Chapter 12

Water Resources

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The Pacific Northwest, considered as a whole, appears to be richly endowed with water. The volume of runoff from the region exceeds that of any other major water resources region in the conterminous United States, surpassing most regions manyfold. Moreover, in terms of per capita runoff, the relative position of the region is even more favorable. The utility of the resource is diminished, however, by marked variations in spatial and temporal patterns of supply.

Supply

The most significant source of fresh water within the Pacific Northwest is the Columbia River system. Rising in the Rocky Mountains of the United States and Canada, this system provides drainage for approximately 75 percent of the region and accounts for about 55 percent of the total runoff. When runoff from Canada is included, the Columbia system discharges approximately 65 percent of the total.

East of the Cascade Range, the Columbia Basin is divided into seven sub-basins (see map 12-1). Much of the land is subhumid to arid, and traversed by rivers that originate in various mountain ranges lying both within and to the north and northeast of the region. The Rocky Mountains are the source of much of the flow.

Three additional sub-basins east of the Cascade Range are not part of the Columbia System. A number of streams in Oregon with internal drainage are designated as the Oregon Closed Basin, and portions of the Klamath and Bear rivers also drain small parts of the region. The Klamath rises in Oregon, flows through northern California, and discharges into the Pacific Ocean. Waters of the Bear River rise in Utah and Wyoming before crossing southeastern Idaho, and finally discharge into Utah's Great Salt Lake.

Of the four humid sub-basins west of the Cascade Range, two—the Willamette and Lower Columbia—are part of the Columbia River system, while the

Map 12-1. Drainage Basins and Sub-basins

streams of the Coastal and Puget Sound sub-basins discharge into waters of the Pacific Ocean.

The relative discharge of some regional rivers is shown in table 12-1. The runoff value for an area is derived by subtracting evapotranspiration and deep percolation from the amount of precipitation received. The values on map 12-2 refer to the mean annual depths in inches of water entering streams and rivers from locations within the various shaded areas. Each inch of runoff per square mile contributes 17.4 million gallons of water to surface flow. The depths of runoff from areas within a shaded area may be inferred.

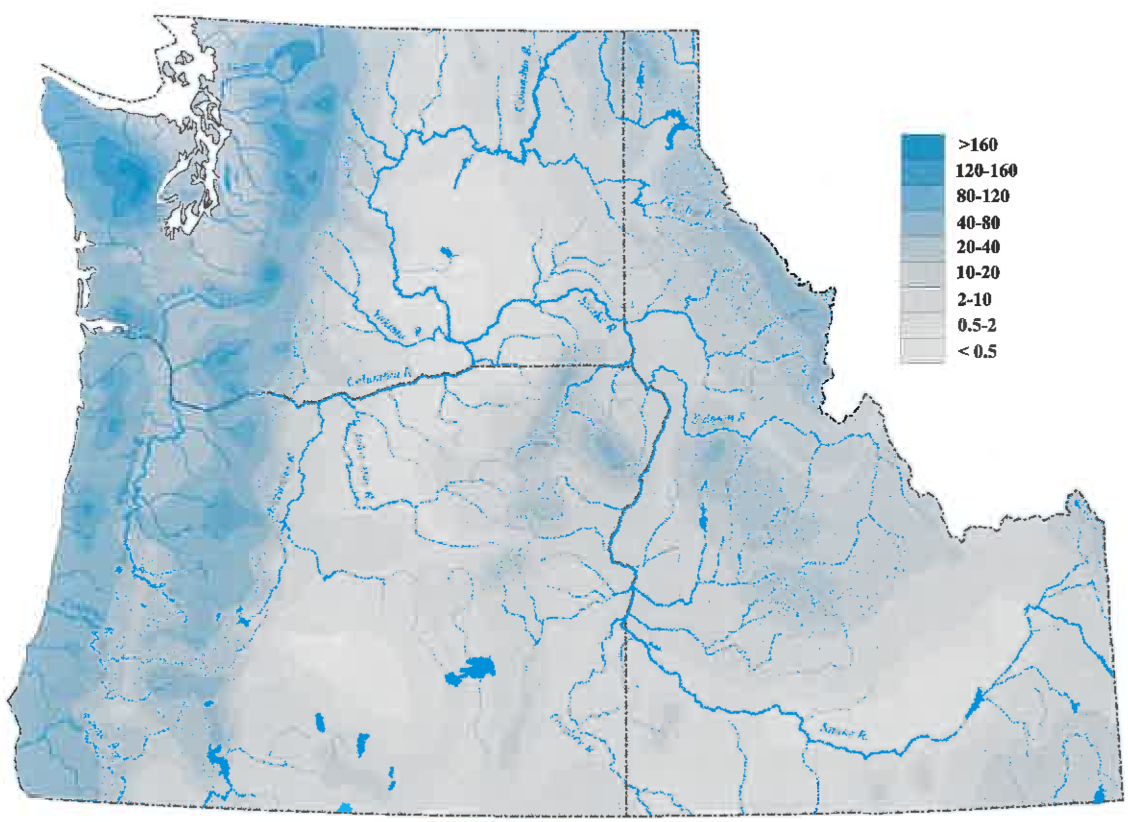
The Pacific Northwest may be divided into two subregions based on runoff characteristics. West of the Cascade Mountains, runoff is generally high, reflecting relatively heavy precipitation and moderate levels of evapotranspiration. Indeed, the yield of runoff west of the Cascades is unrivaled in the conterminous United States. Yields of more than 80 inches are common in the Coast and Cascade ranges, while some of the windward slopes of the Olympic Mountains contribute more than 160 inches. Streams west of the Cascades produce about two-thirds of the total runoff from the Pacific Northwest although they drain less than one-fourth of the region.

