon and Bridge Canyon on the Colorado River, the proposed Knowles project on the Flathead River, and now Appaloosa or High Mountain Sheep on the Middle Snake are the most recent examples.
Two other large reservoirs that stimulated controversy in their time were Grand Coulee from about 1933 to 1936, and the more recent Snake River Hells Canyon controversy. These latter two cases resulted in opposite conclusions. In the case of Grand Coulee, the Federal Government developed its large dam and reservoir instead of the smaller projects advocated by the private utilities. However, in the Hells Canyon case the reverse was true. In this instance, the private power company advocate obtained a license to construct three smaller projects, Brownlee, Oxbow, and Low Hells Canyon completed just this year, instead of the Government's developing a high Hells Canyon project with considerable greater storage capacity.

GREAT RIVER SYSTEM

These discussions and debate sometimes result in an over-all better plan of development, but not always. Sometimes emotional appeal overrules sound engineering judgment. In most other countries the conflict between the private and public sectors for development of a resource does not exist. But even there, the uses for which a reservoir is developed are in competition with each other.

In the Pacific Northwest the central geographic fact, strongly influencing the area's economic well-being, is the Columbia River and its tributaries. It has one-third the hydroelectric potential of the United States, including Alaska. This great river system provides the indigenous energy base of the region. It can be compared as an energy resource, to the oil and gas fields in Texas or the coal fields in West Virginia, Pennsylvania, or Utah, with this difference—the energy from the waters of the Columbia River is a self-renewing or continuous process. There is no using up of a valuable resource such as the continuous diminishing supply of oil or coal in other areas. The generation of usable electric energy is one of the main purposes for the development of storage reservoirs and one of the main contenders for storage operation.

The importance of power is exemplified by Professor W. A. Lewis of the Illinois Institute of Technology who stated recently: "I am convinced that an adequate supply of energy is far more important to the security and future of our country than an adequate supply of gold. . . ."

This is also true in a region such as the Pacific Northwest where the Columbia has been the basic energy supply at lower cost than other areas. The Pacific Northwest rivers also provide many other assets and uses to the region. The Columbia serves as one of the main arteries of commerce. It provides irrigation water for vast areas, it supports a tremendous fisheries resource, and adds greatly to the area's recreation opportunities.
The Columbia River and its tributaries rise in the mountains in Canada and the United States and are fed from ground water affluent and rains and melting snows. The flows of this large river fluctuate sharply from season to season and year to year. At the International Boundary the Columbia's largest flow on record is 550,000 cubic feet per second, and its smallest 14,000 cubic feet per second. At Revelstoke, 130 miles north of the border, the highest measured flow is ninety-nine times greater than the lowest, and at The Dalles, Oregon, before construction of Grand Coulee and later storage projects, the variation in volume flow varied from 35,000 cfs to over 1,200,000 cfs, a peak of nearly thirty-five times the minimum. This variation in natural streamflow of the Columbia, although not as great as many other rivers, would cause a difference in water elevation at Vancouver, Washington, of nearly 35 feet.

The higher flows if uncontrolled by the large water storage projects would have flooded thousands of acres of land. As late as 1948, the extremely high flow of over 1,000,000 cfs broke the protecting dikes and flooded out at that time the second largest city in Oregon, Vanport, and covered the Portland airport with over 15 feet of water.

The major Federal reservoirs constructed in the Northwest have been developed and designed for flood control as well as power generation and other uses. The more recent non-Federal developments also have in their licenses, issued by the Federal Power Commission, rules and procedures that they must follow as directed by the Corps of Engineers during flood flow periods. The primary flood control goal established by the Corps of Engineers was to develop sufficient storage to control all floods of the Lower Columbia River at The Dalles to 800,000 cubic feet per second. With completion of the 15,500,000 acre-feet of storage in Canada at Arrow Lakes, Duncan, and Mica, as provided for in the United States-Canadian Columbia River Treaty, the 5,000,000 acre-feet at the Libby project which the Treaty gave the United States the right to build, and the 2,000,000 acre-feet at the Dworshak dam in Idaho, this goal will be more than met. This will make nearly 41,000,000 acre-feet of usable storage available for multipurpose uses in the Pacific Northwest.

**FLOOD CONTROL VS. POWER**

It would appear that these two uses, power and flood control, would not be in conflict, since water is being withdrawn from the river and placed in storage behind the dams during the high stream-flow period. The higher flows if not stored would create serious flood damages. This operation makes the large volumes of stored water available for subsequent release to supplement streamflows and increase power supply during the low flow months. The withdrawal of stored water during the winter season then in turn provides storage space for the following year flood control oper-
ation. Although this makes it appear that these two uses are completely compatible, it is like a lot of things in life, the actualities are much different than the outside view would make them appear.

For instance, the emphasis on flood control requirement is the need to obtain sufficiently large amount of storage space to protect against the occurrence of the largest forecastable flood. On the other hand, for power purposes the emphasis would be on the need to assure refilling all reservoirs prior to the fall and winter season, the high electrical use period.

Full reservoirs will guarantee that the firm power can be provided. The main problem here is the inability to forecast accurately enough. An accurate forecast would permit a completely compatible reservoir operation for both power and flood control. Without it, there will always be some problems. Much has been done to accommodate both needs, but if there is any doubt flood control prevails. Some of the higher floods have occurred when there is only moderate amounts of snow volume, hence, the desire and need to provide the maximum degree of flood protection.

On the Willamette river the predominant floods occur during the winter season, so storage space must be maintained for flood control purposes. Since the Willamette River floods are caused by extra heavy winter rains, the ability to accurately forecast flood occurrence there is practically impossible. Except for some limited storage which is reserved exclusively for power, the full storage available therefore cannot be assured for firm power production. Storage must be evacuated for flood control mostly prior to the need for power production or at times when system power is in excess of needs. Flood control storage space must remain vacant during the winter and if filled from one flood must be promptly evacuated to prepare for the next. In this instance, therefore, operations for maximum power generation and that for best flood control protection are in conflict.

Irrigation is another major use of the water resources for which large reservoirs are developed, such as Franklin D. Roosevelt reservoir behind Grand Coulee dam, Palisades reservoir on the Upper Snake, and many others. This use is also generally compatible with flood control and power requirements. Since the largest irrigation use occurs during the spring and summer months, water pumped from the stream during this time helps flood control. Most of the power used for pumping purposes is surplus to other needs.

However, the irrigation season extends beyond the high flow period into July, August, and September, and encroaches on the use of water for power generation. The Government, however, has adopted a policy that irrigation uses come ahead of power. Therefore, although we try to
mold these two uses together for most effective operation, any conflict in use is settled in favor of the irrigation needs.

IMPORTANT WATER USES

Although many experts contend that the multiplicity of dam construction on the Columbia has increased the river temperature, there is considerable evidence to the contrary. This increases the problems we are now faced with in relation to heat disposal. Our increasing power needs must be met from conventional or nuclear thermal plants which require some method for heat disposal.

By 1980, forecasts indicate that over 6,000,000 kilowatts of thermal generation will be required here. Can our rivers and streams absorb some of the heat disposal from these plants or will it be necessary to completely resort to other more expensive heat disposal methods such as cooling towers or cooling ponds? Much effort is now being undertaken toward finding a way to beneficial use of the warm water discharge from the thermal plants. Perhaps this, too, can be resolved.

Large reservoirs can be utilized to minimize thermal problems. Grand Coulee has been operated to provide cooler water to counteract some of the heat being dissipated in the river by the Atomic Energy Commission plants near Richland, Washington. This is accomplished by generating more at Grand Coulee, while spilling more water at downstream plants during the months of July, August, and September, when streamflows reach their highest temperatures. Generation at Grand Coulee draws water from the cooler lower reservoir levels, spilling thereby providing the cooling effect needed downstream.

Other important water uses previously mentioned which can conflict with the purposes mentioned above and among themselves are navigation, fish requirements, and recreation, in addition to water quality control. The last three have been recognized for some time but are just now becoming most important. The population explosion has created serious water pollution problems and needs for additional recreational opportunities throughout the United States. Our area is no exception. In fact, other areas are becoming concerned on how we handle our great water and land resources.

The use of the nation's streams as a transport for waste disposal has in many parts of the country transformed whole streams into open sewers. This makes these streams unsatisfactory and unsafe for recreational opportunities and other uses. Although this has not completely happened here, we have traveled a long way in this direction. As a result of these serious conditions nationwide, the Congress of the United States has
passed national Water Pollution Control Laws which affect all of us. These require each state to set up satisfactory limitations and enforcement procedures to not only clean up already polluted streams but to prevent any further pollution. Most of the states have already complied and set limitations on the development and use of water resources.

These factors, water pollution control and recreational activities, have already partially adversely affected power generation. In the Willamette River, for instance, the reservoirs developed by the Corps of Engineers, among other things, have provided for a minimum discharge in the lower Willamette. In recent summers, the oxygen content of the Willamette River in the Portland area became dangerously low and temperatures exceeded desirable limits, seriously affecting the survival of the fishery resources.

As a result of joint consultations with the State and Federal Fisheries Agencies, the Federal Water Pollution Control Administration, the Corps of Engineers, the Bonneville Power Administration, and Portland General Electric Company, additional amounts of cool waters were released from some of the power reservoirs so as to increase the flow in the river and thereby increase the oxygen content. This action was taken and did preserve the fish run. The problem here was that there are several Federal nonpower flood control reservoirs from which storage releases could have been made. However, because the recreation activity was so concentrated on some of them and water releases were already being made from others, it was not deemed advisable to adjust their operation until the use for recreational purposes had subsided.

This would not have immediately relieved the downstream situation, and therefore, the decision to use water from power reservoirs was agreed upon. Here it was agreed that if as a result of these operations the Federal system was unable to meet its firm power commitments, the industrial polluters would pay the bill. Fortunately, better than critical water conditions occurred and no firm power loss resulted.

**RECREATION REQUIREMENTS**

Water once dedicated primarily to irrigation use is now being put to more valuable application for municipal and industrial uses. More leisure time has increased recreational pressures geometrically. Reservoirs have created vast new areas for recreation but have also brought their problems.

Banks Lake, once called the Equalizing Reservoir on the Columbia Basin Project, was constructed to serve as the balancing pool to meet the fluctuating needs of irrigation demand and provide for realistic and economical pumping schedules at Grand Coulee dam. Banks Lake, over
25 miles long, attracted large numbers of boaters, swimmers, fishermen, and nature lovers. Resort areas now dot the shores of this blue jewel in an otherwise desert area of sand, sagebrush, and granite. With this development came a clamor to maintain the reservoir at a constant elevation during the tourist season and also incidentally during the period of the greatest irrigation demand on the system.

Another example of the increasing recreation pressures is that of Pend Oreille Lake, a Corps of Engineers project. The project was justified for power and flood control storage. Since its construction the lake has had a more uniform and higher level, particularly during the summer and early fall months than in its natural state. It has always been a rather good fishing lake.

The combination of a more stable lake level and the good fishing has created a large boating and fishing activity on the lake. However, since the kokanee fish spawn in November, there has been a request not to lower the lake further until several months after the spawning to allow time for the eggs to hatch. It is therefore important for power purposes that Pend Oreille Lake storage be withdrawn early in the winter in order that as much storage as possible can be beneficially used at site and downstream before the fish spawn takes place. Then, unless firm power resources are needed, the lake is operated for the fisheries resources. However, now the people interested in recreation have requested limited drawdown of the storage in order to improve boating and other recreational activities.

On the other hand, a certain amount of drawdown is needed to prevent bank erosion during the windy winter period. Here you have conflicting needs in four areas, fish, recreation (boating), bank erosion, and power.

I have emphasized the conflicts of the other uses mainly with power. However, it is recognized that even though power revenues pay the bill, the other uses are extremely important. Great effort among the responsible agencies and utilities have been made to cooperate in relieving critical problems. The Pacific Northwest Coordination Agreement, signed by the power producing agencies, the private utilities, public agencies, and the Federal Government, provides that operation of a reservoir for any other purpose can come ahead of the operation for power.

This very complicated agreement with specific rules for operation of all power storage reservoirs to assure each participant the appropriate level of firm power makes this overriding exception. This exception was made partly in recognition of the potential changes in operation that might become necessary to accommodate the most important use as
the relative importance of all uses change. Any change will reduce the firm power supply to the area and to the project owner.

Since more of the larger reservoirs are Federally owned, the greatest effect would be on the large Federal hydroelectric system, which is best able to absorb it.

FEDERAL DEVELOPMENT ADVOCATED

Now let us return to the present situation, of the conflict of who should develop, probably the last large feasible storage project remaining in the Pacific Northwest area. I believe it should be the Federal Government for several reasons. First, all of the downstream projects which would be affected, either existing, under construction, or authorized, are Federally owned projects. This means that better coordination of water resources and power use can be achieved if the upstream reservoir is a Federally owned project.

Second, changing needs, concepts and technology dictate that the maximum degree of flexibility be provided in reservoir operations to meet these new requirements. Under our present institutional management of reservoirs, I believe this can be best achieved by Federal operation. A non-Federal project owner would not be obliged to change operation as subsequent conditions might require unless at the time the license was issued by the Federal Power Commission this change, which could occur many years in the future, was recognized and provided for in the license.

Third, with a Federal development more emphasis can be placed on the nonpower uses since the over-all benefits can justify completion of the project without covering all the costs from power revenues. This would enhance the possibility of achieving the best over-all development and operation for the total resource picture and not merely the power part of it. In the case of non-Federal development there is presently no provision for the Government to reimburse the private or non-Federal owner for power lost as a result of operation for nonpower purposes.

The non-Federal applicants have good reason to apply for the project. They are in need of additional energy and peaking capacity. They have already initiated construction of the Centralia thermal plant and are seriously planning the first 1,000 mw nuclear power plant to help meet these needs. The hydro peaking capacity from the Middle Snake plant, if available to them, would complement the relatively higher energy production of their thermal plants. There are now taking place discussions between the Federal Government and the license applicants leading toward a cooperative development of the project. Such an arrangement could be beneficial to all parties and provide the flexibility necessary to accommodate all multi-
Whenever a large storage project is constructed, such as this one, certain land areas are flooded. This can be quite damaging to wildlife by flooding forage areas and other valuable lands. Further, in some cases, scenic areas, historical places, mineral deposits, and archaeological values can be lost.

These factors tend to support those who propose no further project construction. The proponents of this argument are very strong in their belief that any dam would also destroy the beauty of the Snake River canyon. They claim it should forever remain as a natural river undeveloped and unsullied.

Other people feel all of the presently proposed structures above the Salmon River are not the best or most economical. They recommend a larger project below the mouth of the Salmon River. In addition to the detriments mentioned above, it could seriously affect the Snake River salmon runs.

Senators Church and Jordan of Idaho have proposed a ten year moratorium on any development until further studies are undertaken to more clearly define benefits and detriments. It is hoped by that time sufficient information will be available to determine if the larger structure would be desirable. In the meantime, however, billions of kilowatt hours that could have been generated will be foregone and perhaps more of our higher cost exhaustible resources used up.

We have been working on the problem of how to resolve the conflicts involved in the use of our natural land and water resources for a long, long time. Some success has been achieved. However, this problem is a dynamic one ever-changing and increasing in complexity. It is a challenge to you and to future generations to seek new ideas, new concepts, and new solutions to these problems in order that the abundant land and water resources of this area may continue to serve mankind.
I am fortunate this is 1968 and not 1908, for 60 years ago my subject was one of very warm controversy. People of that time— that is, from the late 1880's to almost 1920—were very conscious of the fact that timberlands in the eastern half of the country had been badly exploited. A great forest conservation movement took root during the early part of that period in reaction to the uncontrolled depletion of our Nation's forest resources. To sell the conservation concept, all kinds of claims were made as to the virtues of maintaining forest cover on timberlands. In fact, some of the claims would remind you of advertising for patent medicines. Statements were made that forests had great influence on climate, on the air we breathe, on the occurrence of floods, and many other things. Interestingly enough, there was some truth to these claims, but we all know that half-truths can often be misleading.

In the matter of flood control through watershed management, and this is the subject area of my remarks, there were those who maintained that the cutting of forests was the fundamental cause of some of the disastrous Ohio River floods of that time. To be fair to those people, we should remember that while they were perhaps a little over-zealous, they had honest convictions. Very little research data was available then to either prove or disprove a causal relationship of forest cover to floods. And, probably what little data did exist was projected too far—kind of like the fellow who asserted that all Indians walk in single file, because the one he saw certainly did! So, perhaps seeing an abused watershed, where a sudden high-intensity rainstorm did, indeed, cause a local flood situation, constituted proof enough.

At least it did make for some very interesting debates on dam construction vs. watershed improvement. And, this great conservation movement did result in legislation such as the 1911 Weeks' Act which
authorized the Federal Government to acquire lands for resource conservation; namely the maintenance of desirable streamflows and the assurance of adequate future timber supplies.

It must be apparent to you now that I didn't come here to further advance the old argument of what we should have -- dams or watershed management -- for flood control. I think it is abundantly clear that in most cases it is not an either-or situation. Rather, it is a case of one complementing the other.

FACTS ABOUT WATERSHEDS

Let's look at a few facts about watersheds, and particularly forest watersheds. The basic material constituting a watershed is soil, and it has definite physical properties related to water. The soil (and rock) occurs in varying depths; is composed of various materials, chemical elements and compounds; and is structured and arranged in various ways. It has the ability to hold so much water and it permits the movement of free water at certain rates. The soil material may be very susceptible to movement or it may be inclined to stay in place pretty well.

So, what causes floods? That's simple! It's a great excess of water that's not being retained in the soil, and it's water that isn't being contained within its normal or natural flow channel. The severity of a flood depends on how far the water gets out of its channel and how long it stays out, and how much damage it does in the process.

How can floods be prevented? It's easier to say than do. Assuming we can't do much about the amount of water coming from the sky, the logical answer is to either store or detain the excess water, or provide bigger channels for it to get away in safety.

Both methods amount to containment. Looking at the first method, we have soil storage and reservoir storage. Both have some features in common. Both have limits to their capacity, and both depend on how much residual water they start with to determine how much additional flood water they can accept. And, when full, they discharge any excess water received.

Now, we're getting down to the role of the watershed in flood control. The watershed--more specifically, its soils--is a storage reservoir. The amount of storm precipitation or snowmelt water it can store or detain depends on antecedent soil, and the infiltration capability of the soil or the rate at which water can move into it.

I've already said what's important about the soil reservoir is its capacity to retain water and the rate at which it can accept it. Water that
enters the soil either is retained in its pores or is percolated downward or laterally. The pores in dry soil consist of air spaces. Generally, the larger pores are the ones that give soil its permeability and aeration. The small pores give it its water-holding capacity. Sands and clays are good examples.

Sand with its large pore spaces has low waterholding capacity, but high permeability. Clay has a characteristically high waterholding capacity but a low permeability. Within a given watershed, the ability to dispose of precipitation onsite is closely related to the makeup of the soils found there.

VEGETATION AND HYDROLOGY

We can leave soils for a moment and turn our attention to vegetation and its hydrologic roles.

It is estimated that about two-thirds of the water that falls in the United States as rain or snow, passes by evaporation into the atmosphere ---a large part of it being discharged through the life processes of plants. The vegetative cover of the land, the root systems and the plant and animal organisms in the soil, greatly affect hydrologic processes. This includes not only evaporation in its different forms, but also infiltration, groundwater recharge, runoff and the mechanical and chemical work of the water.

Plant transpiration is often the largest component of total evaporation, and is defined as the process by which water vapor escapes from the living plant, principally the leaves, and enters the atmosphere. I don't want to bog you down with technical terms, but a form of evaporation is also a part of the transpiration process, the combination being referred to as evapotranspiration.

Another factor in the disposal of precipitation is interception. This is the process by which precipitation is caught and held by foliage, twigs and branches of shrubs and other vegetation, and evaporated from their exposed surfaces. In terms of flood control, this is an important factor because it is water that doesn't reach the ground. In a dense Douglas-fir forest here in the Northwest, over 40 percent of the summer rainfall may be intercepted in this manner. For average forest conditions, interception may range between 10 and 25 percent of precipitation; for cut or burned areas, it may approach zero. Here again, even with interception, the water "storage" capacity is finite. Once the vegetative surfaces are charged with water, they lose their ability to store any more.

If you will pardon a frequently overworked expression that seems to be popular these days, we are finally getting down to the "nitty-gritty"
of the part watershed management plays in flood control. Much depends on the condition of the watershed immediately prior to the flood conditions.

Let's look at some situations that commonly arise. Consider the summer rainstorm in an area such as Eastern Oregon, where we might have two different kinds of watershed: first, well-forested or otherwise vegetated, and the other, quite sparse vegetation and sometimes known as a "tin roof" watershed. When a high-intensity summer rainstorm hits these two areas, part of the precipitation in the forested watershed is accounted for by interception. If this amounted to—say 25 percent—and the total precipitation was 4 inches, then 1 area inch of flood potential would thus be reduced. In addition, if the soil were permeable enough to take the intensity of rainfall that occurred after interception, then there would be no overland flow of water and all of the storm would be taken up by a combination of plant and soil factors.

As a practical matter, however, many Eastern Oregon soils are quite clayey in content, and if you remember our earlier look at the difference between clay and sand soils, you will recall that clay soils have low permeability; hence, a low infiltration capacity. So, in actual practice we might expect some of the summer rainstorm water to run off and occur as increased summer streamflow, despite the fact that the watershed may be in a very healthy condition.

**MOISTURE HOLDING CAPACITY**

The second example is the case of the watershed that is largely devoid of vegetation. Here, nearly the full amount of the rainfall reaches the soil and with only a limited infiltration rate, it can take only a small part of this rainfall. Thus, a highly-increased rate of runoff occurs. If the total quantity of rainfall is rather large, and its rate of fall greatly exceeds the infiltration capacity of the soil, then we get what is known as a "gully washer". In other words, just like rain hitting a sheetmetal roof—nearly all of it runs off. This is the type of watershed that is most susceptible to treatment and where the greatest flood prevention, through land treatment, can be done. The evapotranspiration process, in both cases, does not really have time to function and can largely be disregarded in the two instances cited.

Now, if we set up a different set of conditions on these same two watersheds, and consider instead a gentle rain that falls over an extended period of time, then other factors come into consideration. At the start of the rainy period we would expect the soils under the forested area to be much drier: this resulting from the use of water by the plants in the evapotranspiration process. In the unforested or unvegetated area, soil moisture would likely be greater, since it would not have been depleted by plants;
thus, the drier soils would have a greater capacity for storing water than would the moister soils in the barren watersheds.

With continued rain, streamflows in the forested watersheds would eventually increase as water reached streams through soil moisture movement, and increased flows would extend over quite some time. The soils of the barren watersheds would reach their moisture-holding capacity sooner than in the forested watersheds because they started out with more water in them. Streamflows would be increased much more rapidly, and if the rains persisted, might even reach flood-flow proportions. This, of course, could happen in either watershed.

RESULT OF SNOWMELT

The same basic principles would apply even to snowmelt. Ability of the watershed to satisfactorily reduce floodflows from snowmelt, again depends on the condition of the watershed and its soils at the onset of the snowmelt period and the rate at which the snow melts. Rapid snowmelts, which exceed the infiltration capacity of the soil, and are in such volume as to also exceed the moisture storage capacity, wind up in streamflow. This is the rule rather than the exception. Spring freshets are a common occurrence. In fact, they are a normal occurrence.

We've talked about East Side conditions, now let's shift our attention over here to what we call the West Side--or west side of the Cascade crest. The very same principles apply but over on this side we are dealing with much more precipitation, on the order of five times as much. In the first fall rains here, the condition of the watershed may be an important factor in the amount of streamflow that will result directly from these early rains.

Heavily forested watersheds with depleted soil moisture may actually account for nearly all of the precipitation in the first good rainstorm. As rains continue, however, the watershed is filled to saturation and much of the surplus goes to immediate streamflow. Because of the difference in soils between the East Side and West Side, we find that West Side soils generally have very high infiltration rates and over-surface movement of water is not common, but even sponges have a certain capacity, and while precipitation may not run off the surface of the soil once the soil is filled with water, it will move through the pore spaces and wind up as ground water recharge or streamflow.

The purpose of all this explanation is to point out that, while important, watershed management is certainly not the sole answer to flood control problems. Major floods are the result of sustained periods of rainfall, and often are coupled with rapid melting of an extensive snowpack.
While the condition of a watershed affects the amount of storm precipitation or snowmelt that can be intercepted onsite, in terms of major runoff it may be a rather insignificant percentage over an entire river basin.

However, on a small watershed or local basis, the difference may be of real significance. A watershed managed for maximum water retention will not only reduce the percentage of precipitation occurring as streamflow, but it will also smooth out peaks in stream discharge. Conversely, if maximum water yield were the objective, then creation of the "tin roof" watershed condition might be sought.

Through increasing scientific management, we are after the optimum condition whereby water yields can be increased to serve downstream uses, yet not to the point where increased flood peak flows are created which would offset the benefits. The key is not just watershed management, but a combination of land management practices and a system of water regulating and storage structures prescribed to satisfy whatever objectives are to be met.

One other extremely important consideration is water quality. The watershed must be maintained in such condition as to avoid accelerated erosion. I use the term "accelerated erosion" in recognition of the fact that erosion is a normal geologic process. While we can't eliminate it, we can control the amount resulting from man's activities on the landscape. Keeping the soil in place has many on-and offsite benefits, not only in terms of water quality, but also in the reduction of problems associated with sedimentation.

Before we go on to Mr. Ellson's talk on reservoir impacts, I do have a few slides which picture some of the land management practices we use in watershed management.

In conclusion, let me read this quotation:
"We now plow horizontally, following the curvature of the hills and hollows on dead level, however crooked the lines may be. Every furrow thus acts as a reservoir to receive and retain the waters; scarcely an ounce of soil is now carried away. . . ."

-- Thomas Jefferson, commenting on farming practices employed on his Piedmont farm.
The mighty Columbia is nearly tamed. Except for one area near Richland, Washington, it is a series of placid pools from Bonneville to the Canadian border. The Ben Franklin Site now under serious consideration would close this remaining gap.

Water is man's basic resource. The impoundment of water with associated benefits dramatically affects every one of us. It is still our major source of power. Irrigation is essential to the food industry of this country. In short, it's difficult to picture ourselves without this resource. It's a way of life.

A reservoir in addition to providing its designed benefits has a profound effect on its surrounding environment. For this reason coordination is essential with many interest groups.

Ask the Bureau of Reclamation or the Corps of Engineers about the coordination involved in planning a reservoir project and they'll likely tear their hair out. A typical reservoir project requires coordination with upwards of 50 separate organizations, each representing its unique point of view.

Proposals for reservoirs are made because their sponsors expect to benefit from their operation. But as the number of organizations involved in planning indicates, the development of a reservoir has many far-reaching effects. Some of these are good, some bad; some direct, others indirect; but all are important to the conservation of the Nation's natural resources, to the development of its economy, and to its social makeup.

The Forest Service, as manager of the National Forests, has a uniquely broad area of concern for reservoirs by virtue of its basic charter.
BACKGROUND OF FOREST SERVICE

A brief background explanation of the Forest Service charter might be in order. The National Forests basically date back to the Organic Act of 1897 which provided for forest reserves to be set aside for the production of timber and the regulation of river flows. These reservations later became the National Forests which traditionally are managed "...for the greatest good for the greatest number in the long run." In recent years, the purpose of the National Forests was further defined by the Multiple Use-Sustained Yield Law in which Congress directed that the National Forests should be managed for the sustained production of water, outdoor recreation, wood, forage, wildlife and fish in the combination that best meets the needs of the American people, but not necessarily that which produces the greatest monetary returns.

Protection and development of the local economy remains an important consideration in all National Forest management decisions. In this context, the control of water through development of reservoirs on National Forest lands is a proper use of the National Forests, providing the project proposed is compatible with the purpose for which the lands are being managed.

As managers of the National Forests, the Forest Service conducts impact surveys of all projects affecting National Forest lands to determine whether the proposed project is basically compatible with National Forest management and, if so, what may be done to maximize public benefits through modifications in National Forest management or in modification of the proposed project itself. These determinations are not always easy to make, but they are made, and the general process used by the Forest Service on the National Forests is applicable to the analysis of reservoirs in other forest land situations.

The first step of the land manager in the analysis of a reservoir and its relationship to the people and to the natural resources it affects is, of course, to gather the facts. These are then analyzed, conclusions are drawn and recommendations formulated.

The Forest Service employs persons of many disciplines—foresters, engineers, landscape architects, range conservationists, hydrologists, fish and wildlife biologists and soil scientists, to name a few. To the extent necessary, the services of all these specialists are used in the inventory of the project area and interpretation of the project effects on the area's resources and improvements. Factors, such as the existing and potential use of the project area by and for recreation, wildlife, fish, timber production, transportation systems, etc., are recorded.
Special soil surveys are often conducted to gather information on the characteristics of the soils. This soils information is important in planning recreation developments, determining sanitation requirements, predicting potential soils problems such as slumps and slides triggered by reservoir drawdown, and in foreseeing turbid reservoir conditions caused by combinations of particular types of soils and shoreline wave action. Reconnaissance hydrologic analysis may also be made of the drainage to determine whether the drainage has a potential for enhancing or detracting from the project.

On the basis of these studies, the project proposal, and other data, an analysis of the project is made. Two of the most important early determinations to be made are: (1) Is the project basically compatible with management of the area that is affected? (2) What alternatives are there?

Sometimes the answers to these questions are clearcut and obvious but more often they are not.

**COMPATIBILITY IS A PROBLEM**

Take, for instance, the case where a reservoir is proposed for development in a classified wilderness area. Man-made developments in classified wilderness areas are simply not compatible with the purpose for which these lands are being managed under law—usually. In writing the Wilderness Act, however, the Congress provided that reservoirs could be constructed within wilderness areas with approval of the President of the United States. This immediately brings us to an application of the second question. What alternatives are there? In the case of the wilderness area, the Forest Service might, after carefully studying all aspects of the proposed project, recommend that it be authorized even though it was not compatible with the wilderness classification. This is if the impact survey indicated there were no alternatives to project development and the project would greatly improve the social and economic conditions of the country.

On the other hand, the Forest Service might find that a project is not compatible with National Forest management and recommend against project authorization. This might happen even in an undedicated area, if reasonable and less adverse alternatives to the project are available, if unique, irreplaceable resources would be lost, or if the project would cause loss to many persons for the gain of a few. This brief discussion is only intended to illustrate that compatibility is relative.

Assuming that during the impact survey, the decision has been made that the proposed project is basically compatible with the purpose for which the effected lands are being managed, the task is then to determine: how should the project be designed and how should the project area
be managed to realize the greatest public benefit?

We have found through experience that if our requirements are well-founded and are made known early in the game, the chance of their being accepted and incorporated into the project design are good. On the other hand poorly supported requests or requirements, made after the project proponent has completed design or otherwise made project commitments, are very difficult to secure.

At one time, single-purpose reservoirs were common. Now, the accepted practice is to consider all potential uses from the beginning of planning.

It is the rule rather than the exception that the uses of any specific reservoir might be a combination of flood control, power, irrigation, fisheries enhancement, recreation, water cooling, etc. In determining the relative value of a project, it is important that the cost/benefit ratio be tempered with considerations for all values, whether tangible or intangible, because, generally speaking, the project with the highest cost/benefit ratio receives the most favorable consideration by Congress or the stockholders. It is a natural tendency of project developers to try to keep costs down and benefits up. Their attention is usually focused on those economic factors which can be readily measured. The land manager, on the other hand, has a tendency to think more in terms of natural resources and people.

The final project authorization report should represent an honest, forthright coordination of both viewpoints if the public trust is to be protected. Since we are talking about the effects on forest resources, let’s consider some of the five major uses of the National Forests:

1. Recreation is a major factor in planning today's reservoirs because, for one thing, it usually contributes sizeable benefits to the cost/benefit ratio. It is important, therefore, that recreation not only be properly evaluated in the benefits, but that it is also properly developed. The difficulty in projecting recreation use over a 100-year project life can best be illustrated by imagining someone back in 1868 trying to predict the recreation use of the Yellowstone Valley during 1968. They simply could not have imagined what today's conditions would be. Many factors must be considered in predicting recreation use, such as proximity of the project to population centers and to travel routes; its relationship to other bodies of water and other recreation attractions; the amount and type of land suitable for recreation development at the project; aesthetics, reservoir operating characteristics, water quality, fishery potential, climate and length of season --- to name part of them.
Each one of these factors can significantly affect the recreation potential of a project. For example, reservoir operating characteristics alone can either make or break recreation development. A reservoir with an extreme drawdown during the recreation season can seriously hinder recreation use except for the hardier souls who are willing to walk across a mud flat to fish in the remaining pool. At the same time a reservoir that can be operated at nearly full pool has almost the same attraction as does a natural lake.

2. Timber production is another important National Forest use which is affected by reservoir development. In determining compatibility and costs of the project, it is important that the value of the timber resource, its potential growth, the dependency of local communities on its availability, and the effect of changes in haul routes, be properly evaluated. In designing the project, alternatives must again be considered: How should the surrounding timber stands be managed? Would it be best if they were included in landscape management units under reduced allowable cut, or that they be managed as commercial forest land? Can timber harvest be designed to modify water yield and/or timing?

3. What about the transportation system? What standard should be developed? Will there be mixed traffic? What is the best road location - on water level, where cost and grade is most favorable or away from the reservoir where recreation areas are protected?

I could go on and on giving examples of the questions we ask about the resources, improvements, etc., when we analyze the various alternatives before making recommendations on project design, but I feel that my point has been amply illustrated.

Before I close, there are two points I would like to emphasize. One of these is that it is important for the land manager to study the whole project. His attention can be so intently focused on the reservoir, for instance, that he ignores the effects of canals, powerlines, effects on downstream water releases, etc. These "incidents" can often have a bigger impact on forest land resources than the reservoir itself.

The other point is that "coordination" is an essential element of the game. We found long ago that our best efforts can be to no avail if our studies and recommendations are not thoroughly coordinated with those other parties studying and reporting on the same project. Conflicting recommendations only succeed in causing confusion and seldom benefit anyone.

In this short time, I've only been able to present a generalized
description of how we in the Forest Service go about analyzing reservoir project proposals and arriving at recommendations. Let me assure you it's a job we must take seriously. It's your resource we are managing.
Eutrophication Problems in Reservoirs

About a year ago the Chicago Tribune issued a colorful booklet titled "Save Our Lake". It is a compilation of newspaper articles and supporting photography that tells the story of eutrophication in Lake Michigan, Lake Erie, and others of the Great Lakes. This commendable effort did much to bring to the citizenry of the region an awareness of the eutrophication problem and what it means. While held by some to be the total spread of elements in the aging process in lakes, and by others to be only the exhibited increasing productivity, the symptoms of the eutrophication process are fairly well recognized.

They include increasing availability of plant nutrients, such as nitrogen and phosphorus, loss of dissolved oxygen resources in the deep water layers, shifts in fish populations from desirable cold-water salmonids to less desirable warm-water species, and, at later stages, gradual shift from clean shoreline to floating bog, and eventually to dry land.

For many of the 100,000 small lakes of the United States, the aging process began some 12,000 years ago at the time of the continental glaciation. This is what created many of these lakes in the first place. From the time they came into being, they immediately fell victim to the aging process and, while the rates varied from lake to lake, under natural conditions the speed of change was fairly slow.

Then came people, and eutrophication in lakes moved at an accelerated rate. Rivers initially seemed untroubled by the influences of eutrophication, but there, too, evidence of increased fertility appeared. Much later, there emerged a national campaign to convert many rivers to series of pools or flow-through lakes. These circumstances are the historic setting against which eutrophication must be viewed.

The theme of this seminar series is "Reservoirs: Problems and Conflicts". No one can deny that reservoirs have many values and serve
mankind in many different beneficial ways. But it must be noted that along with these virtues, many problems and conflicts also arise. One can point, for example, to organizations that advocate the preservation of wild rivers in their natural state.

One can point to intense opposition to proposals to inundate land sites that may be of value because of their scenic qualities or archeological significance. With respect to salmon migration in the Columbia River, questions have been raised as to the impact of dams and, recently, how best to husband resulting cool water resources to regulate temperature at desirable levels.

In relation to this theme there is also the question of reservoir impacts on water quality. Interest in this question comes from several points of view. Section 3(b) of the Federal Water Pollution Control Act (Public Law 84-660) requires that consideration be given to inclusion of storage for regulation of streamflow for the purpose of water quality control in connection with planning of any reservoir by any Federal agency. But, in addition, there is profound interest in the biological involvements in reservoirs, especially when they lead to increased expression of fertility—the same eutrophication problems that exist in lakes.

It is not surprising, then, that people in some geographic settings are concerned about excessive production of algal blooms that impair the usefulness of reservoirs or unfavorably influence the quality of water discharged downstream. There also is concern about concurrent taste and odor problems associated with excessive productivity. Sometimes there are problems with fishkills which appear to have a relationship to or result from increased reservoir fertility and production.

If in small lakes the ravages of eutrophication are permitted to run their course, the ultimate result is an extinguished lake and a final shift from water to dry land.

In reservoirs, where the product of increased production are flushed out downstream, developmental movement toward dry land moves at a much slower pace. Sometimes because of the internal workings in the deep waters of the reservoir, increased concentrations of plant nutrients are permitted to pass downstream. In some cases, as currently in Hell's Canyon, increased nutrient availability leads to an abundance of attached algal growths, such as *Cladophora*, which create undesirable water quality problems.

At present, there is little understanding of the mechanisms within reservoirs that determine their expressions of fertility or how to predict
during the planning stages what the production levels are likely to be. These implied questions identify areas of ignorance that call attention to needed intensified research efforts.

**EUTROPHICATION PROBLEMS**

In examining the impact of eutrophication tendencies in reservoirs, a number of basic points seem obvious. First, impounding fertile water in a reservoir generally leads to algal blooms or other aquatic plant problems. Conversely, in the Columbia River, with its water of low fertility, one can expect low production in impoundments. Available data show this to be true.

Studies on the Missouri River some 15 years ago when Fort Randall Reservoir was created showed that fertile, free-flowing river water is capable of noteworthy production of aquatic plants once the water becomes quiescent and clarified through sedimentation. Impoundments on the Snake River also exemplify high algal production in the presence of impounded fertile water. Similar examples occur in the TVA system, also.

Second, in the context of eutrophication, reservoirs and flow-through lakes are not fundamentally different. It is possible, therefore, to look at lakes—for which there is a much greater store of observational experience—to obtain an understanding of principles that can be applied interpretatively to reservoirs. So far as eutrophication of lakes is concerned, there is a voluminous scientific record, and many examples can be identified on a worldwide basis.

At the moment, intensified publicity is focused on Lake Erie where it is estimated that an eutrophication prevention and remedial program will cost $1.1 billion for appropriate municipal waste treatment and $285 million for required industrial waste treatment. Attention has been directed recently to Lake Michigan, also, in an intensified effort to prevent this vital water resource from progressing to the stages of deterioration through which Lake Erie has passed. One can also cite Upper Klamath Lake in southern Oregon as an example of a lake which has moved far down the eutrophication pathway almost solely under natural influences.

Many other examples of eutrophication problems could be cited both in the United States and worldwide.

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Third, there are two symptoms of eutrophication that people find most distasteful: (1) algal blooms, because they make the water green and unattractive, produce foul odors upon decay, and generally prohibit many water uses, and (2) over-abundance of unwanted rooted waterweeds that interfere with swimming, fishing, boating, and other uses. Occasionally there are other special problems that could become common in reservoirs.

In Lake Winnebago in Wisconsin, for example, the outflow of algae from the lake into the Lower Fox River has created serious water quality problems. During some summer periods in the past as much as 660,000 lbs. of BOD in the form of algae have been discharged downstream. The oxygen demand of an algal mass of this magnitude is equal to the raw sewage from almost 4,000,000 people. Similar problems have arisen in the Klamath River in Oregon as a result of the outflow of algae from Upper Klamath Lake. Under conditions such as these, the algae obviously compete with all other waste sources for the limited assimilation capacity of the river.

In October 1946 a similar outflow of algae (*Aphanizomenon flosaquae*) from Lake Kegonsa in Wisconsin into the Yahara River caused a fishkill of major proportions. The mechanism of fish destruction was an interaction of oxygen depletion and release of toxic agents during algal decay.

At Seattle it became evident by 1950 that changes were occurring in Lake Washington, apparently related to input of treated sewage from the surrounding populated area. It was observed that the standing crop of algae in the lake, the level of phosphorus and the oxygen deficit in the deep water hypolimnion all were increasing. These were noted as generally accepted symptoms of eutrophication. As a result of a $85 million program to divert sewage away from the lake, completed in 1967, improvements already have been noted.

**WHAT MAKES THE BIOLOGICAL SYSTEM GO?**

To visualize better the interaction between eutrophication forces and conditions of impoundment, it is necessary to consider some of the growth requirements of algae. While it is acknowledged that light, suitable temperature, and quiescent water are contributory to algal growth, attention is directed most frequently to the nutrient requirements. Some ten major and several micro-nutrient elements are required for growth, but nitrogen and phosphorus receive greatest emphasis whenever nutrient limitation is considered as a potential remedial mechanism.

In reference to the significance of nitrogen and phosphorus, it should be pointed out: (a) that the peoples of the world have long been involved in rearranging the distribution of these two elements in the environment so that concentrations in surface waters increase; (b) that in some
waters, at least, the size of the plant crop is determined by the availability of nitrogen and/or phosphorus; (c) it is frequently observed that if more nitrogen and phosphorus are added to a given water, more plant material is produced; and (d) while no precise nitrogen-phosphorus ratio is recognized, a ratio in the neighborhood of 10 to 1 generally seems favorable.

While acknowledging that the size of the plant crop is conditioned by nitrogen and phosphorus availability, past observations on a limited number of lakes suggest the following: (a) if soluble phosphorus is present in the amount of about 0.4 oz. per acre-foot (0.015 mg/l), this is sufficient phosphorus to support a population density that people may find objectionable, and (b) for inorganic nitrogen, the corresponding level is about 0.5 lb. per acre-foot (0.3 mg/l).

In the production of aquatic plants in reservoirs, it makes no difference whether the sources of nitrogen and phosphorus as nutrients are the natural soil of the watershed, municipal sewage, or some other kind of waste. If the water of the reservoir is sufficiently fertile and clear enough for effective light penetration, the water is fine for plant production.

WHERE DO NUTRIENTS COME FROM?

If nutrient limitation is to be considered as a potential remedy, it is necessary to know the origin of nutrients and their interactions within the reservoir and the biological systems. Nationwide, a major source of nitrogen and phosphorus is the treated or untreated sewage from cities. It has been estimated that 260,000,000 lbs. of phosphorus are discharged annually in this form. If this sewage discharge represents a volume of 450,000 billion gallons, the resulting phosphorus concentration could approximate 0.27 mg/l—eighteen times the critical level cited above.

Similarly, the estimated annual nitrogen discharge is 511,000,000 lbs., giving an estimated concentration of 1.35 mg/l—four and a half times the critical level. Cities also yield nutrients in their surface runoff and in storm drainage that do not pass through the sanitary sewer system. At present, the magnitudes of such sources are not well known.

As remedial programs curtail the nutrient input from cities and industries, the remaining input that results from runoff from agricultural and other lands take on an added significance.

The quantities leaving agricultural land are variable depending upon land use, slope, and soil characteristics, but for phosphorus has been noted to reach 2 lbs. or more per acre per year and for nitrogen
from 0.06 to as much as 3 lbs. per acre per year. In the United States about a million tons of phosphorus are applied as fertilizer each year.

One can wonder how much of this finds its way to surface waters, but presently the answer is not known. If, however, as much as 10 percent reaches streams, the average concentration could be 0.05 mg/l—about five times the critical levels. Some recent observations suggest that the percent loss is much less—perhaps about one percent.

There is concern about nutrient inputs from feedlots and poultry factories, especially when they are situated adjacent to watercourses. Some idea of the potential impact of these sources is indicated by the fact that one ton of fresh cow manure contains 1.7 lbs. of phosphorus and poultry manure contains 6.9.

At some localities wild waterfowl must be acknowledged as a potentially significant source of phosphorus input. The estimated amount is 0.45 lb. of phosphorus per bird per year. In Upper Klamath Lake, for example, with its high density waterfowl population, this source of input may be significant—perhaps as great as two percent of total input. Even rainwater, which we ordinarily think of as an example of pristine purity, can be a notable contributor of nitrogen and phosphorus. Limited sampling in some geographic areas suggests that nitrogen input may commonly reach 5.5 lbs. per acre per year and phosphorus may reach a concentration in rainfall from 0.01 to 0.03 mg/l. Significance of precipitation as a nutrient source is under study in several laboratories.

The nutrients that enter a given reservoir also recycle within the biological system. The nutrient substance of a given alga is released upon death and decay and is made available for uptake by a succeeding generation. It has been observed in connection with phosphorus, for example, that the recycling interval may vary from more than a year to as little as minutes, depending upon organism size.

The smaller the organism, the faster the recycling rate. There is also recycling from bottom sediments. Research underway is designed to delineate the nature of the recycling, identify the factors that contribute to it, measure the magnitudes under circumstances, and seek means by which recycling from sediments can be impeded.

In addition to these avenues of nutrient access, consideration must be given also to the ability of certain blue-green algae to fix atmospheric nitrogen to a form acceptable for algal use. This is a factor that must be considered in connection with the total management of nutrient input.
REMEDIES

In the light of the foregoing orientation, it is possible now to consider remedial approaches that may be taken toward the objective of turning back or slowing down the eutrophication processes. The first step is to recognize that each lake and each eutrophication problem is unique unto itself.

Therefore, it is necessary that first effort be devoted to a thorough assessment of the problem at hand. One must ask: What is the role of phosphorus, of nitrogen? What nutrients must be curtailed? What laboratory approaches can be used to evaluate the nutrient regime as a backup to scientific judgment? Once an assessment of the problem has been made it is possible to judge if nutrient limitation is the remedial approach of choice.

If so—and this usually is the case—consideration must be given to the procedures by which phosphorus, and less often other nutrients, can be kept at low levels.