Table 12-1. Discharge (in millions of acre-feet/year) of selected rivers in the Pacific Northwest

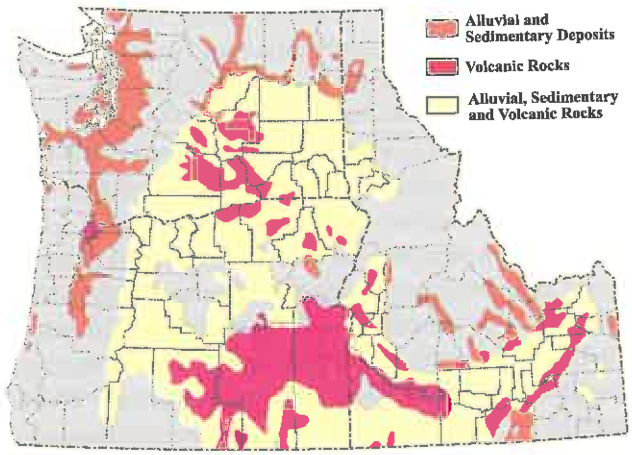
Columbia	180.1
Columbia (at The Dalles)	133.7
Snake	36.8
Willamette	23.8
Rogue	8.2
Skagit (at Concrete)	10.3

By contrast, the much larger subregion east of the Cascade Range generates markedly lower levels of runoff per unit area. Much of it contributes less than 10 inches per square mile, and most of the surface water originates in relatively small mountainous areas. The position of mountains can be identified on the map by locating areas of relatively high runoff (20 inches or more). For example, the Blue Mountains in northeastern Oregon and southeastern Washington, the Wallowa Mountains in northeastern Oregon, and the Bitterroot and Coeur d'Alene mountains along the northeastern border of Idaho stand out as islands of relatively high runoff.

Map 12-3 indicates that about one-half of the Pacific Northwest is underlain by aquifers with moderate to large potential yields of groundwater. The value of this source is great because it generally coincides with areas of heavy water use. At present, aquifers in the Snake River Plain account for most of the groundwater use in the region, although extensive withdrawals are