If the indicated decision is to curtail phosphorus input in all manageable ways, the following possibilities come to mind: (a) diversion of nutrient-bearing municipal or industrial wastes away from the lake—a practice already in being at two or three locations; (b) tertiary treatment of wastes for phosphorus removal—a mechanism technologically now available; (c) improvement in agricultural practices so as to cut down nutrient contributions—technology toward this objective has not been completely developed; and (d) prevention of soil erosion—a procedure for which technology and experience are available.

Also to be considered are the possibilities for retrieval of nitrogen and phosphorus from reservoirs. While it would be desirable to have effective and economical chemical processes for this purpose, none are now available. As an alternative, attention has been directed to harvesting aquatic organisms so that the nutrient substance of which they are composed can be retrieved from the water.

It is not uncommon for the natural algal crop to attain a density of 2 tons per acre, but such mass contains only about 1.5 lbs. of phosphorus and about 15 lbs. of nitrogen. It seems obvious that with this low return of nutrients for the high cost of algal harvesting, the outlook to use this as a practical remedial measure is not presently favorable. With rooted vegetation, however, it is not uncommon for the crop to reach more than 7 tons per acre, containing in the neighborhood of 3.2 lbs. of phosphorus and about 32 lbs. of nitrogen. Effective harvesting equipment is now available.
Therefore, in addition to the physical improvement that results from harvesting waterweeds, a notable nutrient removal benefit can be enjoyed. While one can also consider harvesting other aquatic organisms, such as fish, as a means to remove plant nutrients, the effectiveness of such procedures has not been determined.

Consideration is sometimes given to dredging bottom sediments as another means of removing substantial quantities of plant nutrients from the body of water. This may also impair nutrient recycling between bottom sediments and the overlying water. At present, the reactions of a body of water to such treatment are not predictable. Dredging and all of the other nutrient retrieval approaches cited above are under study at the present time in research programs of the National Eutrophication Research Program, Federal Water Pollution Control Administration.

In addition to these approaches, exploration is being made of other potential remedies. Among them are destratification or prevention of stratification in impoundments, non-dredging impairment of nutrient recycling from sediments, preparation of reservoir sites so as to minimize the availability of nutrients when initial inundation occurs and, finally, whatever approaches are possible to maintain as great a depth in relation to surface area as is possible in the impoundment. This latter is for the purpose of having an arrangement in which the smallest possible volume participates in the activity of photosynthesis, and thus production of plant material.

IMMEDIATE GOALS

From this point in history, immediate movement toward several goals is exceedingly important.

First, there should be agreement on a national policy to stop in every way possible the presently active rearrangement of nutrients in the environment.

Second, there should be curtailment of nitrogen and phosphorus input to reservoirs and lakes in all possible ways now available.

Third, there should be movement toward definition of water quality standards designed to prevent eutrophication in reservoirs and other potentially susceptible waters.

And, fourth, there is need to move forward boldly through expanded and intensified research to develop and perfect the remedial tools needed.
Losses in Reservoirs

As you know from the topic assignments, I have been requested to discuss "Storage Losses in Reservoirs". My predecessors on this seminar have discussed: Multiple and Single Purpose Uses, Flood Control, and Water Quality Problems. I have not seen their papers, but, hopefully, my presentation will not get very far into fields covered by them.

As indicated in the introductory remarks I have been associated with water resource investigation and planning for thirty years. During this time, I have been intimately involved in studies of projects--some of which have been eminently successful--some of which, though quite useful, have been beset by problems of the types I will describe.

As an introduction to my discussion, I would like to repeat in essence what was said by E. D. Eaton of the Secretary of Interior's Office in regard to Water Resources Planning. He stated that by its nature, water resources planning is a hazardous undertaking. It is highly subject to failure, with consequences that are extremely damaging. Inescapably, it is performed with incomplete information about phenomena whose occurrence is uncertain and deals with time spans far longer than human foresight. Its action recommendations, with few exceptions, have little support from previous experience, and they generally depend upon human actions in the future far beyond the governance of any instrumentalities heretofore devised.

Planning of reservoirs as a facility in water resources development is indeed risky. This is illustrated dramatically by various failures--some reservoirs don't hold water; some trap so much sediment that their initial function is aborted; some become fringed or invaded by myriads of water-loving plants; others lose so much water through evaporation as to become uneconomic; and some become the focal point for angry contention in water-right controversy which precludes effective use.
Let's consider this latter point a minute. Why should a storage facility create problems? Water rights in this state date back more than 100 years. They are set up and guaranteed under state constitution and managed under state law. They are jealously guarded as the life blood of agriculture in the arid West—and rightly so.

However, times are changing with development, and dependence upon unregulated natural flow rights becomes somewhat risky. Increasing amounts of storage to regulate the poorly distributed natural flow must be constructed if reasonably complete development and use of our water resource is to be achieved. But storage development and operation on certain streams necessitates regulation—not only of unappropriated waters (there are very little and in some cases none) but also of jealously guarded natural flow rights. By this I mean that certain streams are already overappropriated because far more potentially irrigable land is available than can be served from the supply.

Spring flood flows, too short in duration to be effectively utilized, are diverted at rates which are far above the early season requirements in the hope that possibly some beneficial effect will be achieved. To a point, such over-early irrigation might be useful. However, it would be eminently desirable to store a large part of this appropriated flood runoff for use later in the season when higher temperatures parch the fields.

**STORAGE REGULATION**

Let me illustrate this by citing an example: Phillips Reservoir, recently constructed by the Bureau of Reclamation on Powder River above Baker, Oregon, has almost 100,000 acre-feet of capacity to regulate flood flows for greater beneficial use. Effective use of this capacity, however, may mean storing water in April and May; water which, although adjudicated to various rights, is above their effective requirements. Such storage cannot be accomplished except by agreement among all the affected right holders, since natural flow not diverted by a senior right is by law available for diversion by the next right in order of priority. Lack of agreement on this matter will result in much wastage of spring flows with resultant small use of the storage capacity provided.

Thus, effective storage regulation of Powder River can only be accomplished through agreement of all water users to limit their early season diversions to what can be used effectively under their entitlement—a self imposed limitation enforced with a view to providing storage for later use. The District is getting off to a good start in this direction. What they need now is an early answer to their prayers for more water in the Elkhorn Mountains so they can test the theory.
Another type of storage problem shows up on a stream like the Walla Walla River where downstream seepage losses from flood flows recharge ground waters which, in turn, are used to serve irrigation through diversions from springs and wells. In such cases, early over-irrigation is not completely lost but is largely, or at least partially, reused. It is extremely difficult to determine what water can be stored for late season use and what water should be left in the stream to meet established rights and uses. Possibly the only way to effectively determine how this should be done may be through development, trial, and error.

Let me illustrate more clearly what I mean by high diversions in early spring, which, although presently permitted under adjudicated water rights, forestall effective use of storage. Water-right adjudications in this state permit continuous diversion of 1/40th and even up to 1/32nd of a second-foot per acre, or a total of 1.5 acre-feet or more in early months when consumptive use would generally use up only 2 or 3 inches. Diversion, allowing reasonable efficiency for delivery system and farm use, should average only about 0.5 acre-foot per acre. Revision of early season water rights, either by law or by agreement, is necessary to permit most effective use of storage.

I have already mentioned some of the relationships of storage rights to natural flow rights. In general, it might be said that, regardless of priority, natural flow rights or usable direct diversions of runoff are met before water is stored. Thus, storage should be filled before early spring diversion rights demand all of the flow.

This is not always the best way to operate. In modern day planning, reservoirs are constructed to serve several uses; some of the uses might be conflicting unless meticulously governed by effective rule curves. For example, reservoirs constructed for use for both irrigation and flood control provide such problems of conflicting use of space. To be effective for flood control, space must be held vacant until danger of flooding is past. For irrigation use it must be filled while there is yet storable flow. Water released to provide space for flood control in a reservoir cannot always be refilled. This constitutes a valuable loss of water if followed by a drought period.

Careful planning for multiple-purpose use must, therefore, be carried out so as to obviate holding of space vacant too long and not filling prior to critically dry periods. In some cases it may be desirable or necessary to provide insurance storage in additional reservoirs in locations where storage of water is the more important function and where carryover storage need not be evacuated for flood control.
CONFLICTING WATER RIGHTS

Another problem in storage management arises from possible difference in storage right held by different users. For instance, there are reservoirs where, in recognition of different seniority or as a political expediency in fostering support for a project, certain interests are given bottom rights. These so-called "bottom rights" are filled first and, in some cases, even benefit from unused storage carryover by junior rights which do not have holdover privileges. In some cases, certain rights have holdover privileges and some do not. Without holdover privileges, water allocated to a given user and not used is redistributed at the beginning of the new season according to proportionate rights in the reservoir and thus are lost to the careful user. This inconsistent type of management may lead to exaggerated, unnecessary use of storage by some users in an attempt to "get all that they have coming" regardless of actual need.

Provision should be made in planning storage use for coordination in operation of several reservoirs so as to retain most of the storage in the best reservoirs. Where possible, leaky reservoirs, which may lose a substantial portion of the stored water, should be operated in conjunction with tight reservoirs, which are capable of serving the same areas, so that maximum holdover storage is retained in the latter. Bookkeeping credit should then be given to rights to such exchanged storage. This can be accomplished by mutual agreement to the benefit of all concerned.

LOSSES FROM STORAGE

The foregoing were examples of loss from reservoirs caused by management where the water is not actually lost from storage, but rather it is lost to storage. In other words, it is not stored because of technicalities. In regard to the other or non-man-caused water losses from reservoirs it has been roughly estimated that:

1. Evaporation from reservoir water surfaces amounts to possibly 5 percent of the water flowing into the reservoirs;

2. Consumptive waste to phreatophytes (the name generally applied to non-useful deeprooted water-loving plants) averages about 2 percent; and

3. Loss by seepage—probably 1 percent of the available inflow.

In addition, the loss of reservoir space due to sedimentation will be tremendous over the long run unless drastic measures are taken to reduce erosion.
Evaporation from the surface of reservoirs results in a tremendous economic loss to this country. J. Stuart Meyers of the U. S. Geological Survey estimated in 1962 that for this region alone—the Pacific Northwest, which embraces primarily the area drained to the Pacific from Oregon, Washington, Idaho, Montana, and Wyoming—over 2 million acre-feet of water is lost annually through evaporation from our principal reservoirs and regulated lakes. This is more than the average discharge of a stream such as the Boise River in Idaho, where an average annual flow of 1,975,000 acre-feet supports an irrigation development of over 330,000 acres and a population of some 140,000 people. Thus, you can see that the evaporation problem is not peanuts in our overall economic picture.

In other regions of the West, particularly in the southern California, Arizona, New Mexico southwest, the evaporation problem looms big. In that area, below the Compact Point on the Colorado River at Lee's Ferry, some 1-1/4 million acre-feet of water is thus lost from a total supply not greatly different from that measured in the Willamette River near Albany. (The average runoff at Albany for years 1895-1967 was 10,450,000 acre-feet per year.) In that southwest region, over 10 percent of their water supply is dissipated into the atmosphere from their reservoirs.

To illustrate the variation in evaporation over the United States, I have prepared a vu-graph from a Weather Bureau publication (Chart No. 1) showing isopleths for average annual lake evaporation. You can see that estimated annual evaporation varies from less than 20 inches in northwestern Washington to over 86 inches in the Imperial Valley in southern California. These evaporation figures do not accurately portray the potential net evaporation loss from reservoirs. Net loss from the reservoir water surface must be computed as evaporation less the consumptive use of precipitation on the reservoir site.

Therefore, since precipitation is relatively minor in the areas of highest evaporation, consumptive use thereof, although complete, is minor in its effect. In areas of lower evaporation, the annual precipitation is high and the net loss from the reservoir basin may be proportionately smaller. Hence, in central Arizona, the net loss would average about 84 inches as compared with only 8 or 9 inches at Corvallis, Oregon.

Efforts have been made to learn more about this phenomenon and to determine whether it can be reduced. Extensive studies were carried on throughout the West. Most widely publicized and probably most intensive of these was at Lake Hefner in Oklahoma and on Lake Mead behind Hoover Dam on the Colorado River. The Lake Hefner studies were undertaken in 1949 as an outgrowth of intensive cooperative studies carried
on at Lake Mead in 1947-1949 by the Bureau of Reclamation and Geological Survey of the Department of the Interior; the Bureau of Ships and Navy Electronics Laboratory of the Navy Department; and the Weather Bureau of the Department of Commerce. This broad cooperation on the problem points up its importance to our Nation.

At Lake Hefner, water loss by evaporation was determined by three methods: (1) by Water Budget, (2) by Energy Budget, and (3) by mass transfer analyses. Results of these analyses were compared with pan evaporation data, thus providing additional and, hopefully, better information on the relationship of open-water surface to pan evaporation. Accurate determination of this relationship has been the subject of much research. The Standard Weather Bureau Class A pans have been compared with 6- and 8-foot pans used by agencies of the Department of Agriculture and with larger pans--up to 100 feet in diameter in various research projects.

Also at Lake Hefner studies were carried out later to determine whether an economic method could be found to reduce evaporation losses. I have already mentioned what some of these losses amount to on a regional basis. In the 17 western state portion of our nation, it is estimated that over 23 million acre-feet of water is lost each year. Even a small percentage reduction, if found to be economic, could be of tremendous value. Because of this, much research was carried out in many places--but notably at Lake Hefner, Lake Mead and by various collaborators in Texas--where it was found that use of certain long chain alkanols such as hexadecanols or octadecanols could be applied effectively to produce a monomolecular film on the reservoirs at a cost probably about equal to the value of the water saved.

It is hoped that these costs can be reduced so that widespread application of methods evolved might be made. Research indicates that such a film would have no adverse effect on recreational fishing in reservoirs.

PHREATOPHYTES

The loss of water by evapotranspiration waste by non-useful deep-rooted plants or phreatophytes, is of extreme importance in some sections of the West. For example, in southeastern New Mexico, the water used up by saltcedar in the backwaters of McMillan Reservoir on the Pecos River amounts to 5.0 acre-feet per acre. When one considers the acreage presently covered by this rank growth and the relative scarcity of water in the area, it can be readily seen why it is considered to be such a menace. Prior to 1920, relatively little information was available in regard to saltcedar in the delta area of Lake McMillan.

No reports are available for years prior to 1912. The rapidity of
its spread is illustrated by the fact that by 1925 it covered 12,300 acres
and by 1960 over 57,000 acres were covered by the plants in the 200-mile
reach between Alamogordo Dam and the New Mexico-Texas State Line. At
5 acre-feet per acre, this mass of vegetation had the potential of using up
some 290,000 acre-feet from a water source which, as measured near Ma-
laga, New Mexico, prior to 1936, averaged only 197,000 acre-feet.

It is easy to see why Texas interests on the lower Pecos River are
extremely desirous of complete eradication and control of this pest. This
water-loving plant has spread over more than 900,000 acres of river bottom
area in the western states. It was even introduced and now covers possibly
1,000 acres in the Owyhee River basin in Oregon and some minor acreage
in Idaho and Montana. Unless controlled, it will rob us of millions of acre-
feet of water annually.

More than 70 plant species have been classified as phreatophytes.11/ Among these there are eight for which enough information is available
to warrant mention in my brief paper: pickleweed, rabbitbrush, salt grass,
alfalfa, cottonwood, willow, greasewood, and saltcedar. Of these plants,
only one, alfalfa, is cultivated as a useful crop, although it appears that
saltcedar may have been considered useful for its apparent medicinal qual-
ities in the early days. The annual use of water by these plants ranges from
a few tenths of a foot up to more than 9 feet, generally limited only be the
available supply.

The water use by saltcedar has been measured carefully by tank
experiments in Safford Valley in the Gila River area of Arizona. Here,
evapotranspirational use of 9.2 feet was measured with water table at 4
feet, and 7 feet when water table was at 8 feet. The losses were spectac-
ularly shown when plotted as water table fluctuations over a period of years.
The growing season fluctuations were reflected in the well hydrograph very
dramatically even though water table varied below 7.4 feet depth.

In this region, thankfully, saltcedar has not been introduced to
any great extent. However, in certain shallow storages, rank growth of
willows, cottonwood trees, reeds and cattails result in considerable loss
of water in areas where water is already at a premium. Reduction or elim-
ination of such growth in these water-short areas would be desirable. In
most places in the northwest, however, these phreatophytes are looked upon
as providing better habitat for game, waterfowl, and fishlife and, consequ-
ently, are not regarded so much as a nuisance and "stealer of water."

SEEPAGE

Some reservoirs won't hold water. Somehow this sounds contra-
dictory. Is it correct to refer to such basins as reservoirs?
Webster defines a reservoir as a place where water is collected and kept for use when wanted. Thus, a place that won't do this is not a reservoir, even though considerable expense and effort have been expended to construct a dam. Such a basin was developed on Tumalo Creek in the Deschutes Basin west of Bend by the State of Oregon in 1913-14 as a proposed aid to irrigation in that area. No water could be stored in the basin, however, because of excessive leakage, except in the upper portion of the basin, where a low dike was constructed to hold some 6 to 8 hundred acre-feet of water. This illustrates one of the hazards of water resource development of which I spoke. Sometimes, in the effort to provide storage where the water is and from where it can be utilized on potentially irrigable land, the force of optimism overrides caution.

In the broad pumice-covered lava fields of central Oregon, it is extremely difficult to determine what basins might be water-tight if developed as reservoirs. Crane Prairie, in the upper Deschutes River basin, first developed in 1922 by construction of a rock-filled timber crib dam, provided effective storage. This structure was rehabilitated and enlarged in 1939-40 as an earthfill dam 36 feet high to provide some 55,000 acre-feet of capacity at the time Wickiup Reservoir was being developed downstream to provide a supply for the North Unit of Deschutes Project.

From the information which was obtained by several geologists and engineers who investigated various considered dam and reservoir sites on the Deschutes River over a period of 35 years, it was concluded that the Wickiup Reservoir site offered the best chance of efficient storage. Although the reservoir basin is underlain at depth by lava flows, these flows are everywhere covered by a considerable thickness of sedimentary deposits; and it was believed that these sediments would adequately seal the reservoir floor and sides to prevent rapid loss from the basin. 12/

It was found by experience, however, that the upper portion of both the Crane Prairie and the Wickiup sites were destined to "leak like a sieve." The most noticeable losses occurred from Wickiup Reservoir during the early years of its use in the late 1940's. Relatively large seepholes were found as the reservoir was drawn down in October of 1945 after storing water to elevation 4318 feet. These holes were repaired, plugged, and blanketed; and storage operations were continued. In 1948, after storage had reached 4332.2 feet for a second year in succession, large seep holes developed along the southern periphery of the reservoir near the base of Davis Mountain.

Records of inflow, storage, and outflow indicated an average loss during May of that year of over 500 cubic feet per second. The largest opening in the area, dubbed the Big Leak, was losing an estimated 350 cubic feet per second of water into the porous lavas of the Davis Mountain area.
Upon detailed investigation of the area, it was found that the condition was probably due to some rather recent faulting which occurred after development of the mantle of overlying sediments. This faulting disturbed the formations, provided rather wide fault zones through the basalts to great depth, and set the stage for seepage breakthrough. During the investigation of the area, Regional Geologist C. J. Okeson was lowered 40 feet into the resultant crevice, and he lowered a light some 30 feet farther without reaching bottom. The holes were subsequently plugged and blanketed and storage has continued to higher elevation. As other permeable areas were found, they were treated or were diked off where this could be done economically.

Our Area Office in Salem has developed hydrographs of storage, estimated losses, and downstream gains which illustrate fairly well the magnitude of seepage loss effects on these reservoirs. (See Chart No. 2.) It is estimated that reservoir losses, which at first averaged possibly 160 cubic feet per second, have been reduced by sealing operations to possibly 50 cubic feet per second or to 36,000 acre-feet for an average year's operation. This amounts to about 6 percent of the average annual inflow to the reservoir.

I have described some rather extraordinary seepage losses which could be readily seen and accounted for. The present losses, estimated at plus or minus 6 percent of the inflow, are not so readily seen and are difficult to determine not only in quantity but also as to where they go. The vu-graph which I just presented indicates quite well, we think, that the losses from the reservoir reappear in large part in the Deschutes River above Benham Falls, although with considerable lag due to the effect of ground water storage.

Had information of this type been available 20 years ago, the history of storage development on the Deschutes River might have been substantially different due to its effect on planning.

SEDIMENTATION

The other effect which I mentioned as causing losses from reservoirs—sedimentation—acts quite differently. It does not lose water which has been stored, but rather, by reducing the storage space available, precludes the storage of otherwise nonusable flows unless additional storage sites can be developed.

Furnish Reservoir was constructed on Umatilla River about 1912. Deposition of sediment, eroded from upstream dryfarmed areas, was so bad as to result in abandonment of this storage in 1934 after some 82 percent of its usable capacity of 5,500 acre-feet was filled with sediment.
Nearby Cold Springs Reservoir provides another example of rather high sedimentation. It was constructed in 1906 as an off-stream reservoir with a capacity of 50,000 acre-feet. It is filled primarily by a feeder canal from the Umatilla River. Relatively little runoff is intercepted in Cold Springs and Despain Creeks, which drain the area above. When surveyed for sedimentation in 1951, it was found that the active capacity was reduced by 5,041 acre-feet (approximately 10 percent in 45 years). Most of this sediment (almost 85 percent) was estimated as coming from the dryfarmed wheat land which covers some 80 percent of the basin above the reservoir, even though only a very minor portion of the storable flow is from that source.

In contrast to these examples, McKay Reservoir, in the same general vicinity, stores water in McKay Creek south of Pendleton, where only 10 percent of the drainage basin is dryfarmed wheat land. Here the accumulation of sediment in 20 years (1926-46) amounted to only 0.07 acre-feet per square mile per year, which is only about 10 percent of the rate of accumulation in Cold Springs.

These illustrations provide a graphic picture of sedimentation in this state and region. They also point up the need, particularly in cultivated dryfarmed areas, to provide ample capacity for sediment detention if storage is to be kept effective over the expected life of the project. For the most part, however, storage reservoirs constructed in this region can be and have been so located as to intercept relatively sediment-free waters from upland forested areas so that sedimentation of the reservoir sites is not a serious problem.

Although there are few locations in this region which are critical problem areas in respect to sedimentation, in the Southwest Region, the problem is very serious indeed. In such areas, engineers must give very close attention to estimates of anticipated sedimentation as they examine sites for storage development.

Here again, even more than for evaporation, basic data is scarce, inaccurate, and hard to get. In general, the only guide for allowances to take care of sediment deposition are found in intermittent, spot sampling of the sediment load in streams.

Sediment samplers have been developed which can, if used carefully through a rather long period of time, provide a reasonable index of anticipated sediment inflow to a reservoir. However, as just stated, this must be carried on over a long period of time and is, consequently, expensive. It is often found that the sediment contribution from a single large flood, such as occurred in December 1964, will provide gross sediment loadings in a river far greater than what might have been measured over
many, many years of more nearly normal runoff. Furthermore, sediment measurements on the rising stage of the hydrograph show by far the heaviest loading.

If these loadings are missed, and they usually are, the measured data for the stream is quite inaccurate. I point out these characteristics to indicate how it is that information on sedimentation potential is so scarce and relatively unreliable.

**PROTECTIVE MEASURES**

With a sedimentation rate (the rate at which sediment is deposited in a reservoir) established from the sediment inflow rate, the dead and inactive storage capacities receive consideration as replacements for useful storage lost through sedimentation. It would be most desirable to have sediment deposited in these capacities because the space, whether filled with water or sediment, will serve the same purpose in reservoir operation. This is not, however, the case at any reservoir, as it is recognized that sediment occupies space throughout the length of the reservoir and does not deposit expressly at the lowest part of the reservoir pool.

Physical conditions at a site often affect the design of a reservoir and thus influence the manner of its operation and the purpose it is to serve. The physical considerations often provide dead and/or inactive storage capacity equal to or larger than the capacity which would normally be allocated to sediment. In instances, the dead storage capacity and inactive capacity may greatly exceed the useful capacity required for successful reservoir operation.

When this excessive capacity is available and the sedimentation rate for the particular reservoir is low, it probably will not be necessary to give further consideration to sediment in reservoir design as impairment to the useful capacity may be easily determined as inconsequential for the period of years specified.

Obviously, should such capacities be equal to or larger then the space requirement for sediment, some measure of protection against sedimentation is provided automatically in that the designed, useful capacity will be assured behind the dam at the end of a specific period of time. However, the portion of capacity available to replace that lost by sediment will generally not be in a position where it can be used for the purpose or purposes the reservoir is to serve. Part of the capacity will exist below the originally designed position of the useful capacity and the position of the outlets may prevent its use by normal reservoir operating procedure.

Design engineers recognize the fallacy of reserving the dead and
SEDIMENTATION CONDITIONS

Reservoir partially filled with sediment.
Dominantly in course particle sizes.

Reservoir partially filled with sediment.
Dominantly in silt and fine particle sizes.

Reservoir partially filled with sediment.
Dominantly in silt and clay particle sizes.

Reservoir filled with sediment.
At this stage trap efficiency becomes zero and remaining available storage is maintained by sluicing at outlets.

a - FLOOD CONTROL SPACE
b - CONSERVATION STORAGE
c - INACTIVE STORAGE
d - DEAD STORAGE
== OUTLETS

CHART 3
Specific weight of the sediment accumulated in the Colorado delta along the thalweg.
inactive capacity at the lowest storage space for sediment. As a result of
difference in the settling rates of various sizes of sediment and other fac-
tors which control sediment disposition in a reservoir, sediment deposits
will occupy space on the floor of the reservoir starting from the backwater
and sloping in the direction of the dam. This is diagramatically shown in
figures 2, 3, 4, and 5, on this vu-graph. (See Chart No. 3).

The illustrations also show that with design capacities lying super-
posed in a reservoir, deposited sediment will, eventually, transect and
thereby reduce all the design capacities. For example, if the required cap-
acity to be allocated for sediment should be 100,000 acre-feet for a 100-
year period, allowing 100,000 acre-feet of capacity at the lowest part of
the reservoir pool does not insure that all sediment will be deposited there
during the 100-year period. Sediment encroachment into the upper conser-
vation and flood control space may begin soon after closure of the dam is
made. This is particularly true if the sediment inflow is predominantly
fine material.

Conversely, if the sediment inflow is predominantly fine material,
there will be a tendency for the sediment to spread more evenly throughout
the reservoir. This is shown in more detail by the profile drawn to repre-
sent the thalweg of the Colorado River above Hoover Dam through Lake
Mead. 15/ (See Chart No. 4.) You will note the large delta area and still
very appreciable amounts of sediments carried into the deep reservoir.
Density currents have been observed which carry these sediments.

It should be remarked that sediments in the upper delta areas,
especially those subject to intermittent exposure and drying, become hea-
vier and denser than other sediments. Lighter sediments in the deeper
portions of the reservoirs where they are not exposed to alternate drying
periods remain dispersed and take up relatively larger proportions of the
storage space.

**SUMMARY**

In conclusion, I would like to say that this matter of reservoir
losses is probably one of the most complicated and frustrating subjects
which must be considered in water resource development. There is a
paucity of adequate information on most phases of this problem and infor-
mation which is available is subject to wide fluctuation.

As I stated in opening, conclusions in these areas are subject to
modification by future actions and future manmade decisions. Operating
plans for projects can be changed. Reservoirs or sediment detention fac-
tilities may be constructed throughout the catchment basin. Cropping pat-
terns and use of lands can be changed completely. Phreatophytes may be
eliminated or controlled or new strains which are far more difficult to live with may be inadvertently introduced and take over. We may even come up with an economic way of lining reservoirs to eliminate seepage and thereby make possible future use of the Tumalo site before the constructed features disintegrate. Who knows?

In the meantime, we will continue to take into consideration the best available information on these losses with a view to providing structures which will be useful, at least until they have provided benefits to justify development. Hopefully, we will find means to lengthen the life span many-fold.
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Reservoir Effects Upon Fisheries

My talk deals generally with the effects of reservoirs on fisheries but it is not specific to this subject. However, it is confined to the effects of dams on salmon and steelhead in the Columbia River system.

Fresh water is of critical importance to the life cycle of salmon and steelhead. Adult fish must spawn in cool, flowing water with a high oxygen content and free of toxic substances. Young salmonids must rear in fresh water for varying periods up to 3 years before migrating to the ocean where they grow to maturity.

Construction of dams presents several possible problems to maintaining these migratory fish:

1. The dams present physical barriers preventing adult fish from moving upstream to the spawning grounds.

2. If adults are passed upstream, reservoirs inundate much of the spawning areas making them useless and change the environment in which young fish must rear.

3. Water currents or lack of them in the reservoirs may confuse juvenile fish preventing them from migrating downstream.

4. Special facilities are required at some dams for passing juvenile salmonids downstream. There are no set criteria for such facilities and many are unsuccessful at collecting fish.

5. The reservoirs may harbor large populations of predator fish resulting in poor survival of salmonids.

6. The quality of the water in the reservoirs and amounts discharged as dictated by project operations may adversely affect adult and
juvenile salmonids below the dams.

The greatest effect of dams on salmon of the Columbia River has been the complete elimination of extensive spawning and rearing areas (Figure 1). Construction of Grand Coulee Dam on the upper Columbia River resulted in the complete loss of 1,140 lineal miles of spawning and rearing area (Fish and Hanavan 1948). Salmon formerly spawned in the main river nearly to the headwaters at Columbia Lake and in many of the tributaries above Grand Coulee (Bryant and Parkhurst, 1950). Salmon also ascended the Snake River to above Salmon Falls and probably to Shoshone Falls (Gilbert and Evermann, 1894).

Now, fish do not migrate beyond Hells Canyon Dam and they will be pushed further downstream if the High Mountain Sheep Project is constructed. Extensive spawning and rearing areas in the main Snake and in numerous tributaries above Hells Canyon Dam have been lost. Additional to these losses, high dams on many of the tributaries of the lower Columbia such as the Willamette and Deschutes rivers in Oregon and Cowlitz and Lewis rivers in Washington have further reduced areas available to salmon.

Finally, construction of dams on the main Columbia from Bonneville to Wells has eliminated extensive chinook salmon spawning areas. Salmon can still migrate through these areas since the dams all have fish ladders. However, fish are not able to use the main river to reproduce except in a relatively short area below Priest Rapids Dam. This will also be eliminated if Ben Franklin Dam is constructed.

**DIFFERENCES IN FISH COUNT**

In spite of the loss of extensive salmon and steelhead production area in the Columbia, significant spawning and rearing areas remain. Some of the most important ones are the Salmon, Clearwater and Grande Ronde rivers, which are tributaries to the Snake River, and several tributaries to the Columbia in eastern Washington. There are also important salmon-and steelhead-producing tributaries in the lower Columbia. In spite of dams on the Willamette, Deschutes, Cowlitz and Lewis rivers, these all remain important producers of fish.

Adult fish migrating upstream to the Snake River tributaries and juveniles moving down to the ocean will have to pass at least eight dams when those under construction are completed. Fish moving to and from the Columbia river tributaries in eastern Washington must presently pass from four to nine dams. These are generally referred to as low head dams. They are under 100 feet high. Ladders have been constructed for passage of adult fish upstream but downstream migrants must pass over the spillways or through the turbines of these dams.
Figure 1: Dams completed and under construction on the main Columbia and Snake rivers (Canada excluded).
1/ Ben Franklin is planned but not authorized.
Both upstream- and downstream-migrants are having problems passing dams on the main Columbia and Snake rivers. For several years, fishery biologists have noted large unexplainable differences in the counts of adult salmon and steelhead at successive dams. As an example, for certain races of fish passing upstream in a given year, significantly fewer have been counted at The Dalles Dam than were counted previously at Bonneville.

Significant differences in counts have also been noted between other sets of dams from The Dalles Dam upstream. The largest differences have been between summer steelhead counted at McNary Dam and the combined count of these fish at Ice Harbor Dam on the Snake River and Priest Rapids Dam on the Columbia. From 1962 to 1967 the combined count at the two upper dams averaged 44,000 fish less than that at McNary. During these years the average annual count at McNary was 117,000 summer steelhead. The 44,000 fish difference represented over 37% of the count at McNary. We have also noted large differences in the counts of spring and summer chinook at successive dams.

A Fish Commission study (Fredd, 1966) indicated these differences could not be explained by the numbers of fish spawning in tributaries between the dams or by counting error at the dams.

We believe a significant part of the error is due to mortality as fish pass upstream from one dam to the next, but we do not know the exact degree or causes of the mortality. Some possible causes are mechanical injury at the dams, delay in passage resulting in inability of fish to reach their spawning grounds and supersaturation of nitrogen which causes gas bubble disease in fish and may be fatal.

This latter problem which is caused by large volumes of water spilling at dams was a contributing cause of mortality and delay to salmon at John Day Dam in 1968. Fisheries workers found several hundred dead chinook and numerous dead sockeye and scrap fish below John Day Dam last summer. Large numbers of other fish were noted swimming lethargically below the dam. Fish caught alive from below the dam evidenced gas bubble disease. We believe the several hundred dead chinook found below the dam on a few surveys was only a fraction of the total dead present.

A study at Bonneville Dam in 1955 (Merrell and Collins, 1960) indicated only 3% of the dead chinook present were found during intensive surveys made from the dam to a point 56 miles downstream. This study also concluded that significant salmon mortality occurred at Bonneville Dam during periods of high flow. The spillway area was thought to be a major source of mortality.
SURVIVAL OF JUVENILES

We have evidence that adult summer chinook salmon were delayed in passing some Columbia River dams in 1968. Based on the timing of counts for all years of record, a large segment of the summer chinook run passing Ice Harbor Dam in 1968 was about 1 month late. These fish had previously passed Bonneville Dam about 1 week earlier than normal. We believe fish were delayed at The Dalles and John Day dams due to problems of providing adequate fishway attraction water. These problems were further complicated by supersaturation of nitrogen at John Day causing gas bubble disease in fish. The 1-month delay in fish passage measured at Ice Harbor Dam may have reduced spawning efficiency appreciably. Researchers in British Columbia showed that sockeye salmon delayed 12 days or more did not survive to spawn (Thompson, 1945). We have evidence that many chinook salmon reaching the Snake River in 1968 did not spawn.

Several factors may effect the survival of juvenile salmon and steelhead migrating downstream past dams on the main Columbia and Snake rivers. These dams form large reservoirs; John Day is the longest with a length of nearly 80 miles. We presently have little idea how efficiently fish pass through these impoundments. The presence of several large reservoirs instead of a free flowing river could make it difficult for fish to migrate downstream.

Studies by the Washington Department of Fisheries showed that juvenile fish passing over the spillway and through the turbines at McNary Dam experienced mortalities of 2% and 11%, respectively (Schoeneman, et al., 1961). It seems reasonable to expect that similar losses would occur at other main stem dams.

A treaty signed by the United States and Canada provided for construction of several large storage dams on the upper Columbia River. These projects will store water during high flow periods, which generally correspond with the downstream migration of juvenile salmon and steelhead in the spring. As a result of this storage, most of the water and fish will pass through the turbines at the low head dams below Chief Joseph Dam. Losses of 11% of the juvenile fish at each of four to nine dams would definitely be prohibitive. Additionally, storage of water in the spring at the upper Columbia dams would lessen the flow through the reservoirs downstream and perhaps make it more difficult for juvenile fish to migrate through these impoundments.

A beneficial effect of lessening spill at the low head dams would be a reduction in the nitrogen absorbed by the water.

The Bureau of Commercial Fisheries has conducted research over
the past several years which could result in preventing most juvenile fish from passing through the turbines of the dams. They found that juvenile salmon move mainly along the ceiling of the penstocks and that many are diverted into the gate wells. The BCF has collected several hundred thousand juvenile salmon and steelhead from gate wells at a few dams over several years to study downstream migrations. It is possible that the dams could be modified to divert most of the fish from the penstocks into the gate wells. Fish could be collected from the wells and passed safely downstream.

**FACILITIES FOR PASSING**

The BCF also began a study this year of the feasibility of collecting juvenile fish from the gate wells of one of the uppermost dams and trucking them downstream for release below most or all of the remaining dams. An earlier study by the Washington Department of Fisheries (Ellis and Noble, 1960) in which juvenile fish were transported by barge and truck to below Bonneville Dam from the Klickitat River Hatchery yielded inconclusive results. Generally, fish barged and trucked downstream did not return to the hatchery as well as fish released at the hatchery. However, many of the fish barged and trucked did return to the Columbia River as adults but seemed confused as to where they should go after entering the river. Much more study is needed of the possibility of improving survival by transporting fish around the dams.

We do not know what proportions of the downstream migrants pass over the spillways and through the turbines of the various projects at present. It seems probable that large numbers still use the spillways where mortality is relatively low. In a few years, most of the fish will have to pass through the turbines. It is essential that we prevent this if we hope to maintain salmon and steelhead runs into the upper Columbia and Snake rivers.

The study of passage problems at dams on the main Columbia and Snake has been extremely difficult due to the large size of these rivers. It has been somewhat easier to study fish at dams located on the tributaries since these rivers are smaller and since special facilities for passing juvenile fish have been included at several projects.

Relatively high dams have been constructed on the tributaries (100 to over 400 feet). For many years there was no attempt to pass migratory fish at these high dams since there was little spill and downstream migrants would not sound to the deep outlets at these projects. However, in the past 15 years, several projects on the Deschutes and Willamette rivers in Oregon have included facilities for passing upstream- and downstream-migrant salmon and steelhead. The Fish Commission of Oregon has evaluated fish passage at these projects and has studied some of the
LOCATION OF PERMANENT AND TEMPORARY UPSTREAM-MIGRANT TRAPS, COUGAR DAM

FIGURE 2
relationships between juvenile salmonids and the reservoir environment.

Passage of adult salmon and steelhead at dams on the smaller rivers has generally appeared successful. However, we have observed some problems. At most high head projects, adult fish are trapped at the base of the dams and are hauled by truck to the stream above the reservoir.

Two such dams in Oregon have long ladders for passing adult fish upstream. Pelton Dam on the Deschutes River has a 3-mile-long ladder which adult chinook salmon and summer steelhead reject during the summer months. Fish will enter a trap at the lower end of the ladder at that time and can be trucked above the dam. At other times of the year, fish appear to move up the ladder without delay. A similar situation exists at North Fork Dam on the Clackamas River. This dam has a 2-mile-long ladder which chinook salmon reject during the late spring and summer months. The fish will enter a trap at the lower end of the ladder, however, and can be trucked upstream as at Pelton. Chinook and coho salmon and winter-run steelhead accept the North Fork ladder at other times of the year.

The traps at North Fork and Pelton receive cool water from the depths of the reservoirs. Water passing down the ladders comes from the surface of the reservoirs and is several degrees warmer in the summer than that at the traps. We hypothesized that warm water caused the fish to reject the ladders. However, chinook continued to reject the North Fork ladder when it received cool water pumped from the depths of the reservoir.

We found an entirely different situation at Cougar Dam on the South Fork McKenzie River. A trap for collecting adult chinook salmon was constructed in the tailrace channel below Cougar Dam (Figure 2). This facility collected fish successfully for trucking upstream during construction of the project.

After the reservoir filled, however, adult chinook would not enter the facility in late June and early July, the previous peak migration period. Fish were collected at that time in a temporary trap constructed in the lower end of the regulating outlet channel.

Water passing through the permanent trap came from the depths of the reservoir and was 40-42°F. Water at the temporary trap came from near the reservoir surface and was 50-55°F, the temperature range of the stream in most summers prior to construction of the dam. We found that fish were collected best by the temporary trap when no water was released through the powerhouse. Some chinook were collected in the permanent trap in late summer when water passing through the turbines had warmed slightly. We had water samples from the two traps analyzed by a laboratory and found no significant differences in chemical composition. We
believe cold water repelled adult salmon at this project.

The Fish Commission has expended considerable effort in studying the activities of juvenile salmonids in reservoirs. Our studies have emphasized determining the reaction of fish to collection facilities and relating the habits of the fish to measured factors of the environment.

Passage of downstream migrants has failed at most projects where special facilities have been constructed for their collection. However, successful passage of juvenile fish has been attained at some dams and requirements for success are becoming better defined. We have shown that juvenile salmon grow larger in reservoirs than they do in streams and that survival of salmonids in reservoirs is high if large populations of predator and competitor fish are not present.

When salmon and steelhead are ready to emigrate from reservoirs, they are distributed mainly near the water surface. This is significant in that collection facilities must be located at or near the surface of reservoirs to be efficient. At a flood control reservoir, which fluctuates widely in depth, it is necessary to have the entrance of the collection facility located near the water surface at any pool level. Quantity of attraction flow appears to be important, i.e., more flow better collection, but we have not established the minimum required amount.

It may not be the same at all projects. It seems advantageous to have a collection facility built into a dam so that the opening is flush with the face of the structure. Schools of fish move along the face of the dam and find the opening more easily than they do when the collection facility extends out into the forebay.

ROUND BUTTE RESERVOIR

While we have learned much in the past several years about the design of facilities for collecting juvenile salmonids, we still cannot be certain of successful collection at all projects. This is because all present facilities depend on fish congregating in a specific area of a reservoir, generally near the dam, for collection.

Conditions in some reservoirs may be such that fish will not congregate in any one area. A good example of this situation is Round Butte Reservoir on the Deschutes River. Round Butte Reservoir has three major water sources, the Metolius, Deschutes and Crooked rivers (Figure 3). A collection facility constructed as an integral part of the dam provides an attraction flow near the surface of the water at all pool levels experienced to date. An attraction flow of 400 cfs is provided, the highest at any facility in the state. In spite of this, collection of juvenile salmon is poor at Round Butte.
THE DIRECTION AND APPROXIMATE VELOCITY OF WATER CURRENTS IN SELECTED AREAS OF ROUND BUTTE RESERVOIR, JUNE 1965

FIGURE 3
Our studies showed that strong upreservoir surface water currents exist in the Metolius Arm of the reservoir (Korn, et al., 1967). Currents in the other arms generally move down reservoir. Salmon and steelhead tagged in two areas of the Metolius Arm and in the upper Deschutes Arm were recovered mainly in the upper Metolius. Few tagged fish were recovered at the collection facility at the dam. Fish were found scattered throughout the reservoir all year, even during the spring migration season. We feel water currents confuse fish at Round Butte preventing successful collection.

The quality of water in a reservoir is also of concern both from the standpoint of fish life in the reservoir and that in the stream below the dam. Water quality depends in part on the amount and quality of water flowing into the reservoir. There are several projects in Oregon, North Fork on the Clackamas River and Round Butte on the Deschutes River are two, which have moderately large amounts of high quality water entering the reservoirs throughout each summer.

In this context, high quality means cool, well-oxygenated water suitable for salmonids. There are also some reservoirs which have the opposite set of conditions. Fall Creek Reservoir in the Willamette system generally has little inflow in late summer and early fall. As a result, oxygen becomes depleted in the cool depths of the reservoir, and in the first 2 years of its existence (1966 and 1967) hydrogen sulfide (H₂S) formed. Juvenile salmon preferred the cool water found in the depths of the reservoir in late summer.

However, they were restricted to the warm surface water of the reservoir after the toxic H₂S formed in the cooler, deeper water. We were surprised to find that chinook salmon tolerated the 70-71°F surface water for extended periods while coho disappeared from the reservoir. We formerly believed that coho were more tolerant than chinook of extreme conditions, but this and other studies showed us that chinook tolerate higher water temperatures.

Fall Creek is a flood control reservoir which does not produce power. The regulating outlets are located at the base of the dam. The reservoir is drawn down in late summer to increase flows in the Willamette. When this was done in 1966, the initial year of operation, water containing H₂S was discharged into the stream below the dam. When discharges were high (several hundred cfs), there was no apparent ill effect on fish downstream. However, when discharges were reduced below 100 cfs, fish were killed. We believe that high discharges created turbulence immediately below the dam which dissipated the H₂S.

At low discharges, there was no turbulence and the toxic H₂S was
retained in the water for several miles downstream thus causing the fish kill. To alleviate this condition, discharges below 250 cfs were released through the downstream-migrant collection facilities which were located above the layer of water containing $\text{H}_2\text{S}$. 

In spite of water quality problems at Fall Creek, the reservoir appears to be a good producer of migrant-size chinook salmon. The down-stream-migrant facilities are only partly effective at collecting juvenile fish. However, it appears feasible to effect migration by a complete draw-down of the reservoir. Fall Creek can be drawn down completely to aid emigration of salmon since it does not produce electricity. This procedure could not be used at hydroelectric projects. In spite of having water quality considered borderline for salmon, we believe Fall Creek and other similar flood control reservoirs have good potential for producing chinook.

In summary, we believe serious problems are evident at the low head dams on the main Columbia and Snake rivers. However, exact causes of mortality are not well defined and more intensive research is needed. There are serious but better defined problems of passing fish at high head dams on the tributaries. We have shown that some reservoirs on tributaries of the lower Columbia River have great potential for producing migrant-size salmon; and we are gaining confidence in our ability to manage these impoundments so they will yield significant returns of adult fish.
LITERATURE CITED


In every phase of the hydrological cycle the quality of the water is affected. From precipitation to final discharge into the seas, various accumulations of contaminants change the composition of runoff. Some of the natural accumulation is harmless or beneficial; however, the use of water for domestic, municipal and industrial purposes by man produces undesirable changes in its composition. From the viewpoint of quality, man's use is the most critical step in its natural cycle.

The lakes, dams and rivers which supply the water for man's needs also dilute and carry the wastes from his environment to the next downstream population center's water supply or to the sea. Thermal quality degradation of these water supplies has been claimed resulting from the construction of new impoundments, poor designs and mismanagement of existing structures. The full influence of impoundments on water temperatures and other quality parameters should be better understood to help define reasonable limits for the control of thermal pollution for prediction of costs and benefits wrought by these structures.