Map 12-2. Surface Runoff, in mean annual inches



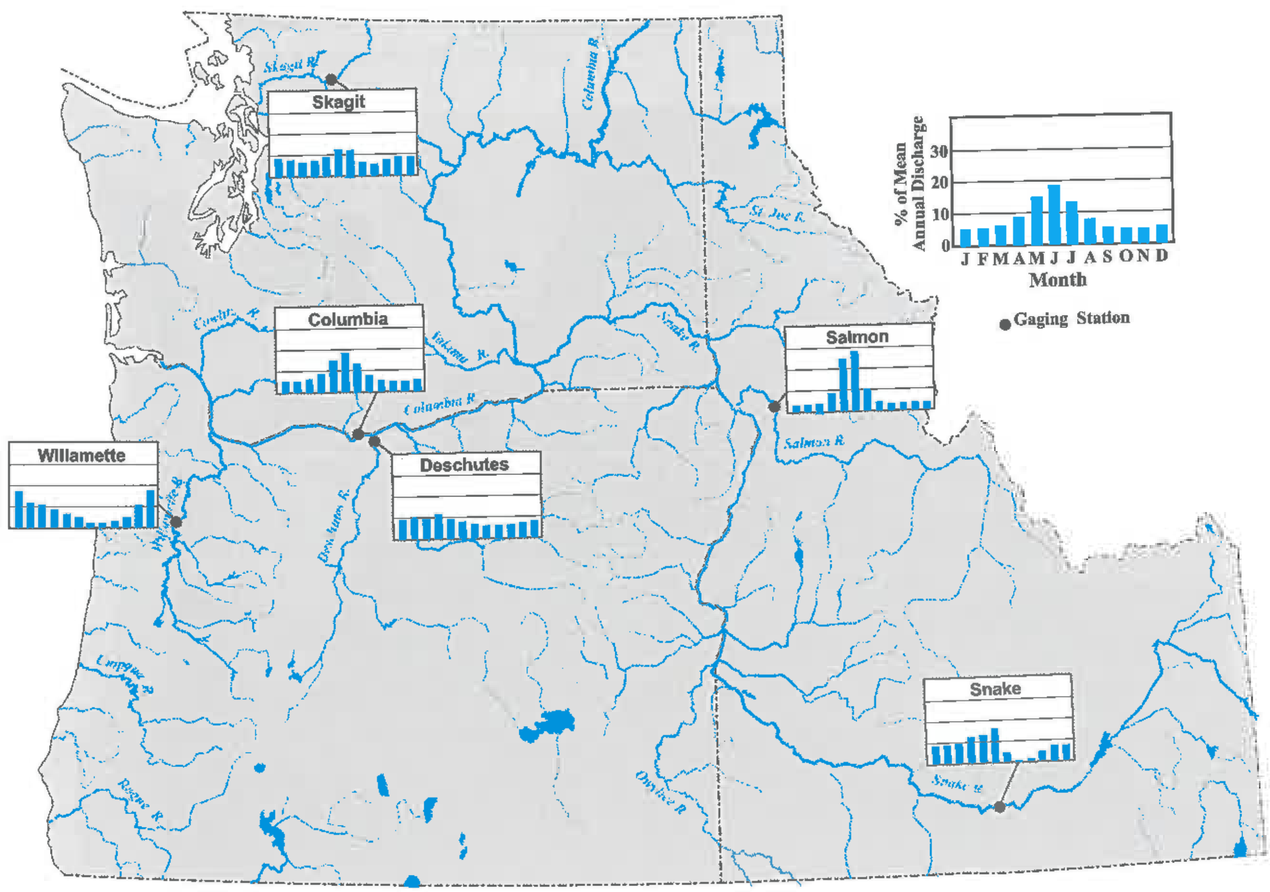
Map 12-3. Major Aquifers

also made in some parts of the Puget Sound and Willamette sub-basins.

Map 12-4 illustrates that the patterns of temporal distribution of surface runoff vary considerably within the region. The hydrographs show average monthly discharges as a percentage of the yearly average. If the runoff remained constant throughout the year, 8.33 percent would be discharged each month.

Through much of the region's history the temporal patterns of runoff largely reflected natural phenomena within a river basin, including: its location in either marine or continental subregions of the Pacific Northwest; the type and extent of natural vegetation within the drainage basin; and the structure of aquifer units underlying the basin. Although the combined effects of natural phenomena remain dominant in most rivers basins within the region, anthropogenic influences have become more important in some basins through increasingly intensive water use. Principal anthropogenic influences include stream flow depletions from extensive irrigation withdrawals and the construction and operation of large dams and storage reservoirs, the major purpose of which is to reduce temporal variations of runoff.

Columbia River. The hydrograph of the Columbia River at The Dalles, Oregon, reflects average discharge conditions for a 120-year period from 1879-1999. It shows that a disproportionately high percentage takes place during the late spring and early summer. This pattern results because most of the precipitation above The Dalles falls on the various ranges of the



Map 12-4. Surface Water Yearly Flow Cycle

Rocky Mountains stretching from northwestern Wyoming through Idaho and western Montana and far into British Columbia. Although most of the precipitation takes place in the late autumn and winter, it is retained in the mountainous headwater areas of the Columbia in the form of snow and ice, being released months later as melt water.

In the latter half of the twentieth century the natural runoff pattern was modified by the provision of large volumes of upstream storage. Thus the main flows of May, June, and July, although still noticeably higher than those of other months, are reduced while, conversely, the mean discharge levels in the late fall and winter are increased by the release of stored water.