**THERMAL STRATIFICATION**

It has been observed that when a reservoir is stratified, the flow regime and current patterns are greatly altered from the regime existing when the reservoir is homogeneous. A site study made by the T. V. A. showed that polluted water entering a reservoir would be propagated through the system as a distinct entity and not mix with impounded water. The effect was that minimal self purification of the polluted water took place. The contaminated water moved as a current, with observed velocities from 0.15 to 0.35 fps. through the series of reservoirs. A two year detention time had been estimated. However, during the time of the year when reservoirs are stratified, water flows through the system in less than 6 months. (1, 2)
Thermal stratification has been noted in impoundments, yet the necessary set of environmental circumstances that enhance the possibility of thermal stratification has not been completely delineated. (3) Thermal stratification is a layering of water resulting from temperatures--induced density differences. Considerable interest in the Pacific Northwest has been directed to the use of cold bottom waters discharged from stratified reservoirs for biological requirements and for industrial cooling purposes.

The classical pattern of thermal stratification in lakes or reservoirs are shown in figures 1 and 2. (4,5) The main factors affecting the thermal characteristics of a reservoir are its depth and the climatic regime of the regions. The temperature cycle can be summarized:

**Winter:** Reservoir isothermal with depth. Water at maximum density throughout; deep vertical motions established by small wind forces at the surfaces.

**Spring:** Warming of surface. Epilimnion and upper layers become uniform in temperature and relatively warm. Water circulates here and is turbulent. Hypolimnion--lower layer remains undisturbed and fairly cold. Thermocline--plane at which temperature decreases most rapidly with depth; also a zone of discontinuity between water masses. Thermocline subject to large vertical motions due to wind motions.

**Autumn:** Epilimnion cools and increases in thickness. Thermocline disappears; lake becomes isothermal.

**Winter:** Inverse of stratification is sometimes observed; in large-deep lakes heat storage is great and ice formation can be nil.

The impoundment of water will produce various temperature effects on both the reservoir water temperature and on the discharged downstream water temperature. These effects depend upon:

- volume of water impounded in relation to mean streamflow,
- surface area of impounded water,
- depth of impounded water,
- orientation of prevailing wind direction,
- shading,
- elevation of reservoir,
- temperature of inflow water with regard to temperature of impounded water,
- depth of water withdrawal. (10)
Seasonal variations in temperature gradients, Lake Mead, 1948.

FIGURE 1

Seasonal salinity distribution and circulation patterns, Lake Mead.

FIGURE 2
A modified energy budget equation used for predicting lakes or reservoirs temperatures states that for a given interval of time the net changes of energy in the body of water is: \( Q_n = Q_s - Q_b - Q_e - Q_h - Q_a \), where \( Q_n \) = net change of energy of the body of the water and

- \( Q_s \) = net incoming solar radiation
- \( Q_b \) = effective back radiation from water surface
- \( Q_e \) = energy loss due to evaporation
- \( Q_h \) = energy loss by conduction from water to air
- \( Q_a \) = energy advected into the water by tributary streams, precipitation, etc.

The ties between the terms in the energy budget and the factors affecting reservoirs are evident; however considerable meteorological data, taken over extended time periods are required to evaluate the terms of the energy balance. Present methods of predicting, in advance of construction, the probable temperature of a reservoir and its subsequent discharge has been at best only partially satisfying. Reliable prediction methods continue to be sought (11, 12, 13, 14, 15, 16).

**SELECTIVE WITHDRAWAL**

Most dams and reservoirs built today are designed to serve multiple purposes. Water quality must be controlled for domestic use, for recreation, for preservation of fish and wildlife, for irrigation, for power, and for industrial processes. Flood control requires a near empty reservoir. The use and/or storage of water for one of these purposes is often in conflict to the other users. Thermal and nuclear power plants, for example, need cool water for cooling of condensers and reactors. This water desired may be too cold for irrigation, biological needs or recreational uses. Since water quality in a reservoir varies with depth, a reservoir may have the water of required qualities to satisfy all of the different users and developed resources. A knowledge about stratified fluid flow may be the tool for predetermination and control of the released water quality.

Chemical effects are sometimes linked with the temperature quality parameter and density flows. Discharge of dissolved inorganic substances from reservoirs is generally the result of the selective withdrawal of the layers of water containing these substances. Some are beneficial, such as: dissolved oxygen, nitrogen and nutrients. Others may include phosphorous, sulphur, iron and manganese.

Concerning the increased fish mortality on the Columbia River during 1968, a recent hypothesis asserts that fish remain in waters with high amounts of dissolved nitrogen, and ultimately drown while under the influence of nitrogen narcosis. The increase of nitrogen is thought to be caused by high head discharge into deep pools— with the successive chaining
of reservoirs from head to pool, head to pool, etc., without sufficient travel
time for the decay of dissolved nitrogen.

It has been estimated that $2 \times 10^9$ tons of sediment accumulated in
Hoover Dam on the Colorado River during the first 14 years of operation,
reducing the maximum depth of the reservoir from 565 to 460 feet. The
storage capacity was reduced 5 percent by these density flows. The need
for increased knowledge in the field of water resources and reservoir opera-
tions is vital to secure a more economic usage of present and future water
supplies.

THE DENSIO METRIC FROUDE NUMBER

Yih (17) found that withdrawal would be selective if the densiometric
Froude number was less than a critical value ($F_{crit} \leq \frac{1}{11} = 0.318$) depending on
the geometry of the outlet.

$$F_{crit} = \frac{V}{\sqrt{(gd)(\rho_{max} - \rho_{min})/\rho_{max}}}$$

where

- $V$ = velocity at orifice
- $d$ = depth of orifice
- $g$ = gravitational constant
- $\rho_{max},\rho_{min}$ = densities of flow field

The analytical basis for the critical Froude number was derived
by assuming a quasi potential stratified flow field. Experimental justifica-
tion for $F_{crit}$ was also obtained (18). These physical and analytical models
in their limited nature do not include the influence of winds; geometrical
effects--slope of inflow, shape of bed, size of impoundment; soils; weather
--rainfall, frosts or orientation. Their results are meaningful however
because they show that selective withdrawal can take place in natural reser-
voirs--based on the rate of discharge on the location of discharge.

The movie shows the complexity of selective withdrawal flows.
This physical study at Oregon State University was done by L. S. Slotta
and T. Spurkland (1) and is being continued by H. Elwin. This investigation
shows that the withdrawal layers will be at the elevation of the outlet as long
as there is no obstruction to the flow such as a seamount or submerged
weir. If there is an obstruction the discharge on the upstream side will
take place at the elevation of the top of the obstruction. Discharge will
continue at the outlet level on the downstream sides, but as water is with-
drawn it will be replaced by water from the upstream side. The "upstream"
waters may not meet the quality standards specified by the user because
it will differ in quality from the water initially discharged at that depth.
Note the similarity of the movie to figures 1 and 2. Quantitative
support for these studies is given by Harleman and Churchill (19, 20).

The problems of waste (e.g., potato wastes) being discharged during the autumn into cold stream waters having low flows creates the hazard of having these wastes settle or remain in static septic condition within an impoundment having natural barriers. These wastes subsequently would not be washed from the reservoir with high flood flows that occur in the winter or spring because they would be passed over by the less dense discharges.

**WIND CURRENTS**

Surface disturbances, caused by wind or wave action certainly affect internal current regimes of impoundments probably similar to the effects resulting from bottom irregularities. Two types of currents are generally present in reservoirs: wind driven circulation and the water movement noted in selective withdrawal from inlet to outlet. Surface temperatures are radically changed by wind driven circulation.

However, the most important deep-water movement from winds on stratified waters is thought to result in internal seiches where the hypolimnion may surge as much as 50-60 feet in deep reservoirs. However it has been noted that little mixing or temperature increases occur in the stable hypolimnion. Turbine intakes generally are located in the hypolimnion; subsequently, limited fluctuations of the selective layer are expected from wave actions.

**SUMMARY QUESTION**

Do stream temperatures increase or decrease as a result of constructed reservoirs?

Before launching into this question I wish to place caution on the danger of excessive generalizations from results of other areas. There is always a tendency to take the experiences of one area and apply it to another --that is sometimes the "art" of engineering. However, temporal changes for one region may vary considerably for that of another. Perhaps results from drainage-reservoir areas in closer proximity are not mutually interchangeable because of the difference of inflows and orientation.

Locally, it is reported that the Green Peter Dam releases waters too cold for spawning of migrating salmon. Ideal salmon temperatures are 45-60°F for attractive migration, 42.5-55°F for spawning, 32-55°F for incubation and 50-60°F for fingerling productivity discharge. It is not that the Green Peter reservoir has totally reduced the discharge stream temperatures, but that the temperatures have been lowered during the period of salmon migration and spawning that is detrimental. This reservoir and its
streams serve in the role of tributary for flow augmentation and for reducing the temperatures of a main artery flow. Relief for this thermal problem is expected from construction of another dam, on an adjacent tributary, having multiple outlets. Then the warm surface waters of one could be mixed with the cold, deep waters of the other to provide ideal fish-spawning temperature conditions.

Cases have occurred in California (Folsom Dam, Whiskey Town Reservoir) where the large surface area and volume is warmed during the summer. The power outlets are situated at considerable depth which results in withdrawal of cold water during the summer, leaving the sun-warmed surface waters. The discharge of these remaining waters unfortunately coincide with the arrival of migrant salmon; subsequently, low production of salmon eggs and fry have been the result.

The operation of these and future reservoirs should include release from upper levels during the spring and summer months and colder releases or combinations during the expected fall salmon runs. The opposite release pattern could be proposed for the "northern" type (Green Peter) reservoir if facilities to do this were available.

Jaske (21) relates about the Hanford studies on the Columbia River....

"One conclusion we have drawn from our entire work--and we drew this very reluctantly and in the face of some opinion to the contrary--is that the erection of dams and reservoirs on the main stem rivers in the Columbia Basin, notably the Columbia and the Snake Rivers, has served to increase the temperature of these rivers. This temperature increase we estimate in the range of 1 to 2 degrees centigrade for each major structure that has been erected"

Silvester (10) states the Grand Coulee Dam on the Columbia has produced a warming effect of about 7°F maximum during the winter and a cooling effect in the summer (March to September), of about 3°F.

In a study of Tennessee Valley reservoirs with deep withdrawal depths, Churchill (20) observed a lowering of downstream temperatures by 15°C below normal summer stream temperatures.

To summarize and generalize, one can say "that large deep impoundments will decrease downstream water temperatures in summer and increase them in the winter, if withdrawal depths are low; that shallow impoundments with large surface areas will increase downstream water temperatures in the summer; that water periodically withdrawn from the surface of a reservoir will increase downstream temperatures; that a reduc-
tion in normal streamflow below an impoundment will cause marked temperature increases; and that "run-of-river" impoundments, when the surface area has not been markedly increased over the normal river area, will produce only small increases in downstream water temperatures" (10).

SIMULATION MODELS

Present models have been restrictive; extensions of experimental and simulation work on stratified reservoirs will need to consider surface disturbances. As more factors are included in the modeling schemes, the combined effect on the flow may be more complex than expected from simple superposition of separate effects. Mathematical models are being generated for analysis by digital and analog computers. These approaches may provide realistic-graphic results to serve as analytic descriptions of flow patterns in thermally stratified reservoirs.

NUCLEAR PLANTS

Editorial headlines "Eugene approves Nuclear Power Plant" have recently appeared in the Corvallis Gazette Times. "This (authority to sell revenue bonds) is the first step in the Eugene proposal which may cause considerable controversy about the possibility of dumping thermally heated water into the Willamette river. How much this might raise the temperature or what other damage it might do, if any, is still open to question."

There are many alternate designs for nuclear power plants. Some use circulation waters for cooling which are discharged into streams; some waters are recirculated in cooling ponds created for this purpose; others may use evaporative cooling towers to improve heat efficiencies with no discharge. I do not know what plant designs are being considered by EWEB, but in my opinion it is the responsibility of "the engineer" to create the alternatives for a promising solution to the thermal problem. The following is to briefly relate about such thermal threats and the problems faced in the release of heated waters into rivers.

What amount of energy and flow are we speaking about? The rate at which circulation water is heated is roughly proportional to the power output of the turbogenerator, heating 6-9°C above inlet temperatures when the generator yields maximum output.

Plants in the range 125,000 - 250,000 kilowatts are not uncommon with intake rates of 30 M³/sec. (River flow rates vary for these plants to 25-50 M³/sec.) Everts (22) relates "thermal pollution is rapidly becoming a problem in the Delaware River Basin where 3-1/2 billion gals. of water daily (5400 cfs) are used for thermal electric power in the basin." Nuclear power stations in England range from Berkeley--300 megawatts, 1000 cfs;
Oldberry, 550 megawatts, 1050 cfs and Blackrock proposed at 2000 megawatts at 3000 cfs. Japanese plants have output of 2000 megawatts using 1000 M³/sec.

In the most modern of thermal plants roughly 40% of the heat content of the fuel is transformed into electricity. More than 50% of the heat content must be returned to a "cold source"—water or air. For a two million kilowatt plant an equivalent of two million tons of coal of returned heat must be dissipated. If cold water is taken into the condenser cooling system a remarkable savings of fuel expenses can be expected due to improved heat efficiencies of the turbine. Again, the cooling water discharged after passing through the condensers can be expected to be 9°C higher than the water temperature at the intake.

**TRAVEL DISTANCE REQUIRED**

The experiences of French, British and Japanese relate that when warm water is returned to a slow flowing or calm river it does not easily merge with the cold water; in particular the warmed water tends to spread across the surface.

Marked two-layered stratifications have been noted 400 meters downstream from French plants in a river 60 meters wide by 5 meters deep. The time of travel to complete the mixing may be several hours. Note Goubet's (23) data below for the Seine River, which indicates only 8-12% of the heat had been dispersed over the selected reach of the river.

| Rate of flow of Seine (cubic metre/sec) | 250 | 115 | 65 | 55 | 38 | 28 |
| Flow offtake by the power plant (cubic metre/sec) | 10 | 10 | 10 | 10 | 10 | 10 |
| Temperature difference at exit from plant (°C) | 6.9 | 7.0 | 6.2 | 6.9 | 6.8 | 7.3 |
| Temperature difference 1400 metres down stream (°C) | 0.9 | 0.5 | 0.3 | 0.0 | 0.5 | 1.0 |
| Time taken for water to travel this distance (hours) | 0.7 | 1.5 | 2.5 | 2.9 | 4.2 | 5.7 |

Japanese research on nuclear heated discharges into the seas support the findings above. Wada has calculated the maximum range of outflow waters in terms of distance and area (24). His data is tabulated below:
Calculated maximum range of influence of the flow by the outfall of warmed cooling water.

<table>
<thead>
<tr>
<th>Cooling water flow Q (m³/s)</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>the maximum range of influence of the flow (distance from the outlets : m)</td>
<td>60</td>
<td>120</td>
<td>180</td>
<td>240</td>
<td>300</td>
</tr>
</tbody>
</table>

Predicted maximum range of influence of the water temperature rise by the outfall of warmed cooling water.

<table>
<thead>
<tr>
<th>Cooling water flow Q (m³/s)</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>the maximum range of influence in which the water temperature of the sea basin rises 1°C</td>
<td>460</td>
<td>920</td>
<td>1380</td>
<td>1840</td>
<td>2300</td>
</tr>
<tr>
<td>its influenced area : m²</td>
<td>$10^4$</td>
<td>$10^4$</td>
<td>$10^4$</td>
<td>$10^4$</td>
<td>$10^4$</td>
</tr>
</tbody>
</table>

Wada’s work helps to complete the picture if heated discharges were dumped into a stream leading into a stratified reservoir.

If heated water is allowed to return to the Willamette one may wonder about its effect on fish breeding and biological growth along the river. The French experience has been that no "heat barrier" to fish is presented in the immediate vicinity of the heated water outfall. However the real problem is the temperature reached by the river after the mixing process is complete and as the river continues to warm naturally as it continues to flow downstream.

Solutions to the thermal pollution problem have been offered; use of heated waters for irrigation would help in producing better crops—and a way of distributing thermal waste. The figures by Silvester (10) illustrate the fate of water diverted for irrigation in the Yakima Valley:

"On the average, water temperature increases of 3.5°F. are experienced in 37 miles of main canal flow.

Irrigation Water Temperature, Yakima Valley, August 1959-1960 -- Mean Values in °F.

Diverted water to Kittitas, Roza, Wapato and Sunnyside
Main Canals . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 61.5°F
Water after traveling average of 37 miles in main canals . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 65.0°F*
Water in sub-laterals as applied to land; average of 7. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 63.7°F*
Water in sub-surface drains; average of 7 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 58.4°F

74
Water in open drains as discharged to Yakima R;
average of \( \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \) 67.0°

*These two figures are not comparable as sampling stations are different.

This is somewhat greater than would have been found in the river for the same flow distance if the water had not been diverted."

The solution to heated irrigation waters returning to the main channel would be acute in the late summer fall months during normal low flows. Perhaps collecting irrigation returns in subsurface drains will keep the temperatures of these flows low. Suggestions for large storage recirculation ponds are in order for thermal power generators. Some think (facetiously) that it would be nice if insulated pipe networks would be installed to provide heat and heated water to homes throughout the Willamette Valley; also, heat pumps could be devised to air condition homes when necessary. An insulated pipe network underground could be used in circulation of flow and cooling. But then why would these communities need added electric power?

I have recently seen thermal heating used in greenhouses in The Netherlands on a large scale, keeping Holland the garden basket of Northern Europe. Greenhouses cover several square miles on the edge of The Hague and are heated internally. The request for heated water to homes or truck farms in the Willamette Valley does not seem as ludicrous after seeing the results grown by the Dutch.

**SUMMARY**

The thermal problems of reservoirs and rivers are a complicated field of study and are quite similar. Some of the imperfections of present thermal modeling are insuperable. However continued research on densiometric and turbulent processes will help improve the interpretation of scale model to prototype results: physical and mathematical modeling and adequate field surveys are advised for thermal/stratification problems associated with major reservoir impoundments and power station developments on rivers.
REFERENCES


Reservoirs are the practical answer of the engineer to many perceived water problems in society. There are often other solutions to these same problems, and there may be other problems that are more important than the problem the reservoir is designed to solve. A full consideration of the impact of reservoirs leads one to questions of social priorities. Professor Hogg pointed out to this group last year that there are many social and cultural impacts of reservoirs in addition to their economic consequences. It becomes appropriate, then, that the social scientist become involved in this series of seminars. The social scientist may be more aware than some of the priority question. He should be the best qualified to estimate social consequences, but there is no particular reason why he is any better qualified than any other to say what national or group priorities "should" or "ought" to be.

The economist, more than any other social scientist, has been involved in water resources planning. Until recently, however, it would be very difficult to make a case that economists have had much impact in this connection. Nevertheless, there is a considerable body of literature on the economics of project evaluation. We will draw on this literature in this seminar paper. Most of what will be said is accepted by the economics profession, and is subject to little debate within the profession. Where this is not likely to be the case, I will so indicate. There may also be some things said that other disciplines will not accept. I will not note these, because this is an interdisciplinary group, and such items should come up for further discussion.

**THE OPPORTUNITY COST CONCEPT**

One of the most basic notions underlying the economics of project construction is that of opportunity cost. When a reservoir is constructed,
certain items of value are withdrawn from the income stream of the nation. The opportunity cost of the reservoir is what these resources would have returned to the economy if they had not been used to construct the reservoir. If unemployed labor and idle capital is utilized, it is obvious the opportunity cost is much less than if they otherwise would have been fully employed. The people who pay the cost of the reservoir are those who would have benefited if the resources had been used in another way. Let us speculate as to who these people might be. We cannot answer definitely, because it makes a great deal of difference as to what the situation is with respect to such things as inflation and the level of employment.

It also makes a difference whether public or private funds are being used. If public funds are used, one must speculate regarding what other government programs are sacrificed. If funds are used that would have generated economic activity in the private sector, there are obviously those who would have benefited from such activity. It is these "unseen alternatives" that are the principal concern of the economist. And it is the people who would benefit from these "unseen alternatives" that really "pay" for reservoirs.

The major source of funds for our large reservoirs is the Federal Treasury. If we want to get at the opportunity cost, we must try to imagine what would happen in the Federal establishment if the reservoir were not built. There are two possibilities. One is that other Federal programs are smaller as a result of the reservoir appropriation. Another is that the Federal budget is larger as a result of the reservoir, and that other programs are not sacrificed. Of course, combinations of the two possibilities can also exist.

If other Federal programs are smaller as a result of reservoir expenditures, one can identify those who are paying the cost by looking at these other Federal programs. The most rapidly growing facet of the Federal budget concerns those programs related to poverty and urban affairs.

If the funds are withdrawn from the private sector, they would be from those who are paying taxes, assuming a balanced budget. If the budget is not balanced, and if the expenditure is financed by increased debt, inflation may be the consequence. Generally speaking, those who are in debt benefit from inflation, relative to those who are not.

Perhaps enough has been said to make it abundantly clear that who "pays" for reservoirs is a terribly complex matter. It is clear in principle, but in practice it gets quite messy. Nevertheless, if we really wanted to know, we could estimate the economic impact at a fraction of the cost of one of our large reservoirs.
REIMBURSABLE AND NON-REIMBURSABLE COSTS

Some of the costs of reservoirs from the Federal Treasury are recovered. This is done by charging beneficiaries part or all of the cost of the service they enjoy. The following are partly reimbursable: irrigation, power generation, municipal and industrial water. Examples of non-reimbursable uses are flood control, recreation, and pollution abatement. Cost-sharing of the latter group may occur at different levels of government. However, it is almost impossible to generalize extensively about cost-sharing, because the rules and regulations are not consistent among agencies. However, the precedence is established for shifting some of the cost from the Federal to the local level.

As a practical matter, power is the use which carries the heavy burden among those uses which are reimbursable. One of the big resource economics battles recently pertained to the Basin Account notion. This was a provision that would permit power revenues within a basin to be used to pay part of the cost of irrigation development within the basin, whether it was a part of the same project or not.

The Bureau of Reclamation program, with respect to irrigation development, requires the principal to be repaid. An interest subsidy exists, however. This interest subsidy can amount to more than the principal for certain loans. For example, a loan for $1,000 at 4 percent interest, amortized over a 50-year period, will require a total interest payment of about $1,300.

Thus, it is a safe conclusion that the people who benefit from reservoirs built from public funds are not, generally speaking, the people who bear the cost of these reservoirs. Some of the beneficiaries may bear part of the costs. The remainder of the cost is borne by the public at large, as outlined above.

ECONOMIC FEASIBILITY AND FINANCIAL FEASIBILITY

A project currently has to meet two tests -- economic and financial feasibility. For a project to be economically feasible, the economic benefits must exceed the economic costs, regardless of the incidence of either the benefits or the costs. To be financially feasible, the reimbursable benefits must exceed the reimbursable costs. Both concepts of feasibility place a constraint on project construction in practice. It can easily be seen, however, that pressure is always present to shift cost allocation to the non-reimbursable functions in the case of multiple purpose projects when both types of benefits are present. It is my understanding that on Federal projects, some variant of the separable-costs remaining benefits method is used to allocate costs.
At the present time the principal policy questions on the economics of project evaluation pertain to (1) cost-sharing and (2) financial feasibility. There will always be pressure, of course, to reduce the financial requirements of a project as much as possible. However, as water becomes increasingly scarce, state and local units of government may be willing to engage in a higher degree of cost-sharing. Recent action by the State of California is a case in point. The State of Arizona also made noises about financing the Central Arizona project themselves. However, the available evidence suggests this would not have been an economically feasible project for that state.