Salmon River. The hydrograph for the Salmon River illustrates the mean monthly discharge for a fifty-five year period of record from 1910 to 1965. In this case the combined discharge of May and June constitutes approximately one-half of the yearly total. The July discharge as a percentage of the total is somewhat less than that of the Columbia River because the more southerly location of the Salmon drainage basin results in an earlier period of maximum runoff. Very little storage or irrigation development in the Salmon River Basin means that the present monthly pattern of discharge remains essentially unchanged.

Snake River. The hydrograph of the Snake River at Milner, Idaho, reflects the headwater conditions in the Middle Rockies as well as anthropogenic modifications. The relatively heavy spring runoff is characteristic of a snowmelt regime, but occurs earlier than those in the Salmon and Columbia river drainage because of a more southerly location. Heavy irrigation use above Milner further reduces the already modest summer flows.

Deschutes River. The unusually moderate temporal variation of runoff in the Deschutes Basin reflects the fact that much of it is underlain with porous basalts. These basaltic and andesitic volcanic rocks of Quaternary and late Tertiary age absorb potentially high runoff and later release it when discharge would otherwise fall to much lower levels. Provision of storage and irrigation development have not notably altered the hydrograph at its confluence with the Columbia, but significant modifications are present in some other reaches of the system.

Willamette River. The temporal flow regime of the Willamette River is representative of many rivers west of the Cascades in both Washington and Oregon. Runoff reflects the temporal distribution of precipitation because relatively little is retained as ice and snow. The Willamette hydrograph is compiled from a thirty-year period of record (1960-1999). The temporal distribution of present flows has been modified somewhat by the completion of many flood-control reservoirs since the end of World War II. While the high mean flows of the mid winter months have remained practically unchanged, those of February through April have been reduced somewhat when reservoirs are refilled. The low mean flows of July, August and September have been increased appreciably by releases from upstream storage.

Skagit River. This hydrograph is atypical of rivers west of the Cascades. Relatively higher mean flows occur in June and July because much of the runoff originates from snowmelt at high elevations in the North Cascades of Washington and British Columbia. Since completion of Ross Dam by Seattle City Light in 1949, considerable reservoir storage space reduces summer high flows while increasing flows during the winter when energy demands are highest.

Water Use

Water uses may be divided into two major categories: instream uses, which utilize water within stream banks, and offstream uses, which divert water out of its channel before use.

Instream Uses include generation of hydroelectric energy, navigation, fish and wildlife habitat, waste carriage and assimilation, recreation, preservation of wild and scenic rivers, and maintenance of riverine ecosystems. Unlike other regions of the western United States, water utilization in the Pacific Northwest is characterized by heavy dependence on instream uses, especially for the generation of hydroelectric energy. The Pacific Northwest is the nation's unrivaled leader in the production of hydropower, utilizing a volume of water that is several times the total regional discharge. This results because the same water is used repeatedly at successive dams and powerhouses along several large rivers. For example, in the United States the mainstem of the Columbia River includes eleven monumental dams with very large hydroelectric generating facilities. For more detail on hydroelectric

Bonneville Dam and lock. (Photo courtesy of U.S. Corps of Engineers, Portland District)

generation, see the following chapter on energy resources.

Navigation is another major instream use. Large expenditures by the federal government have been made to enhance inland water navigation on the Columbia System. From Portland to the Pacific a 40-foot channel is maintained. In addition, from the Bonneville Locks at river mile 145 to the Port of Lewiston in Idaho, a chain of eight reservoirs stretches 320 miles, which not only allows slack water navigational conditions for inland water carriers but also guarantees a navigation channel of 14 feet depth. Spacious navigation locks at the eight dams lift barge tows from 8 feet above mean sea level at the Bonneville lock to 738 feet on the reservoir reaching Lewiston, Idaho.

Early efforts to promote navigation have altered hydrologic conditions even though navigation is no longer significant on some rivers. The situation on the Willamette is a case in point. Although there is no longer commercial navigation on the river above Willamette Falls, near Portland, summer releases of water from flood control reservoirs continue to be made in accordance with a 1938 Act which directs that releases be adequate to maintain a flow of 6,000 cubic feet per second for navigation at Salem. During the normal low water months of July-September these releases coincidentally contribute significantly to improved water quality in the Willamette.

Two proposals related to navigation continue to fuel sharp disagreement: The first would deepen the channel between Portland and the Pacific to facilitate the passage of very large ships used increasingly in modern maritime commerce; the second would breach the four federal dams on the Lower Snake River in order to improve migration for salmon. Channel dredging is vigorously opposed by environmental and fishing interests, while dam removal is staunchly resisted by organizations representing navigation, agriculture, energy, and economic development.

Another significant flow use is the maintenance of fish and wildlife habitat. Water resource developments in the region have affected aquatic life markedly. Although enhancement of habitat sometimes results, the consequences have more frequently been negative. Inadequate consideration of biological factors during project design and/or operation have resulted in severe losses. Animal communities, especially fur bearers, have in general been negatively impacted by the development of water resources. On the other hand, one very large irrigation project (the Columbia Basin Project) has greatly enhanced the habitat for migratory waterfowl by creating many lakes and extensive marshes in a semiarid area.

Valuable anadromous fisheries (salmon and steelhead) have been adversely affected by the development of water resources. This is particularly evident in the Columbia-Snake system. The once bountiful natural runs that were thought to be inexhaustible have declined sharply and some have even disappeared. How to preserve and enhance remaining runs continues to be the focus of controversy among various interests.

Hatchery programs may have mitigated some of the losses. Indeed, hatchery fish now far outnumber wild stocks. These programs are less successful above the confluence of the Columbia and Snake rivers, however, because of the cumulative effects of losses at dams below the hatcheries. Despite the apparent success of hatcheries, many fishery biologists are becoming increasingly concerned about potential threats to wild runs posed by hatchery fish.

Some runs of anadromous salmonoids have been listed under the Endangered Species Act and approximately 40,000 miles of streams and rivers are now reserved for anadromous fish habitat. If anadromous fisheries are to be substantially increased over the present low levels, some reduction in the future output of hydropower, irrigated agriculture, water transport, and perhaps other water-related goods and services probably will be necessary.

Another instream use of water is by recreationists. Many outdoor recreational activities are water-oriented. The region has a disproportionately large per capita supply of surface waters suitable for outdoor recreation, and all types of recreational uses of water in the Pacific Northwest have grown rapidly over the last half century.

The Pacific Northwest has a disproportionately large number of rivers designated under the Wild and Scenic Rivers Act. As shown in the chapter covering recreation, many of the wild and scenic rivers are in rugged and remote parts of the region—locations ideal for upstream storage. Implementation of the Wild and Scenic Rivers Program requires tradeoffs. Superior aesthetic/leisure-time experiences, white-water recreation, and scientific benefits are gained at the expense of such traditional benefits as slack-water recreation, hydroelectric generation, and provision of upstream storage. For example, over twenty million acre-feet of potential storage is foregone at major potential storage sites in existing and study river areas.

One of the principal instream uses of water is to carry away, dilute, and assimilate wastes. When the ratio of wastes to the volume of receiving waters is small, assimilation of organic wastes and adequate dilution of many other waste products takes place. In such instances, water quality is not seriously impaired, and this was the case in the early settlement period of the region. During the twentieth century, however, the rapid growth of population and economic productivity in the Pacific Northwest caused the volume and variety of wastes deposited in the region's waters to increase markedly. This overtaxed the capacity of some of the receiving waters to assimilate and/or dilute wastes, resulting in the present poor water quality (pollution) in some of the region's surface waters. In addition, in some tributaries of the Columbia-Snake system east of the Cascades, heavy irrigation withdrawals and consumptive use also reduce the assimilative capacity of the streams.

Improved treatment by industries—especially in chemical recovery—has been chiefly responsible for decreased levels of biochemical oxygen demand in the region, thus freeing up oxygen for fish and other aquatic life. However, there is an apparent widespread increase in the presence of organic and inorganic toxins from non-point sources of pollution, including over twenty million acre-feet of irrigation return flows. In addition, water quality problems exist downstream from densely populated areas, including excessive counts of coliform bacteria and low levels of dissolved oxygen. Although the region has relatively few problems associated with siltation, erosion of the loess-mantled Palouse Hills creates undesirable levels of turbidity and turbine scour at some of the generating plans on the lower Snake River.

Thermal pollution is considered a serious problem in some river reaches because anadromous salmonoids have a low tolerance to temperatures exceeding 68 degrees Fahrenheit. Such temperatures are periodically encountered, for example, in reaches of the lower Snake River and in the Yakima sub-basin.