The common index of economic feasibility is, of course, the benefit-cost ratio. The benefit-cost ratio, in theory, is supposed to indicate whether the economic benefits exceed the economic costs. A purpose of the discount rate, in theory, is to measure the opportunity costs of the public funds used over time.

THE BENEFITS OF RESERVOIRS

We will not dwell extensively on beneficiaries of reservoirs. However, to be complete, we need to mention both direct and indirect benefits. Direct benefits are those that have been discussed to this point. Indirect benefits are those that result from the economic activity generated by reservoirs, even though the beneficiary is not a water user. The supplier of boats to the reservoir recreationists would be an example. Generally speaking, indirect beneficiaries do not pay reservoir costs. However, one of the principal arguments for cost-sharing by state and local units of government is that this is a way of involving these beneficiaries in the financial repayment picture. The phenomena of indirect beneficiaries may well explain why Chambers of Commerce have typically been much more enthusiastic about irrigation projects than farmers themselves.
A Schematic Presentation

BENEFITS

Direct
- Re-imburseable
- Nonre-imburseable

Indirect
- "Stemming From"
- "Induced By"
A Schematic Presentation

COSTS
(Benefits Foregone)
Read economic costs are opportunity costs or benefits foregone

Public
- Reduced Public Programs
- Reduced Private Spending

Private
- Consumption
- Production

or

Increased Public Debt
REFERENCES


Recreation and Reservoirs

Your panel today consists of two people who could represent opposing factions in a growing conflict involving reservoir recreation. One of us represents a Federal agency which has constructed, and is operating, a Willamette Basin reservoir system which is being used for recreation but is not authorized for that purpose. The other is a member and representative of the using public—the people who need and want full use of all of the potentials of the project. You can readily understand, before this session is over if not at this moment, why we might be at odds if each of us held to a narrow viewpoint in considering what could or should be done.

We hope to dispel any such thoughts and, in doing so, point the way to a possible means of resolving or even preventing any growing conflict. We have a close-to-home example of a potentially serious conflict, and a possible solution through the taking of four basic steps, to illustrate our point.

That example is Fern Ridge Reservoir, on Long Tom River within 15 minutes drive from Eugene and about 45 minutes from Corvallis.

Background Data

Fern Ridge Dam and Reservoir project is one unit of a 14-dam system of multiple-purpose projects for Willamette River Basin. Construction of the project was authorized by Congress in the Flood Control Act of 1938. The authorization, based on a Corps of Engineers' report published in 1938 as House Document 544, 75th Congress, 3d session, provides for flood control and storage of water for navigation and irrigation as the primary project purposes.

Fern Ridge Dam and all of the appurtenant works represent an investment of about $6.5 million. It has been in operation for about 27 years.
During that time, it has prevented something on the order of $53 million of flood damages; a large part of that total (about $39 million) was realized in December 1964. Average annual future flood control benefits probably will be in the order of $1.5 million.

Economic considerations, based on those figures alone, could lead us to conclude that Fern Ridge is such a good flood control investment that we should not allow any other use to detract from its maximum flood control capability. On the other hand, recreation usage began shortly after World War II and has increased at an almost fantastic rate. In 1967 there were almost 1.2 million recreation visits to the project; this year, in spite of "unusual" weather during the recreation season, attendance probably will be about 1.25 million visits. At the arbitrary, and perhaps conservative, unit benefit values assigned to recreation attendance, an annual visitation equal to the average of the last 2 years would have an annual benefit value of about $1.6 million. Such a figure would compare favorably with the projected average annual flood control benefit, but would be a highly conservative estimate of Fern Ridge's recreation potential.

Before going further, let us take a look at what Fern Ridge Dam and Reservoir project is, and how it is operated.

The project consists principally of an earth dam about 46 feet in height by about 1.2 miles in length, which creates a reservoir with a maximum surface area of about 10,400 acres. At maximum pool level it has about 116,000 acre-feet of storage space. Of that total about 109,000 acre-feet are usable for flood control and about 94,000 acre-feet are usable to store water for the authorized irrigation and navigation uses. The pool area, and adjoining project lands, are available to the general public for recreation uses, from picnicking to swimming, water skiing, and sailboat regattas.

Some of the project lands have been developed for recreation use, even though recreation is not an authorized project purpose. That development, which represents an investment to date of about $1 million, has been made principally by the Corps of Engineers and Lane County. The economic justification for such a total expenditure is evident when we consider the estimated $1.6 million annual benefit from use now being made of the pool and the recreation development.

CONFLICTS AND PROBLEMS

With a water area of more than 10,000 acres, about $1 million invested in recreation development, a growing recreation attendance, and more land available for recreation development and use, what is the conflict? What is the problem? To understand, we need to look at how the
The project is operated to serve the authorized purposes of flood control, irrigation, and navigation.

Control of floods requires the availability, at the start of each flood, of enough empty storage space to contain the flood runoff. The irrigation and navigation functions can be served only by having available enough stored water (filled storage space) to satisfy annual needs. Thus, even before recreation is considered, we seem to have a conflict. That apparent conflict has been reasonably well resolved by a seasonal operation schedule which has been developed and tested to take advantage of the seasonal weather pattern.

This schedule calls for an empty reservoir, or a maximum of available storage space, during the major flood season from about 15 November until 1 February and provides for gradual filling between that date and about mid-April. It permits the reservoir to remain full, except as reduced by evaporation and withdrawal for minimum streamflow, navigation, and irrigation, until the end of the summer. Beginning about 1 October, a full pool would have to be drawn down at a rate which would empty all flood control space by mid-November. By such operation we can meet flood control needs and, in each year, fill storage space so that water will be available for irrigation and navigation. Except for summer withdrawal of water, the resulting pool level schedule would be appropriate to maximum recreation use during the normal recreation season. We have been able to approximate that condition in most years to date, because the irrigation demand has been small or nonexistent and navigation needs could be served from other reservoirs.

However, evaporation plus minimum streamflow releases and future withdrawals for navigation and irrigation would change the recreation picture considerably. In an average future year the pool would be full for only a few days, then would be drawn down continuously and at a rate which would use all conservation storage by the end of the summer. In the occasional unusually dry year when the pool could not be filled, the recreation picture would be even worse. We—the Corps of Engineers—understand that the recreation potential of Fern Ridge is seriously reduced as soon as the pool level is lowered a few feet. This is understandable in consideration of the flat topography and shallow water along most of the shoreline. When we consider the average and extreme future drawdown conditions in that light, the problem and conflict are evident. As soon as irrigation demands grow appreciably, we will be required by the present authorization, to release stored water for that purpose. Also, we will have less ability to use water from other reservoirs to offset the need for navigation withdrawals from Fern Ridge.

Irrigation demand is growing, at first slowly, but now by leaps
and bounds. The first contract for stored water from Fern Ridge for irrigation was signed by the Bureau of Reclamation in 1954. As of the spring of 1967 the Bureau had 28 contracts, which could have used almost 5,000 acre-feet of stored water. By next summer, contracts are expected to be in force for something in the order of 14,000 acre-feet of water.

Based on past experience, however, actual use will be somewhat less; perhaps 6,500 acre-feet, as compared to about 2,100 acre-feet actually used in 1967. Even though full contract amounts are not yet being used, the trend to rapidly increasing use is obvious. Equally obvious is the fact that with such increases will come an increasingly rapid annual drawdown of pool level and an increasingly rapid annual deterioration of conditions for recreation. Further, the time apparently will not be long—perhaps as short as 10-15 years—until Fern Ridge annual drawdown will be severe. If that day, and that condition, come to pass, the conflict will be obvious.

Who would win such a conflict? Would the irrigators demand and get the water, under present project authorization? Would the recreationists, a far larger group, prevail on the Congress to delete the irrigation authorization?

Whichever might happen, both groups would lose in the long run. They would lose the full use of a resource, no matter which way the decision was made—irrigators swim, and picnic, and water ski, just the same as anyone else!

**ALTERNATIVE SOLUTIONS**

If both groups are not to enter into a losing battle, what is to be done? What alternatives are available? Both the problem and the matter of alternatives are being explored. The answer is not yet available, but hopefully is near. Please note, however, that the hoped-for answer we will discuss is with specific reference to the specific problem at Fern Ridge. Both the nature of the problem and the alternative solutions, if any, may be vastly different at other reservoirs.

There are two basic alternatives. Both involve the provision of additional water to take the place of storage for irrigation in Fern Ridge. Either might be developed to the full, or some combination of the two might best do the job. The two alternatives are:

1. **Pump water from Willamette River.** This would entail some use of natural flows in the Willamette early in the season, and use of water from upstream Willamette storage for the rest of the season. This would not necessarily take care of navigation withdrawals or evaporation.
2. **Provide additional storage upstream from Fern Ridge.** Such storage would be so located as to offset evaporation and withdrawals for minimum flow, navigation, and irrigation, if enough storage could be developed.

**PROCEDURE FOR SOLUTIONS**

As was stated earlier, the Fern Ridge problem and the available alternative solutions are not necessarily the same in detail as for other reservoirs where conflicts of use may be developing. Neither are the procedures, in exact detail, typical of what might be done in other cases. Nonetheless, the principles and the procedural steps involved are basic. The steps being followed are:

1. Determine the nature and magnitude of the problem and the specific needs involved.
2. Determine what resources or potentials are available as alternatives for development to satisfy the needs involved.
3. Evaluate the development alternatives which are available, considering cost of development, degree to which needs of the area could be satisfied, and the extent of local participation which would be required for each alternative.
4. Inform the using public of the alternatives, determine their views, and reach a conclusion as to actions to be taken, and by whom.

In the case of the Fern Ridge Reservoir, those steps are a part of an overall comprehensive study of water and related land resources for Willametter River Basin. The study is being cooperated in by about 35 State and Federal agencies. It is scheduled for completion in mid-1969. Following study completion recommendations will be made in the Congress for any justifiable new work, or project modifications, for which required local cooperation is available.

As an essential element in avoiding conflict, study of the Fern Ridge problem is being participated in by the using public. Mr. Fraser is chairman of the "Future of Fern Ridge Committee" which is working closely with the study group. He will describe the situation as the users of Fern Ridge see it, and tell you what the users are doing to assist in resolving or preventing the conflict.
I'm Robert Fraser, chairman of the Future of Fern Ridge Committee—a 17-man group representing local interests in Lane and Benton counties.

It should be clear from Mr. Stewart's discussion that a potential conflict exists concerning the use of Fern Ridge Reservoir. Let me make it equally clear that the committee which I represent is concerned with finding a solution which is in the best interest of the people at large. We are not a recreation committee, nor an irrigation committee, nor for that matter are we a Corps of Engineers committee—we believe that the purpose of government is to serve the interests of the people as a whole.

We further believe that projects constructed with public tax money should serve public needs. If the public needs changes, we feel it is both proper and necessary that government agencies be responsive to that change. We are not anti-government or anti-establishment, but we do feel a close kinship to the Bishop of Sheffield who said: "All governments are like wheelbarrows, useful instruments, but they need to be pushed".

In fairness to Mr. Stewart, I must say that the Future of Fern Ridge Committee was formed at the request of the Willamette Basin Task Force, a group of state and federal agencies studying water resource problems in this area. The various agencies, including the Corps of Engineers, are aware that any solution which does not recognize the various local interests is doomed to failure. It is our committee's purpose to make local needs known.

The Future of Fern Ridge executive committee is composed of 17 people representing the broadest range of interests we could put together. We have irrigation people, recreation people; we have recreationists who
farm and irrigationists who sail; we have businessmen, lawyers, and conservationists. I think the only thing we left out was a college professor. We in the committee serve at the discretion of what is termed the "Committee of the Whole," membership in which is open to anyone interested in Fern Ridge.

**RECREATIONAL ASSET**

Even though recreation was not a part of the authorizing of the construction of Fern Ridge, recreational use has developed to where there is in excess of one million visits yearly. The popularity of Fern Ridge comes from its close proximity to the Eugene-Springfield area, from its suitability for boating, especially sailing, because of favorable wind conditions, from its shallow depth whereby the water is warmer than other reservoirs, and significantly from recreational improvements of some one million dollars in parks, boat launching facilities, etc. Fern Ridge is a recreational asset to Eugene, to Lane and Benton Counties, and to the state.

The area below Fern Ridge includes many thousands of acres of farmland which are not only suitable for irrigation, but which because of changing cropping practices and most importantly increasing tax loads, must be converted to crops which will return higher monetary yields. In authorizing the construction of Fern Ridge, the Congress foresaw a need for utilizing some 50,000 acre-feet or approximately one-half the storage of the reservoir for irrigation. It is in the interest of Eugene, of Lane and Benton Counties, and the state that these lands be irrigated.

The problem is simple, there are conflicting demands on the stored water. The solution, however, is not simple. Each potential solution gives rise to new problems. We have under consideration, several possibilities.

It is engineeringly feasible to pump water from the Willamette River into the millrace which flows through Eugene and which empties into Amazon Creek which in turn empties into Fern Ridge. Under this system, water which is withdrawn for irrigation could be replaced from the Willamette River. This is basically a local action program.

**COSTS ARE A PROBLEM**

Problems are basically financial and legal. The cost of pumping equipment, pipelines, right-of-ways, etc. would exceed a million dollars, and monthly pumping costs might run as high as $15,000 during peak months. Who will pay the cost? How would it be assessed and collected? What would be the reaction of landowners along the mill stream to turning the placid canoeing waters into a relatively swift moving canal?
Another possibility involves the proposed Eugene Water and Electric Board thermal generating plant which the voters recently authorized. A possible location of the plant being discussed is near the confluence of the McKenzie River and Willamette River. Cooling water which will be a necessary part of the plant could be utilized to irrigate the land which might otherwise utilize Fern Ridge water.

There are problems here too. Who pays? Would people whose basic interest is recreation be willing to pay for delivering irrigation water? What guarantees would the recreationist have that future irrigation developers would not present a claim to Fern Ridge water after the supply from the Willamette has been utilized?

Another possibility is storage upstream from Fern Ridge to restore waters utilized for irrigation. There are several reservoir sites which could store a partial replacement for irrigation drawdown. Here the problems are financial, legal, and a matter of time. There is a reasonable doubt that the federal construction agencies could construct a project in less than 10-15 years even if problems of economic justification could be solved (there is considerable doubt that under present conditions any major upstream storage could be developed).

At this time we do not have a solution. There is a feeling among some members of our committee that the various possibilities are not alternatives, rather they will all in time be a part of the long-range solution. It may be that eventually we will need both storage above Fern Ridge and diversion from the Willamette.

The increasing rate of irrigation development and the resultant drawdown of the Fern Ridge pool does not allow us to throw up our hands because the solutions are not easy - not unless we can convince water skiers that stumps make for challenges, convince sailors that running aground strengthens their souls, and convince park users that a hundred yards of mud is a good way to keep the kids out of the water.

**RAISING CAPITAL**

There are two requirements which are common to any solution. The first is money. Obviously any local solution, such as pumping from the Willamette, would require complete local financing. It is equally true, though it may not be as well known, that any solution involving federal participation, such as construction of new storage upstream from Fern Ridge, would also require partial local financing. Under Public Law 89-72, one-half of all separable costs of the recreation aspects of a project must be borne by non-federal interests. Also the recreation aspects of a project cannot exceed 50% of the total cost.
In other words, at least 50% of the cost of construction of a storage project must be attributable to flood control, irrigation, navigation, or a like function. Thus, if a project could be developed and authorized, local interest would have to fund 50% of the separable recreation costs. In the case of the Noti site which is under consideration this might run 5-10 million dollars.

Capital could be raised either by taxing or by users' fees. Since those people using the reservoir come from throughout the state and even out of state, it appears that a user's fee might be most appropriate.

The second common requirement to any solution is for a legal entity which could raise capital and enter into contracts either with the government or private organization. This legal entity could be at an existing governmental level such as a county or a new creation such as water control district or recreation district. Even this need which is a part of any solution is not without problems.

Under present statutes, a recreation district can only be in one county. Fern Ridge is not a single county asset or problem. There is also some question whether the public would desire the creation of a new district with power to levy additional taxes.

**SUMMARY**

From the users' viewpoint, the problem is straightforward. We must serve both the recreation and irrigation interests for both are clearly in the public interest.

We in the committee are still idealistic enough to believe that men of good will can find a solution which will serve the public at large, and we are still pragmatic enough to know that the solution to complex problems never comes easy. We also believe that the Corps of Engineers viewpoint must, in common with us, be that of the general public. We believe it is our responsibility to insure that our governmental wheelbarrows are in fact useful tools, for the Bishop may have also speculated that loaded wheelbarrows run downhill by themselves.

It is best that those of us concerned with the cargo go along to steer.
Presented December 5, 1968 by FRED D. GUSTAFSON, Chief Engineer, State Water Resources Board, Salem, Oregon.

State's Role in Reservoir Development

Oregon's role in reservoir development initially was shaped by several events both before and immediately following the turn of the century. The Act of Congress of July 26, 1866 recognized a right to the use of water as independent of any interest in or title to land, and assured "protection to this right whenever it has been vested by priority of possession, provided the 'local customs, laws and decisions of the courts' recognize such a right and such a mode of acquiring it." (Mills, page 13.)

"The Desert Land Act of 1877 (provided) that 'all surplus water from all sources of water supply upon public lands and not navigable, shall remain and be held free from the appropriation and use of the public for irrigation, mining, and manufacturing purposes, subject to existing rights.'" (Lewis, page 23.) John H. Lewis, incidentally, was State Engineer of Oregon from 1905-1918.

By Act of Congress, dated August 18, 1894, the Carey Act was approved. This act, together with subsequent amendments, provided that the United States would grant to the state, free of cost, land to the extent of 1,000,000 acres provided the state would assume the responsibility of its thorough reclamation and disposal to actual settlers in tracts not to exceed 160 acres in extent. Oregon's acceptance of the conditions of Section 4 of this act carried with it the implicit need to adopt legislation that would define local customs and establish water laws.

Finally, the Federal Reclamation Act of 1902 provided "that the right to the use of water acquired under the provisions of this act shall be appurtenant to the land irrigated, and beneficial use shall be the basis, the measure, and the limit of the right." (Lewis, page 23.)
These four acts set forth certain principles related to control of streams cited by John Lewis in his 1907 report to the Governor on "The Need for Water Legislation in Oregon". These principles helped lay the groundwork for Oregon's adoption of the Water Code of 1909 and for a cooperative effort between the State of Oregon and the U. S. Bureau of Reclamation, originally known as the U. S. Reclamation Service, that continues to this date—in spirit if not by actual contract.

As a point of interest, many of you may recognize in the following articles principles which are now included, in part, in Oregon's Water Laws:

"Article 1. No one shall divert public waters or establish any mill or other factory thereon, who has not a legal title or has not obtained a concession from the government, which is subject to the payment of an annual rental and the conditions established by this law.

"Article 2. Concessions are always made without prejudice to the right of others. Perpetual rights to divert water may be granted only by law."

These articles are translations of early Roman water law, and again, were cited in Mr. Lewis' 1907 report.

Mr. Lewis, in his Second Biennial Report of the State Engineer to the Governor of the State of Oregon for the period 1907-1908, reported a fourfold need for some speedy method of determining and recording claims to the use of water in order:
1. to assist the U. S. Reclamation Service in deciding upon feasible projects;
2. that development by the state, under the Carey Act, may be facilitated;
3. that titles to water for constructed works can be conveniently and definitely proven, to facilitate sale to advantage; and
4. that private capital can ascertain with certainty the amount of appropriated water, so that the surplus, if any, can be ascertained.

In his Third Biennial Report, dated 1909-1910, being his first report subsequent to enactment of the historic Water Code of 1909, the State Engineer stated: "The protection granted reservoir owners, under the new law, in conveying stored water along natural stream channels to the place of use will do more to stimulate development in this state than any other feature of the law." If you wonder why this is true, one has only to reflect upon the situations which occur in many of the streams within this state during the summer and fall months. We know it to be a common occurrence
that the flows of many of our streams during this period are at or near the zero level due to natural conditions or consumptive uses, and without a water law there is no assurance of protection for those who wish to develop reservoirs that such reservoirs will have water to store.

As a simile, we would never deposit money in a bank unless the bank officials were employed to handle that money in accordance with some well known system in which we had confidence and which would result in securing the return of at least an equal amount of money when needed at some later date. In effect, the Water Code of 1909 created such a system for water in Oregon and in so doing successfully provided a system which warrants the confidence of those who wish to plan for and invest in storage works.

Under the water code, Mr. Lewis' office devised or set up three different forms on which to apply to appropriate water. One was for original or new diversions, another for the enlargement or extension of existing works, and a third for the construction of reservoirs and the storage of surplus water.

A permit to construct a reservoir to store surplus water did not, in itself, grant the right to divert and use storage water. Separate applications had to be made for each of these purposes, and the owner of the reservoir conceivably might not beneficially use any of the water for himself. He could sell proportionate interests in his reservoir to many owners of ditches scattered along the entire length of the stream below the reservoir, thus using the stream to convey water released from storage. The right of these ditch owners to divert such water is obtained through a secondary permit for diversion and use of stored water subject to written approval of the owner.

Without the issuance of such permits, the watermaster would refuse to permit any diversion of stored water released from the reservoir. It is impossible, of course, to distinguish stored water from the regular flow, therefore, the watermaster must keep track of this by the volume of flow and permit only those who have recorded water rights to divert the water. The State Engineer is authorized to require water users to install measuring devices to facilitate the watermaster's distribution of water in accordance with the relative water rights.

You can see how the water code stimulated the construction of numerous reservoirs throughout the state. Because of the law the investor has the insurance that any water released by him into the natural channel of a stream can be recovered at the desired point, less that amount of water that might be lost by seepage and evaporation in transit. His stored water may well mingle with that of hundreds of others as well as with the regular
flow of the stream to which rights have heretofore been acquired. I will
not belabor the mechanics of the water rights applications system as I am
sure many of you are already aware of its intricacies but I hope I have he-

ted you to comprehend the beneficial impact that the Water Code of 1909
had upon reservoir development in the State of Oregon.

CAREY ACT IMPACT

The impact of the Carey Act can be seen by the fact that, by 1910,
the State had executed contracts, under the provisions of the Act, where
the costs to future settlers amounted to over $22,000,000. The contracts
provided the details of reclamation based on a comprehensive survey by
the applicant for the Carey Act lands and on preparation of complete plans
and specifications. One such project was the Powder Valley Project invol-
v ing 60,000 acres plus storage in Thief Valley Reservoir, Balm Creek Res-
ervoir, and West Eagle Reservoir. Only the latter site has not been de vel-
oped, and that by reason of as-yet-insurmountable foundation problems.

Private development of the Carey Act lands brought a number of
prominent engineers into the limelight such as: Barr and Cunningham, who
were associated with development in the Silver and Summer Lakes area;
and A. J. Wiley, who designed and supervised construction of an outstand-
ing, circular, 60-foot high, concrete dam only 5.2 feet thick on the base--
constructed on Crowley Creek in Malheur County during 1909 and 1910 and
still standing, although subsequently enlarged.

With this type of development, together with the studies being made
by the U. S. Reclamation Service, the need for physical data such as topo-
graphic maps and hydrologic data was becoming quite clear. In fact, the
State Engineer, in his biennial report for 1907 to 1908, cited the efforts of
the Oregon Conservation Commission to compile information concerning the
water resources and topographic features of Oregon which led to this conclu-

"Without doubt the most significant feature, and one without justifi-
cation, is the lack of physical data. We believe this lack is greatly retard-
ing the development of our natural resources, and in some cases actually
aiding monopolization."

This seminar has probably made it readily apparent to you by now
that the general subject of reservoirs touches on many subjects, each of
which has a significant, and often critical, effect. Needless to say, without
the proper physical data in the planning stages of reservoir development, it
would be foolhardy indeed to proceed with any expectation of success.

The need for streamflow data had early been recognized by Mr.
Lewis, who in his report for 1907-1908 asked for a material increase in
his annual appropriation of $2,500 for matching funds in a cooperative
effort with the United States Geological Survey to obtain such data. With respect to the early need for topographic maps, between the years 1905 and 1910 surveys were made and maps prepared for over 2,000,000 acres of the state's area under the cooperative agreement between the state and the Survey. Today, some 58 years later, there still remain substantial portions of Oregon in need of topographic mapping. Fortunately, however, recent development of map-making techniques, utilizing aerial photography and photogrammetric projections, is vastly speeding up the mapping process and some of us feel that the end is in sight. Through the state–USGS cooperative programs, numerous reservoir sites have been located, surveyed, and analyzed by many private and public entities and the evidences of their successful efforts are readily visible today.

**LOCAL INITIATIVE INVOLVED**

In 1913, under date of February 27, later amended under date of May 5, the United States and the State of Oregon entered into a far-reaching agreement pursuant to the Reclamation Act. For those of you who may be interested in the details, the authority and the agreements entered into are contained in the Deschutes Project Report of December 1914, published by the cooperating officers of the State of Oregon and the Reclamation Services Office at Portland.

Now, of course, the bulk of Oregon is served out of the Bureau of Reclamation office located in Salem, Oregon. Cited in the Deschutes Report is an Act, Chapter 87, General Laws of Oregon, adopted by the Legislature in 1913. This act authorized the State Engineer, on behalf of the State of Oregon, to enter into such contract or agreement with any federal agency or bureau having jurisdiction in such matters for the cooperative execution of such surveys and investigations and the preparation of such plans, specifications, and estimates or other data best suited to accomplish the purposes of the act -- reclamation. It further provided that the State Engineer could withdraw and withhold from appropriation any unappropriated water which might be required for projects under investigation or to be investigated under the provisions of the act.

Under the provisions of the Carey Act and the Reclamation Act, investigations were initiated, extensive withdrawals were made, of which some are still in effect, and the reclamation projects of Southern, Central, and Eastern Oregon began to emerge: namely the projects in the Umatilla, Powder, Owyhee, Malheur, Malheur Lake, Goose and Summer Lakes, Klamath, Rogue, and Deschutes Basins. Most of this development, however, was taking place either through local initiative associated with the Carey Act or through the cooperative program with the U. S. Reclamation Service, now the U. S. Bureau of Reclamation.
Oregon's entry into state sponsorship and actual construction of reclamation projects was short-lived. In 1914, construction of the ill-fated Tumalo Project was completed. This project, initiated under the Carey Act as the Columbia Southern Project, was taken over by the state in 1913 when the Legislature appropriated $450,000 from the General Fund for complete reconstruction of the project.

This step was widely heralded as an advance step in the matter of reclaiming lands within the domain of a state. It was further classed as one of that era's most progressive legislative actions for the development of a western state. Involved were reconstruction of the distribution system developed by Columbia Southern plus construction of the 20,000 acre-foot Tumalo Reservoir to supplement direct flow appropriations in serving 22,500 acres of project lands. Unfortunately, Tumalo Reservoir did not hold water as had been optimistically forecast by the project engineer in his 1914 final report on the Tumalo Irrigation Project.

Oregon shook its head and, burned once, to this date has never again grasped the torch to light the flame of another irrigation project.

Investigations continued, without direct state participation, however. The year 1916 saw publication of two cooperative reports: Harney and Silver Creek Projects and Malheur and Owyhee Projects. Of the Harney Project, the cooperative report stated, "Attention is called to the fact that the water rights of Silvies River are being adjudicated by the State Water Board, and until this adjudication is completed it will probably not be practicable to begin any irrigation development in Harney Valley by either Government, State, or private enterprise." How true those words were! What the author did not know was that with the adjudication proceedings long since completed, the practicability of irrigation development some 54 years later still is not much better. There have been individual storage developments, many fraught with expensive lawsuits, but the Harney Project's Silvies Unit, still one of the lowest-unit-cost potential projects in the state, may be yet another 54 years away.

The Malheur and Owyhee Projects fared better, however. Warm Springs and Agency Valley Reservoirs have long been constructed as has the Owyhee Reservoir. Many similar sites were identified, as well, and a number of them have been built privately.

Twenty-eight withdrawals involving 36 water rights still are in effect, some involving both storage and direct flow. Priorities range from as early as July 31, 1911 for direct flow and storage withdrawals on Summer Lake, comprising the total capacity of Summer, Abert, and Alkali Lakes to as late as April 1, 1938, for 125 cfs of waters from Mollala River and Milk Creek in the Willamette Valley. These withdrawals still pose
valid prior claims against subsequent appropriators. Between 1956 and 1962 a few withdrawals were canceled in areas where it had become quite obvious that development or further development would not take place.

DEVELOPMENT OF COLUMBIA

The year of 1916 saw another publication, Bulletin No. 8, "Oregon's Opportunity in National Preparedness." The title page contains the following modest statement: "A presentation of tentative plans and estimates of cost for the construction of a number of large waterpower projects, discussing possibilities for marketing some of the power, and pointing out the direct and indirect benefits which will come through the early development of our water-power resources."

What makes this particular report so interesting? Herein, State Engineer John Lewis and associate authors - L. F. Harza, Garfield Stubblefield, and E. J. McCaustland, described what could be called a blueprint for 1970 development of the Columbia River, identifying practically every major dam constructed, under construction, or authorized to date on the Columbia and its principal tributaries. Sites were described where Bonneville, The Dalles, John Day, and McNary Dams now stand—Pelton on the Deschutes and another near the present Round Butte Dam—the Snake River Dams: Asotin and Mountain Sheep—as well as many others.

Mr. Lewis has been described as being fifty years ahead of his time. I question this, twenty-five years, perhaps, but not fifty. Bonneville was constructed less than 25 years following its 1916 reporting, closer to 22 years. This is little different than can be expected on any new project being investigated today and where even without major impediments, 15 to 20 years can be expected to lapse between initiation of study, authorization, and construction.

The post-World War I period saw little change in the state's role in development of reservoirs until the tragic failures of the St. Francis Dam in California and the Bully Creek Dam in Oregon, both about 1926-27, alerted the State Legislature to the need for strengthening the state's control over the design and construction of dams and reservoirs. In both 1927 and 1929, the State Engineer was given additional authority needed to insure the adequacy of design and construction of all dams 10 feet or more in height or impounding 3,000,000 gallons or more of water.

The law currently states that it is unlawful to construct any dam or other hydraulic works, failure of which would result in damage to life or property unless the State Engineer has made an examination of the dam-site and the plans and specifications, and shall have approved them in writing. The state law further provides that any person residing or owning land in the neighborhood of any dam, dike, or other hydraulic structure
may apply to the State Engineer for an inspection thereof. The State Engineer may order such an inspection or make an inspection on his own volition. As a point of interest, during the 1964-66 biennium the State Engineer's office conducted 320 inspections in accordance with this provision. This included inspections of damsites for proposed works, inspection of projects during the course of construction, inspection of dams and dikes without a State Engineer's permit, and inspections of operating hydraulic structures and of two dams that suffered complete failure.

During the great depression of the 30's, Public Works Administration funds were utilized to bolster the economy and a number of irrigation projects were benefited: Rock Creek on the east slope of Mt. Hood above Dufur; the Burnt River Project was completed; one small reservoir, then known as Mud Lake, was started, almost 20 years later to be completed as Trillium Lake just south of Government Camp on Mt. Hood; to name but a few.

With the advent of the 40's, came World War II and another period of depressed construction activity; then the post-war boom arrived with its burgeoning power demand. At last the power markets, ill-defined and obscure to John H. Lewis 30 years before, were here, not only to stay but to grow and grow and grow -- to the extent of a predicted 1,000,000 KW annual increase for the period 1980 to 2000 and even on to the year 2020. With the dramatic increase of power needs, the state is presently concerned with the concomitant problems of transition from primary reliance on hydro power to that of thermal power.

Questions now arise such as where should such thermal plants be located in order to assure the necessary supply of water and appease esthetic requirements; what will be the result of the water discharge of such plants with respect to mineral and thermal aspects; and can such discharges be subjected to further beneficial uses? I am sure that you have been exposed to such questions and discussions recently, both in this seminar and in the many forms of news media.

STATE BOARD CREATED

Not unexpectedly, with the demand for power came conflict---conflict over the use of the waters of the Deschutes River with the resulting Pelton Decision, the Federal Government's first major infraction of State's rights to water. This decision, together with increasing pressure on the legislature for single-purpose water legislation, led to the creation of the State Water Resources Board in 1955 to serve as the single state agency responsible for the progressive formulation of a state water policy and for the devising of programs and plans for the development of the state's water resources.
In particular, ORS 536.300 states that the board is to study the existing water resources of the state; means and methods of conserving and augmenting such water resources; existing and contemplated needs and uses of water for domestic, municipal, irrigation, power development, industrial, mining, recreation, wildlife, and fish life uses and for pollution abatement, all of which are declared to be beneficial uses, and all other related subjects, including drainage, reclamation, flood plains and reservoir sites. In addition, ORS 536.310 proceeds to set forth the policy that multiple-purpose impoundment structures are to be preferred over single-purpose structures.

Based on the foregoing, it is quite apparent that the state is interested in reservoir development and seeing to it that this development is carried out in the best interests of the multiple-use concept. This desire in itself creates certain vexing problems. One current problem is that in multiple-purpose federal development, the federal law now requires that assurances and or repayment be provided for local flood protection projects; repayment of costs assigned to irrigation; repayment of one-half the separable costs assigned to recreation, fish and wildlife; and repayment of storage facilities to be utilized for municipal and industrial purposes.

State participation, however, in providing these assurances is prohibited by the state constitution, and has led to board efforts to recommend elimination of such constitutional restrictions or enactment of legislation permitting the local governmental entities to carry out the federal requirements. If reservoir development is to proceed in the state of Oregon it appears mandatory that such steps must be taken.

The State Water Resources Board was also charged with the responsibility to classify, and reclassify where necessary, the waters of the state as to the highest and best use. It further was authorized to withdraw from further appropriation such unappropriated waters for any or all uses as found to be in the public interest. Still further, the board was authorized to negotiate contracts with and assist Federal and other state agencies in water resources planning and was directed to coordinate such planning.

By about 1960, after conducting the Rogue and other basin investigations and after adopting programs for the use and control of the basins' waters, a good, strong working relationship began to evolve between the board and the Federal agencies working in basins studied by the board. Thus, in 1963, when the Corps of Engineers was authorized to review and update its 531 Report of the Willamette Basin Project, it was only natural that the board confer with the Corps and jointly recommend that the review become a comprehensive, multi-agency study involving both state and federal agencies. Congress authorized the study to be undertaken under the auspices of the Columbia Basin Inter-Agency Committee (CBIAC), which
was subsequently dissolved and superseded by the Pacific Northwest River Basins Commission. Since all of the study area for the Willamette Basin lay within Oregon, CBIAC specified that the state should provide the chairmanship to a Task Force assigned to coordinate the study. The Board's Director, Donel J. Lane, thus became Chairman of the Willamette Basin Study Task Force.

**TASK FORCE REPORT**

In the Willamette Basin Comprehensive Study, in addition to providing the Task Force Chairmanship, the board is providing a representative on the Task Force Technical Staff. It has been my privilege to fill this assignment.

I believe in previous seminar presentations you have been exposed to some of facets of the Task Force's endeavors. Here I will attempt to quickly point out the particular significance of reservoirs in this study. The study's plan formulation is expected to result in recommendations for some modification to existing projects and programs, and recommendations for additions of new projects and programs. The specific procedure that we are following in the plan formulation consists of four basic steps.

In Step No. 1 an evaluation was made of the total needs for each potential project function. Here we attempted to quantify the water and related land resources needs in the basin in excess of those which can be met by a base system, that is, development existing under constructed, authorized, and assured federal storage developments.

In Step No. 2, we conducted a screening or preliminary evaluation of approximately 600 potential reservoir sites in the basin. This step was carried out cooperatively by the federal construction agencies with the advice and counsel of all study participants. The screening process consisted of 8 sub-steps, in each of which the sites were evaluated and rated as either potential, marginal, or of no potential. The sub-steps were as follows: map evaluation; field inspection; preliminary cost estimates; surface geology; detailed mapping; subsurface geology; real estate appraisal; and detailed cost estimates.

Step 3 consisted of analyses of the potential storage sites with reference to the determined needs and resulted in yet another screening of the sites, which were subsequently considered for early, or short-range, development and those being considered as potential long-range projects.

In short, the fourth and final step is to hold final public hearings and then complete a report on the study. This, of course, is one of the
public's opportunities to participate in the Task Force effort similar to that which is now going on throughout the basin as a result of the recent public presentation of the preliminary plan given last August. The Task Force is currently meeting with interested groups throughout the basin in regard to the specific projects which were either included or excluded as a result of the aforementioned screening process.

Recent legislation to which I previously referred, has expanded the definition of "water resources of this state" to include both reservoir sites and lands inundated by flooding. With the board having nearly completed its initial round of basin investigations geared toward establishing state water policy, a series of review studies are being initiated. In these studies emphasis will be placed on developing flood plain information and on reconnaissance studies to identify reservoir sites and their potential for development. Contributing to the data on potential damsites will be the lists of damsites and information related thereto, obtained in recent board studies through cooperation with the U. S. Department of Agriculture, Soil Conservation Service. Economic analysis will be facilitated by inputs under the same cooperative agreement using data from the Economic Research Service of USDA.

LONG RANGE NEEDS

To amplify on my quickly spoken words regarding identification of reservoir sites and their potential for development, I might add that the board is currently engaged in a study to determine the state's long-range water requirements, which will be used, in turn, to evaluate and develop methods of meeting long-range water requirements within the state. This means that in the board's upcoming series of review studies, the general results of the Ultimate Needs Study will be refined and applied to particular regions within the state to determine the water surpluses and deficiencies; to analyze the adequacy of existing, authorized, and proposed projects to meet the identified future needs; and to develop plans and programs to meet such deficiencies not satisfied by the foregoing. It is logically expected that the status and functions of reservoirs in such development plans will be of prime importance.

In another area of endeavor, the State Engineer's Watershed Planning Division is actively involved with reservoir development by engaging in watershed planning work as a means of (1) overcoming the backlog of unattended P. L. 566 applications and (2) providing technical assistance to new groups interested in conserving their water resources. In its various levels of investigations, a major portion of the Division's work is expended on topographic surveys of individual damsites and on extensive engineering, hydrologic and geologic analyses of such sites. Upon completion, the studies are presented to the Soil Conservation Service and the project spon-
sors for utilization in preparing the final Watershed Work Plan.

I hope that what I have given you here today can be beneficially considered in conjunction with what you have heard from the other seminar participants, thereby adding to your understanding of the very broad subject of reservoirs. In addition, I hope I have also successfully presented the point that the state has been and continues to be vitally interested in reservoirs and is an active participant in all phases of reservoir development within its constitutional and fiscal limitations. We recognize that reservoirs are not the answer to all of our water problems but we continually strive to understand better the advantages and disadvantages inherent in reservoir development for the future optimum benefit of Oregon's citizens.

Regardless of the fact that the state has not yet shown an inclination to return to the reservoir construction field, I do feel that legislation, within the past fourteen years particularly, has greatly reinforced the state's role in reservoir development by strengthening the activities of the State Engineer's office and by vesting in a single state agency, the Water Resources Board, the primary responsibility for state water policy and for devising plans and programs for development of the state's water resources.

REFERENCES


Determination of what to present in forty minutes on the issues of water storage in the middle or canyon reach of the Snake River has not been an easy exercise. The resources involved and the range of their uses are multiple and extensive; the guiding goals and principles for planning and development are broad; the historical background is long and frequently controversial; and vital policy and plan decisions are pending. Moreover, the mass of relevant data is monumental.

The effort will be to reduce the volume of material to manageable proportions, to feature the more fundamental public issues, and to provide a general perspective for further exploration and examination. The "angle" of view sought is that of one concerned primarily with the general public interest in resources, environmental, river basin, and regional conservation and development.

That general interest lies most fundamentally in the use of water and related land resources for advancing the well-being of all the people.¹

The central aim in the present context is that of achieving an integrated planning, conservation, development and management, for multiple and intermeshed physical, economic, social and environmental purposes, of what is an integral natural resource--the Grand Canyon of the Snake, including its central and spectacular Hells Canyon. That aim would be met primarily through a comprehensive system of water and related land development and use for the whole Canyon reach, in turn integrated in a Columbia basin-wide system.

GENERIC SITUATION AND OUTLOOK

The comprehensive view of middle Snake development and use has been unbalanced to a considerable extent by a more intensive focus on hydroelectric power than on the other, interlocked, multiple uses of the resource. This is a result of the high economic and social values of electrical energy, coupled with applications for power development licenses, by non-federal and essentially single-purpose power agencies, under the Federal Power Act. The trend has been inimical to the desirable single responsibility and coordinated management, for optimum development, use and benefit, of an important national resource.

In license proceedings, the regulating authority, the Federal Power Commission, has two main choices in promoting development: (1) To grant, or deny, a license to an applicant for dam and power plant development and operation, with incorporated provisions intended to safeguard the public interests in this and other multiple uses involved. (2) To recommend development by the federal government.

However, in its Snake Canyon decisions up to the present, the FPC has not given effective recognition to the values and requirements of integral resource management and has not taken the second course open to it under its enabling Act. In the presently-open case, that of the High Mountain Sheep project, this position of FPC has been questioned by Supreme Court opinion of June 1967.

In the present situation, then, we might note the desirability of consideration in a public forum not dominantly that of power but one moving toward the ideal of an equitable and balanced evaluation of all of the beneficial uses of water and related land.

The need of such consideration has been accentuated over the past few years by a growing realization of the mounting severity of impacts of growth and development upon environment and ecology, particularly in degradation of aquatic life-supporting conditions.

Elaborating a little, an increasingly deep concern extends to the quality of water, land, and air. With respect to water, we are concerned

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River Miles Above Mouth

Plan 1
- High Mountain Sheep
- China Gardens

Plan 2
- Low Mt. Sheep
- Appaloosa

Plan 3
- High Mountain Sheep
- Pleasant Valley

Plan 4
- Low Mt. Sheep
- Potential Damsite
- Existing Dam & Reservoir

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MIDDLE SNAKE RIVER

PROFILES AND LOCATION MAP
with chemical and bacteriological contamination, with excess nutrients, with higher temperature, and, as a result, with serious losses of values of water for agricultural, domestic, municipal and industrial supplies, for fish and wildlife, for recreation. Over all, we are concerned with a crucial lowering of the quality of the environment—economically, socially, culturally, and esthetically.

From this general background, the situation with regard to middle Snake water storage may be discussed along these lines: (1) The basic principles, concepts, and uses of water storage and flow regulation. (2) The resources of the Snake canyon reach for storage purposes. (3) The evolution of planning, development, and administration for development in this area. (4) The present situation and needs.

CONCEPTS OF STORAGE AND FLOW REGULATION

The objectives and uses of water in a river system have long been recognized and will have been discussed in the prior course of this seminar. Most simply, the purpose is the detention of excess flows and their release at more favorable times from the standpoint of beneficial use. The principle applies to retention in watersheds, headwaters, and main streams, and in the soil, underground, or surface reservoirs. In terms of magnitude of works and effects, main-stem and major-tributary reservoirs are most significant in the general control system of a large river basin. However, the upstream and watershed measures are indispensable elements in the total system of control. Inherently, water storage is a basic element in any comprehensive plan for optimum conservation, development and use of the water and related land resources of a river basin.

The concept of a main control plan—a system of coordinated facilities and measures for the beneficial regulation of flow from headwaters to estuary and sea, for the beneficial use of water in the stream and on the land, and for wise use of watershed, waterfront, flood plain, and other related lands—is fundamental and central in river basin planning, development and operation.

Essential qualities in the main control plan include those of comprehensiveness as to coverage of multiple uses and benefits and of geographic area, internal consistency and balance, and external consistency with plans for other river basins.

With respect to the Columbia River system, planning of the past quarter century has aimed toward the control of a substantial fraction of the average annual flow of about 180 million acre-feet. The present prospect is for the attainment of a usable storage capacity, in reservoir projects, of about one-third that amount, or of the order of 60 million acre-feet well...
distributed among main stem and major tributaries. More than a quarter of this capacity would be located in projects now under construction on Columbia main stem and tributaries in Canada. The large benefits in power and flood control have been widely noted. Regional power resources are being economically expanded in terms of firm power and dependable capacity. Lower River flood discharges will be cut in half in terms of the maximum flood of record in 1894, bringing such a flood down to a limited-damage stage, greatly mitigating damages of the potentially larger floods, and increasing values of waterfront and flood-plain lands. The values of this regulation for water-quality control and general water supply purposes will expand markedly, bringing them into high rank among the major economic values of storage development.

The water-storage capabilities of the middle Snake canyon reach are very significant, from standpoints of location, topography, hydrology and capacity, in the Columbia scheme of well-distributed capacity. Their important and unitary role, and strategic location, in the larger main control system will be apparent.

ROLE IN BASIN DEVELOPMENT

The Snake basin, constituting the southeasterly two-fifths of the Columbia basin, has an area of 109,000 square miles. In terms of water flow, the Snake accounts for about one-fifth of the Columbia's annual discharge, or about 37 million of the latter's 180 million acre-feet.

At the High Mountain Sheep site, on the Snake just above the Salmon confluence, the tributary area is about 74,000 square miles and the average annual runoff about 14 1/2 million acre-feet. The annual yield here has ranged between about eight million and 22 million acre-feet. In the long run this runoff may be depleted by several million acre-feet due to further consumptive use in upstream irrigation. A few miles downstream, at the Nez Perce site just below the Salmon confluence, the tributary area is about 89,000 square miles and the annual runoff about 23 million acre-feet.

The mean discharge at the HMS site is about 19,000 cu. ft. per second, while the minimum and maximum of record are about 5,000 and 135,000 cfs. The probable peak or design flood has been computed at 430,000 cfs. The usable storage capacity in the canyon reach is presently one million acre-feet at Brownlee reservoir. That in the upper basin, largely in headwater reaches of the Snake and tributaries, is of the order of five million acre-feet -- a capacity subject to doubling in the foreseeable future. Natural underground storage in the upper basin is also a factor in the stream regimen.
High as well as average flows are significant in the Snake-Columbia perspective. A major areal segment of the Columbia basin such as the Snake basin is a potentially large contributor in Columbia main stem floods. That contribution will vary considerably among such floods according to conditions in the particular flood season—such as in snow pack, temperatures, and precipitation volume and form. As a matter of fact, the Snake River as a whole contributed about one-quarter of the volume of the record 1894 flood as well as the disastrous 1948 freshet. Under the circumstances, the control capabilities of the middle Snake reach are strategic in the large scheme of regulation of the Columbia River system as a whole.