Despite considerable flood storage, levee construction, and channel improvements, much riverine land remains susceptible to inundation. Unregulated flows on some tributaries of the Columbia and in the Puget Sound and Coastal sub-basins contribute to continued property damage. Another contributing factor is the continued conversion of flood-prone lands to more intensive uses, which may be encouraged by a false sense of security following structural flood protection measures.

Offstream Uses include: irrigation; livestock watering; public supply (which usually furnishes municipal, residential/domestic, commercial, and light industrial needs); self-supplied industrial; mining; and thermoelectric cooling.

Irrigation is clearly the dominant offstream use in the region, accounting for more than four times the total withdrawals by all other uses combined. Irrigators in Idaho withdraw slightly more than half the regional total while those in Washington and Oregon each withdraw almost one-quarter. East of the Cascades irrigation is the dominant use in each of the ten sub-basins. Agricultural water use even represents an important part of the total withdrawals in two of the sub-basins—the Willamette and the Coastal—in the relatively humid western part of the

Pacific Northwest. This reflects the normally dry summers which require agriculturists to irrigate many of the crops.

An important aspect of irrigation is its large consumptive use, which can adversely effect other water users. Consumptive use refers to the part of the water withdrawn that is evaporated, transpired, or incorporated into the product. Therefore it is not returned to streams or economically accessible groundwater for subsequent uses. In the Pacific Northwest approximately 40 percent of the water withdrawn for irrigation is used consumptively, which represents almost 96 percent of total water consumption in the region. Finally, much of the irrigation water that does return to surface and groundwater contains undesirably high levels of silt, salts, and agricultural chemicals, reducing its value for reuse.

Public supply withdraws the second largest volume of water in the region, although it is only 7 percent as much as irrigation. The relative amounts withdrawn by state are roughly proportional to their populations. The leading sub-basins in declining order of use are Puget Sound, Willamette, and Spokane. The region's two leading municipal systems—operated by Seattle and Portland—rely heavily on surface waters from the Cascades, while Tacoma and Spokane depend on groundwater. In Idaho groundwater provides over 90 percent of the public supply, reflecting the widespread availability of subsurface sources. Public water supply in Oregon derives over 80 percent of its water from surface waters, owing to the state's population concentrations in the Willamette Valley. In Washington sources of public supply are about evenly divided between surface and groundwaters.

Self-supplied industrial withdrawals in the Lower Columbia sub-basin comprise approximately 80 percent of the total. The distribution of industrial withdrawals reflects in large measure the location of the pulp and paper industry, which is concentrated in the Lower Columbia, Puget Sound, and Coastal sub-basins. Food processing is usually the most significant industrial use of water east of the Cascades, but primary metals are significant in the Clark Fork-Kootenai-Spokane and Mid-Columbia sub-basins.

In the Pacific Northwest relatively little water is withdrawn to cool thermoelectric plants, reflecting the continued dominance of hydroelectric generation. This is in sharp contrast to most other major U.S. water resource regions where such withdrawals rank either first or second among offstream uses. In the Pacific Northwest thermoelectric withdrawals are concentrated in the Hanford Nuclear Reservation and in southwestern Washington to serve large coal-fired plants near Centralia.