The whole Snake basin is divided, at the middle stretch under consideration, by a wide and high mountain belt, cut through by the deep Grand Canyon of the Snake. The canyon reach extends, roughly, from the confluence of the Weiser River (near Weiser, Idaho) down between Idaho and Oregon to the confluence of the Clearwater (at Lewiston, Idaho and Clarkston, Washington). To the South and East of the canyon reach are the great Snake River plains and plateaus (largely in Idaho) and to the North and West the plains and plateaus of the Columbia basin proper and lower Snake (in Idaho, Washington and Oregon).

The middle Snake canyon reach lies around the geographical center of the Columbia basin and Pacific Northwest region. For geographic, topographic and hydrologic reasons, it provides one of the strategic features for control of the flow of the upper and middle Snake basin, and thus a substantial fraction of the Columbia's flow. The reach is not at the center of gravity of the Columbia system's hydropower capability, but it is a material contributor to the regional hydropower potential. Thus the place of the middle Snake in the Columbia basin scheme is very relevant in the planning and development issues under consideration. In numerical terms, that place can be outlined only approximately because of varying assumptions as to plans of development.

EVOLUTION OF MIDDLE SNAKE PLANS

The most far-reaching and inclusive plans for the development of the Columbia River system were presented by the Corps of Engineers in 1948 and modified a decade later. They contemplated a main


control system with a usable storage capacity of the general order of 40 million acre-feet. Of this, about a quarter or nearly 10 million acre-feet would have been provided in the middle Snake canyon reach, at the High Hells Canyon and Nez Perce sites.

The 1948 Army report presented the middle Snake among the strategic reaches in the control of the Columbia River system. It included the Hells Canyon project in the main control plan's initial phase. The Nez Perce project for the immediately-downstream reach from Hells Canyon damsite was seen as a superior control project but was not recommended for the initial plan because it would block major runs of anadromous fish which spawn in the Salmon River system. The High Mountain Sheep project was suggested as "a possible alternative to the Nez Perce project." The High Hells Canyon project was also recommended by the Bureau of Reclamation and Department of the Interior at approximately the same time.5

Public hearings on the federal High Hells Canyon project were held in the field in 1947. This high dam and reservoir would have occupied the upper half of the canyon reach.

The Idaho Power Company submitted to FPC a series of permit and license applications relating to this reach: for a single dam at Oxbow in 1947, for a five-dam plan in 1950, and finally for a three-dam plan (Brownlee, Oxbow, (Low) Hells Canyon) in late 1952. This last-mentioned plan provided for a one-million acre-foot storage capacity as contrasted with the federal plan's 3.88 million. The power capabilities, at site and downstream, were also considerably less than would have been inherent in the federal high-dam plan.

Congressional authorization of the federal high dam project failed to come through during the 1952-1957 period in which FPC and federal court proceedings were in progress.

Meanwhile, FPC hearings on the IPC three-dam project were held in 1953 and 1954, culminating in a license to the Company in 1955. The FPC decision was appealed to the U.S. Court of Appeals by the National Hells Canyon Association, intervenor in the FPC proceedings, in the same year. Later in that year, the NHCA petition was denied by the Court, that body refusing to substitute its judgment for that of FPC concerning technical questions before it. The U.S. Supreme Court later, in 1957, denied petition of NHCA et al for review of the Court of Appeals decision.

Construction of the IPC project began at Brownlee in 1955 and was completed at Low Hells Canyon in 1967.

SEVERAL PHASES NOTED

Among the major effects of this three-dam development, as compared with the proposed federal high-dam project, were: the loss of nearly 3 million acre-feet of storage capacity and about 500 kilowatts of saleable firm power at site and downstream, and lessened economic benefits due to a power unit cost three or four mills per kilowatt-hour higher in a part of the region's wholesale power supply. The passage of anadromous fish through the canyon above Hells Canyon dam was practically cut off before the construction was completed.

Planning and development in the lower half of the canyon—that is, in the Nez Perce reach—has gone through several phases.

In 1948, Nez Perce and High Mountain Sheep were considered by the Army Engineers as alternative projects, as already indicated.

In 1954, the Corps of Engineers and Bureau of Reclamation reported jointly on revised development plans for this area, including a low Mountain Sheep dam and pool and a Pleasant Valley dam and reservoir of relatively small capacity. 6

In the same year, the inter-utility Pacific Northwest Power Company was incorporated and in 1955 it applied to FPC for license to develop the Low Mountain Sheep-Pleasant Valley project. Hearings were held in 1956. In 1957 the FPC Examiner recommended licensing, but the Commission's opinion and order of January 1958 denied the license. Denial was on the ground that in the Commission's judgment the proposed development was not best adapted to a comprehensive plan within the meaning of Section 10 (a) of the Federal Power Act.

The Mountain Sheep-Pleasant Valley project would have provided about 0.6 million acre-feet of usable storage (at Pleasant Valley), as compared with about 2 1/4 million at High Mountain Sheep or over 4 million at Nez Perce.

In 1957 and 1958 the Corps of Engineers again examined the Nez Perce and Mountain Sheep reach in connection with its revised study of

the main control or major water plan, and a new round of power applications was inspired. The report, submitted by the Division Engineer in 1958, presented the High Mountain Sheep project as a unit in the major plan for the Columbia system, with Nez Perce again serving as an alternative.

PNPC applied to FPC for a High Mountain Sheep license in 1958 and submitted an amended application the next year. The Washington Public Power Supply System submitted application for the Nez Perce project early in 1960 and in the following year amended its application to include a High Mountain Sheep project as an alternative should its application for Nez Perce be denied. FPC hearing, brief, and argument proceedings began in 1960 and continued through 1963. The FPC granted license for the High Mountain Sheep project to PNPC early in 1964, on the basis of a split, three-to-two, decision. Exceptions and appeals were taken by WPPSS and the Secretary of the Interior but FPC reaffirmed its order later in the year.

In petitioning the Court of Appeals, WPPSS and the State of Washington held that FPC erred in failing to recognize WPPSS preference rights as a municipality under the Act. The Secretary of the Interior sought relief on grounds that the Commission erred in finding that the PNPC proposal was best adapted to a comprehensive plan (per Section 10 (a)) and in failing to recommend federal development (Section 7 (b) of the Act).

**PETITION TO COURT**

The separate petitions of WPPSS and the Secretary of the Interior, presented in 1964, asked the U.S. Court of Appeals for the District of Columbia to review and set aside the FPC order licensing PNPC to develop the High Mountain Sheep site. In March of 1966 that Court entered its judgment affirming the FPC order, holding that the evidentiary record established that the Commission was amply justified in refusing to recommend federal development and in issuing the PNPC license.

The Secretary of the Interior and WPPSS promptly, in the same year, petitioned the U.S. Supreme Court for reversal of the Appeals Court judgment. The Interior brief reiterated the grounds of FPC failure to recommend federal development under Section 7 (b) of the Act.

further stressing the great impact that this major storage project would have on the varied and predominantly federal interests involved in the development of this arm of the Snake River.

In June 1967--

. . . . on writs of certiori, the United States Supreme Court reversed and vacated the Court of Appeals' judgment and directed that the cases be remanded to the Commission for further proceedings. In an opinion by Douglas, J., expressing the views of six members of the court, it was held that the issue of federal development was never explored by the Commission, that the Secretary should have been given an opportunity to reopen the record and supply evidentiary deficiencies, and that the Commission should explore all issues relevant to the public interest, including future power demand and supply, alternate sources of power, the public interest in preserving reaches of wild rivers and wilderness areas, the preservation of anadromous fish for commercial and recreational purposes, and for the protection of wildlife. 8

In short, the Court's lengthy decision expressed concern with the question as to whether licensing to a private, state, or municipal agency is a satisfactory alternative to federal development in view of the several interrelated uses of the project and the need of coordination of the conservation of natural resources, and of the public interests in these matters. The decision said, in part: 9

We indicate no judgment on the merits. We do know that on the Snake-Columbia waterway between High Mountain Sheep and the ocean, eight hydroelectric dams have been built and another authorized. These are federal projects; and if another dam is to be built, the question whether it should be under federal auspices looms large. The release of stored water at High Mountain Sheep may affect navigability; they may affect hydroelectric production of the downstream dams when the river level is too low for the generators to be operated at maximum production; they may affect irrigation; and they may protect salmon runs when the water downstream is too hot or insufficiently oxygenated. Federal versus private or municipal control may


9. Ibid.
conceivably make a vast difference in the functioning of the vast river complex.

Beyond that is the question whether any dam should be constructed.

The FPC ordered the proceedings reopened in July 1967. PNPC and WPPSS joined in application for license for the High Mountain Sheep project, and the Secretary of the Interior introduced evidence on a proposed comprehensive development for the area affected. At this writing, FPC hearings are still open, but a joint federal government and power agency venture is forming. Under an agreement between PNPC, WPPSS, and USD1, announced November 8, 1968, FPC has been asked for a six-month stay of the hearings to enable Interior to seek Congressional authorization for a cooperative plan of construction by federal agencies of a multipurpose project in the reach, with non-federal financing of a major share of the costs. That financing would be arranged through prepayment for a block of power equivalent to the project output for a period of 50 years at BPA rates, with a balance of necessary construction funds furnished by the government. During that period, the non-federal agencies--private and public--would share 50-50 in the power supplied to help meet customer needs in the six-state area involved.

INTERIOR'S APPALOOSA PLAN

The extensive interagency investigations and planning carried out by the Department of the Interior have resulted in a plan centering upon a major dam and reservoir at an Appaloosa site several miles upstream from High Mountain Sheep, rather than at the latter location. The general features and relationships of this revised plan are briefly summarized.

In recent years some federal river basin planning has trended away from maximization of reservoir capacity primarily in the interest of power and flood control and toward a more broadly based and balanced consideration of the diverse and multiple uses of water and of resource-conservation and environmental values. The point may be illustrated, in the middle Snake reach under consideration, by the withdrawal from the Nez Perce project with its 4.7 million acre-feet usable capacity in the Snake and Salmon River valleys, or from the alternative High Mountain Sheep and Lower Canyon projects, on the Snake and Salmon respectively with a similar total capacity, and the present focus upon the Appaloosa project on the Snake with a usable capacity of 1 1/2 million acre-feet. Flood control values would be diminished in general proportion. The corresponding difference in prime power, at-site and downstream attributed to the "full" development scheme and to the Appaloosa project would be of the order of 600,000 kilowatts.
The Appaloosa project complex would consist of the Appaloosa dam and reservoir located on the Snake about ten miles above the mouth of the Salmon, about eight miles above the High Mountain Sheep site, and about six miles above the mouth of the Imnaha River. A low re-regulating dam would be located about five miles downstream from Appaloosa, at the Low Mountain Sheep site and about one mile above the mouth of the Imnaha.

As indicated, the usable storage capacity of the Appaloosa reservoir would be 1.5 million acre-feet.

The installed power capacity would be 2.1 kilowatts at the main dam and 0.4 million at the reregulation dam; a pump-back storage power facility of 1.3 million kilowatts capacity is contemplated for ultimate development. Prime power to be produced, at site and downstream, from the complex is something over a half-million kilowatts.

As will be apparent, the Appaloosa-Low Mountain Sheep project is at some disadvantage with the High Mountain Sheep and China Gardens reregulating dam combination from a strictly power point of view—since some of the benefits of hydraulic head and power output are traded off for valuable natural resource and environmental benefits. The difference in dependable capacity is about 500,000 kilowatts and that in average energy about 150,000 kilowatts.

In comparison with HMS standing alone, without the reregulation dam, Appaloosa is superior. It has a large advantage, of several hundred thousand kilowatts, in the particularly significant matter of dependable capacity, while the disadvantage in average energy output is relatively small. A Pleasant Valley-LMS combination falls appreciably short of Appaloosa-LMS as a power project, and, more importantly, lacks storage capacity to serve effectively in downstream water quality regulation; the Pleasant Valley capacity is only about half that of Appaloosa.

As a federal power system undertaking, the Appaloosa project would enjoy material advantages over a non-federal project of equivalent characteristics. These would include a superior position due to direct and full integration in the primary federal power system, to favorable allocations of cost among non-reimbursable benefits, to lower annual fixed charges including interest and taxes, and to the lower unit costs of dependable capacity and energy. Such lower costs would bring regional and national advantages in the location of and service to industries in which power supply is a major cost item. Only a partial mitigation of non-federal disadvantages may be obtained through power supply coordination agreements alone.
CONDITIONS FOR FISHERIES

The project location, above both Salmon and Imnaha river confluences, is designed to permit favorable access of anadromous fish runs to those streams—the former the largest producer of salmonid fishes in the Columbia River system. The project provides a stretch of open or free-flowing river below the reregulating dam, as conducive to the attraction and movement of upstream migrant fish toward spawning grounds and hatcheries and to some natural replenishment of dissolved oxygen in the stream. With elimination of HMS and China Gardens from the development scheme, the Appaloosa-LMS project will leave about 20 miles of open river on the Snake (including about one mile above the Imnaha and four above the Salmon); in addition there will be about 10 miles of open river on the Imnaha and two on the Salmon that would not be left under the HMS-CG combination.

While much fishery-oriented opinion is broadly, and inherently, opposed to dams per se, there is a significant body of opinion in this case that conditions for the anadromous fishery will be better with than without a properly and effectively located, designed, and operated storage project like Appaloosa. The water quality, including temperature, and environment in the Snake River down to the Columbia confluence may be better controlled, and, consequently, fish passage to the Salmon and Imnaha better assured, through flexible and selective multiple-level outlet facilities at the reservoir. The location with open river from LMS to the Imnaha and Salmon is calculated better than the alternative HMS-CG to provide for the access to those streams and for preservation and propagation of remaining Snake runs as well.

In the same expert view, the fishery situation would be better by reason of elimination of the first dam below the Salmon-Snake confluence, the formerly proposed China Gardens project, with its wide fluctuations of water level and its backwater extending above that confluence, making it more difficult for upbound migrant fish to find their native spawning streams.

The fishery problem should be considered in the light of conditions in the Snake above as well as below the Appaloosa project. The Hells Canyon dam (existing at the head of the proposed reservoir) does constitute an effective block to the passage of anadromous fish farther up the Snake. Measures intended for such passage failed of their purpose during construction of the first two of the series of Idaho Power Company dams (Brownlee-Oxbow-Low Hells Canyon). In this, division of responsibility among power company, regulating agency, and conservation agencies was a notable contributing factor. Fish conservation policy now provides for partial mitigation of losses through collection of upstream migrants, artificial spawning, and relocations of runs.
Since late-summer temperatures in the Snake River between canyon and mouth approach a point inimical to passage and survival of the salmonid fishes, the Appaloosa project would be used in temperature regulation, through the multiple-level outlets to permit the drawing off, as required, of cooler water from lower reservoir levels. It is anticipated that temperature conditions can be improved by this means. The ultimate pumpback power facility at Appaloosa dam is not calculated to disturb the temperature-regulating operation since it would be used only in mid-winter before temperature stratification begins in the spring.

Storage on the Clearwater River—as at Bruces Eddy—may be operated, presumably, to supplement Appaloosa in mitigating critical late-summer or early-fall temperature rises in lower Snake reaches.

Because of the lower dissolved oxygen content of the lower-level, cooler waters released from the Appaloosa reservoir, reoxygenation is needed at and below the dam and would be provided for in the project. A corollary problem is that of potential nitrogen gas supersaturation at the dam, a condition subjecting fish to fatal embolisms, or "bends". Accordingly, afterbay hydraulic tube designs are being evolved—first to degasify flow from the turbines, removing excess nitrogen, and then to reinject oxygen to provide a safe environment in the stream below the dam. The design of these facilities is subject to ongoing research.

The water-quality regulation to be provided by the Appaloosa project will have benefits beyond those to the anadromous fishery—that is, in maintaining values for future agricultural, domestic, municipal and industrial water supplies and in aiding in maintaining a favorable ecology and environment in and along the waters and shorelands of the Snake and Columbia rivers downstream.

**EFFECTS ON SEVERAL RESOURCES**

Wildlife resources of the High Mountain Sheep reach would be variously affected under the alternative plans of development. Principal effects would be in the overflow of canyon shorelands, including wet and meadow lands in the canyon bottom interfering with normal regimens of waterfowl, streamside and big game animals. Overflow will be less with the Appaloosa project than with the longer and deeper HMS reservoir, but compensations and readjustments will be necessary under any of the plans.

Development of the reach will have notable impacts on the scenery, landscape, and recreational uses of the canyon. The landscape of the canyon bottom will be materially altered—most so by the HMS-CG project. Under the Appaloosa plan, many more miles would be unaltered...
from the free-flowing condition. However, the larger recreational effects of development would be felt in increased accessibility and expanded visitation and use; the general pattern will be changed from a wild area with limited numbers of visitors to a recreation area of some regional and national significance. The slackwater reach for water access and pleasure boating will be several miles less for the Appaloosa than for the HMS version of development.

Opposition to development from protectionist scenic and wilderness points of view has frequently featured the argument that nuclear power plant development will make the further hydroelectric development unnecessary or obsolete. Power and conservation and development people, however, have noted the contrasting and complementary roles of nuclear power, primarily on base load, and hydropower, primarily in peaking, in the integrated regional power system. Thus nuclear and hydro power are not true alternatives; both must be used in combination for reliability, efficiency and low cost in operations, and the development of feasible hydro must continue, particularly in the field of dependable capacity to back up the inevitable thermal generation. Environmental conservationists will be concerned—if they are not already—with the vital problems of protecting ecological systems and human environment from any ill effects—of heat, vapor, and radioactive emissions from nuclear power stations and cooling facilities, fuel units and processing plants—upon water bodies, atmosphere, and land.

With other elements of the Columbia-Snake main control plan, Appaloosa dam releases will contribute to downstream navigation. More local navigation contributions will be those of small boat use on the reservoir and the open river reaches downstream and of facilitation of access to canyon reaches. In relative monetary terms, the project's navigation benefits are not among those of larger economic significance.

Flexibility to meet changing conditions and needs—including frequent emergencies of a number of kinds—in and among multiple uses is an important over-all requirement in project planning, design, and operations.

CONCLUSIONS

A balanced, multiple-purpose and comprehensive plan for conservation and development of the remaining reach of the middle Snake has been evolved by the federal government through several changes, each followed by a non-federal power license application. The fundamental resource issues of comprehensiveness, multiple use, optimum and integral development have been involved. A public versus private power element has also appeared among the issues, but the joint action by a
private and public agency in the current application to FPC has somewhat dampened that aspect. Generally, public interest in the development, pro and con, have expanded at state and local, as well as federal, levels.

In brief review of the project development and management situation, the Appaloosa project involves--in its research, planning, construction, and operating phases--a complex and expanding series of interlocking systems:

The project is a system in itself--of two primary water control dam units and of these and other facilities for uses of water and related land for power, flood control, navigation, water supply, quality control, fish and wildlife, recreation, and other purposes. Pump-back power development is proposed for the long-run future.

In turn, the project is a part of a system of dams and reservoirs--in the strategic Snake Canyon reach between upper and lower Snake basins--that are important in the control of the Snake for multiple beneficial purposes.

It is a part of the larger unitary main control system for the entire Columbia River system, as mentioned above.

It is also a part of subsidiary systems in the main control plan, as, for example, those for water quality control and for power generation and transmission.

At a strategic point in a water quality control system, the project will operate to protect and enhance the character of water in the Snake downstream to the Columbia confluence--this in parallel with a similar function of Grand Coulee dam on the Columbia main stem.

The project will be an important unit in the primary regional power system, with strategic central regional location and capabilities; the facilities may also play a significant role in the support of major interregional power exchanges through future lines in the extra high voltage transmission system.

In addition, project planning and management involve an outlook extending far beyond that of engineering, administrative, and fiscal efficiency. Social benefits and costs not measurable in monetary terms are involved and may often be overriding. Resource-use efficiency in meeting human and environmental imperatives rather than economic
efficiency or profitability should be the primary concern. Economic evaluation should be based upon the project's equitably proportioned worth in the ongoing system rather than upon the order of its addition to the system.

In view of the complexities to be met and new technological ground to be broken, there is a special need for concerted effort and for time to carry out the indicated research and development work needed for most effective design, construction, and operations.\(^{10}\) Research, planning, and project management are inseparable and must proceed hand-in-glove. Especially important are continuing investigations in the fields of water quality control (including temperature), aquatic biology and engineering, ecological and environmental protection and enhancement.

Under the conditions, the need of unitary responsibility is also great from an organizational and procedural point of view. One would not deliberately design an administrative set-up under which primary and closely interrelated proprietorship, powers, and major functions of a project are divided among a number of governmental and private entities. Moreover, such fragmentation is particularly anomalous, organizationally, in a situation where administrative and decision-making strength and flexibility are needed. Large, complex and interdependent and multiple-purpose, short- and long-run problems and needs of resource conservation and development must be met. Further, frequent changes and emergency conditions will arise and call for decisions relating to a living resource, an ecological system, or human safety and well-being.

In closing on this note of unitary and responsible management, a conclusion from an earlier study of the middle Snake is reiterated:\(^{11}\)

Responsibility is the key concept ... in the middle Snake, in the Columbia basin, and elsewhere.

The establishment of a working scheme of responsibility may be considered as the central and controlling issue

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10. In this general connection, Senate Bill 4025, 90th Cong. 2d Sess., by Senators Jordan and Church of Idaho, will be noted. This proposed act would "prohibit the licensing of hydroelectric plants on the Middle Snake River below Hells Canyon Dam (including Mountain Sheep and China Gardens reaches) for a period of ten years."

11. Bessey, op. cit., p. 132
in the further advance of that development:

This, the Columbia, is one basin, and the middle Snake is a strategic subdivision, to be developed under a unified comprehensive plan. It represents a great natural, regional and national resource to be conserved and developed in accord with vital and expanding public needs.

That development is already in mid-course, but the maintenance and improvement of plans is still crucial from the standpoint of public interests in the beneficial use of its resources.

The responsibility for conservation and development is primarily federal, by reason of federal property, commerce, defense, and welfare obligations.

That responsibility has not been clearly and effectively assumed through federal leadership in planning and development, federal and intergovernmental action in planning, construction and operation, and in licensing and regulation of public utilities. In fact, the opposite is often the case--as may be gleaned from the record of fragmented and sporadic development, lost resources, and foregone opportunities in the middle Snake.

REFERENCES


5. Federal Power Commission proceedings—hearings, briefs, decisions, orders, opinions—in middle Snake licensing cases: Hells Canyon, Idaho Power Co. (Nos. 1971, 2132, 2133); Mountain Sheep-Pleasant Valley, Pacific Northwest Power Co. (No. 2173); High Mountain Sheep and Nez Perce, PNPC and Washington Public Power Supply System (Nos. 2243 and 2273, respectively); High Mountain Sheep, remanded, PNPC and WPPSS jointly (Nos. 2243-2273).