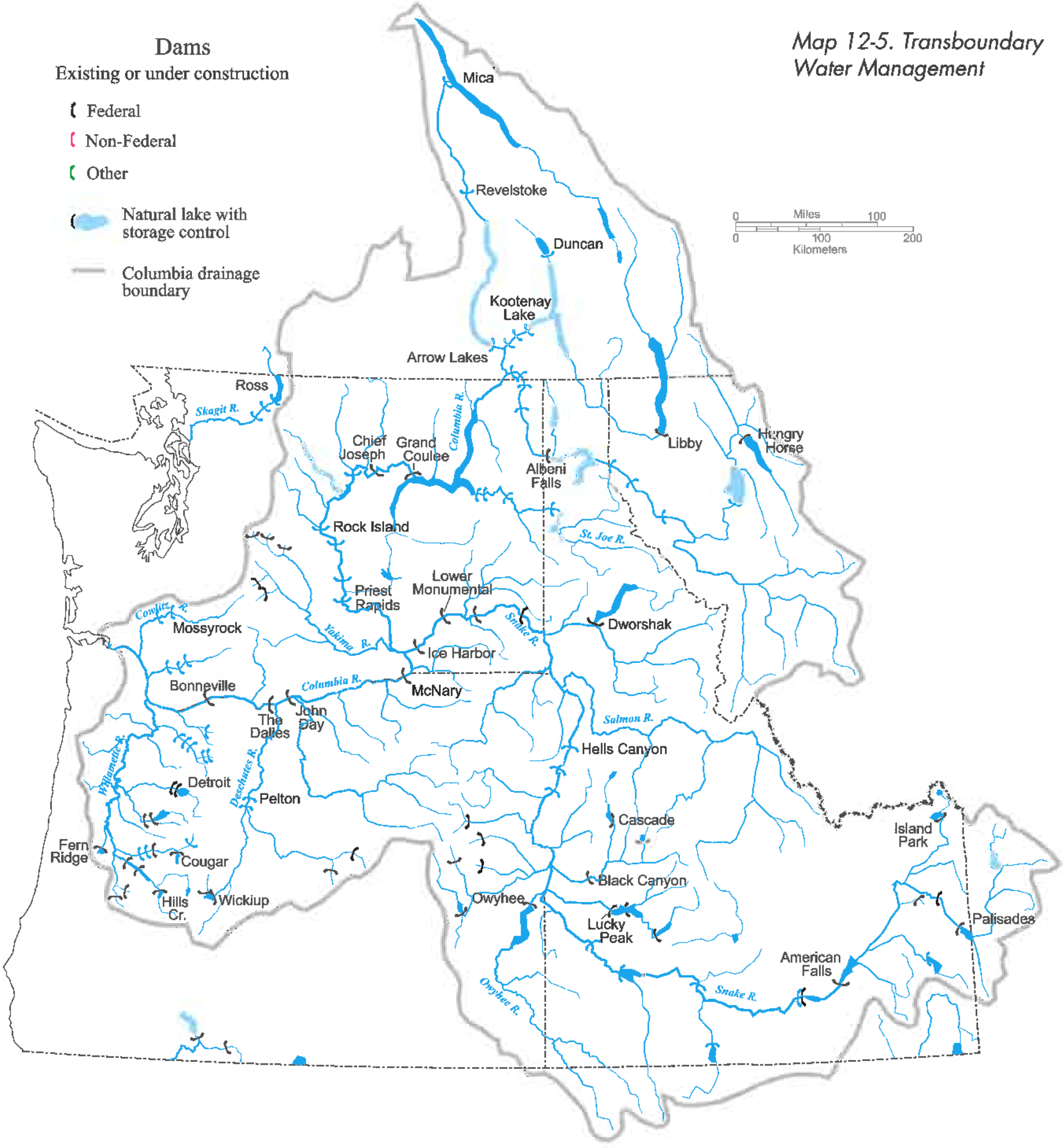
Transboundary Water Management

Transboundary water management in the Pacific Northwest is significant because rivers cross jurisdictional boundaries at many points in the region, potentially carrying negative and/or positive attributes with them. Actions by water users upstream may significantly alter the quantity, quality, and/or timing of runoff in the rivers of a down-stream jurisdiction. Conversely, water management downstream may affect those upstream through creation of impoundments that encroach into the upstream area or by limiting access of migratory fish or barge traffic to upstream areas. Water-related externalities such as these involve both national and subnational jurisdictions in the region.

International Water Management. The Columbia River system is shared by seven U.S. states and the Canadian province of British Columbia. The Columbia's drainage area in Canada comprises 15.4 percent of the total watershed but contributes 30.6 percent of the total runoff. British Columbia contributes about as much runoff to the Columbia-Snake system as the combined input from Idaho, Montana, Wyoming, Nevada, and Utah.

Cooperative management by the United States and Canada results from a treaty finalized in 1964, under the terms of which the two countries agree to the principle of sharing downstream benefits. Canada provides storage capacity and in return receives one-half of the value of the resulting benefits accruing to the United States. Canada received a lump-sum payment of $254 million as its share of anticipated increased hydroelectric generation in the United States over a thirty-year period after completion of the treaty dams. In addition, the United States paid Canada $64 million for sixty years of reduced flood damages which would result from Canadian storage. Since the thirty-year period has elapsed, Canada's share of increased generation in the United States is returned to the border.

Interests associated with electrical energy and/or more intensive development of riverine lands benefit from the cooperative development of the Columbia River system. It has markedly increased hydroelectric output, while also decreasing flood damage in both countries. This was achieved for the



Map 12-5. Transboundary Water Management

most part through provision of large storage reservoirs at Libby, Mica, Arrow Lakes, and Duncan (see map 12-5) which reduce high flows from snowmelt in the late spring and early summer and increase flows from the start of October through March, when the regional demand for electrical energy is high. The graph of the Columbia River's annual flow cycle is shown on map 12-4.

Both Canadian storage and contribution to total runoff are very important to hydroelectric output in the Pacific Northwest. Most of the region's total hydroelectric generating capacity is installed on the mainstem of the Columbia River at eleven dams from Grand Coulee to Bonneville Dam (see map 10.5 of electric generating facilities). On this 725-mile reach of the Columbia, 19,000 Mw of generating capacity have been installed, much of it since the treaty to take advantage of increased flows from storage releases during the autumn and winter seasons. Canada contributes significantly to the total volume of water flowing in this major power-producing reach of the Columbia River: approximately threequarters of the flow at Grand Coulee decreasing to two-fifths of the total river flow at Bonneville Dam.

Cooperative development of the Columbia River also creates important flood damage reduction benefits in both countries. The major benefits in the United States are in the Portland-Vancouver area. Here total storage in the system—much of it in Canada—is projected to reduce record flow by 45 percent. In Canada, the principal benefits are along a major tributary, the Kootenay (Kootenai in the United States), which rises in Canada and then swings through Montana and northeastern Idaho before returning to Canada. Libby Dam in Montana provides flood control and hydropower benefits downstream in Canada. The dam also backs water across the U.S.-Canadian border and many miles into British Columbia, which Canada agreed to under the terms of the treaty. It is noteworthy that Libby Dam also provides flood crest reduction benefits on the United States side of the border, as well as increasing hydropower output in the autumn-winter period at downstream power plants in Canada and the Pacific Northwest. Downstream benefits accruing in Canada from storage at Libby are not shared with the United States

The results of the 1964 treaty are not all positive. Treaty implementation has been harmful to anadromous salmonoids by altering the annual flow cycle and stimulating the installation of additional generating capacity along the Columbia between Grand Coulee and Bonneville Dams. The interests of salmon fishers—tribal, commercial, and sports—received little attention during treaty negotiation.

The Ross Dam agreement is another example of innovative cooperation. Seattle City Light wanted to increase the output of hydroelectric generation from its Skagit River plants by increasing the height of Ross Dam. But doing this would have caused the existing reservoir to further encroach onto Canadian territory, which was strongly resisted by British Columbia. A solution was reached when the provincial utility, BC Hydro, agreed to supply Seattle City Light with the electrical energy that increasing the height of the dam would have provided. This energy is supplied in return for payment to BC Hydro of the funds Seattle would have expended in the construction and operation of the higher dam.

The United States and Canada have made considerable progress on cooperative transboundary water management, but challenges remain. For example, how can provisions of the U.S. Endangered Species Act be met in transboundary waters, when doing so may have negative effects in Canada, which does not have similar legislation? This problem became apparent when United States efforts to increase numbers of white sturgeon in the Kootenai and salmon in the Columbia affected the timing of discharge from storage reservoirs.

Intraregional Water Management. There is also need for increased transboundary water management within the Pacific Northwest, particularly between upstream and downstream states. Idaho, Montana, Utah, and Wyoming are usually considered to be the upstream states, while Washington and Oregon are downstream entities. Water management in one part of the region can have repercussions on water uses in other parts. For example, if new large-scale irrigation developments are undertaken in Idaho's Snake River Plain, the quantity of water available for hydropower and other uses is diminished in the downstream states of Washington and Oregon. Conversely, salmon harvest in reaches of the Columbia system in Washington and Oregon adversely affect fishing interests in Idaho. Over the last several decades, sporadic attempts by states in the Pacific Northwest to allocate waters of the Columbia-Snake system between them have been unsuccessful. Only piecemeal progress has been made: Idaho and Wyoming have concluded an interstate compact on division of the Snake River, while Oregon and California have done the same for the Klamath River.

Since 1980 a four-state organization—the Northwest Power Planning Council—has attempted to influence the planning and management of energy production and fish and wildlife in the region. It has had some modest success but in recent years strains between upstream and downstream states have resurfaced. Discord stems from desires by downstream states to aid salmon migration through releases of water from reservoirs in upstream states. Upstream states benefit relatively little if at all from improved salmon migration and prefer that the reservoir waters in question be used for resident fish and recreation.

Sources

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