REVIEW OF SELECTED LITERATURE ON THE UPPER COLORADO RIVER SYSTEM AND ITS FISHES

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ABSTRACT

A review of selected literature provides the foundation for this symposium and a background for those unfamiliar with the Colorado River. The Upper Colorado River System is discussed and its fishes are introduced by reviewing easily accessible reports. Readers are referred to the bibliographies of Ecology Consultants, Inc. (1977) and Wydoski *et al.* (1980) as guides to other literature.

The Colorado River arises at the headwaters of the Green River in the Wind River Range in western Wyoming and among the peaks of the Rocky Mountains in north-central Colorado. It flows through or adjacent to seven states and 145 km of Mexico to the Gulf of California (Frontis.), receiving major tributaries and losing its waters to major diversions. Including the Green, the river is about 2,735 km long; it flows over 1,609 km through deep canyons, including the Grand Canyon in Arizona. Its basin contains 1/12 of the land area of the United States (Bishop and Porcella 1980). The Colorado River supplies more water for consumptive use than any other in the United States but is not on the U.S. Geological Survey list of 33 rivers with highest discharge (Pillsbury 1981).

The Colorado River Compact approved by Congress in 1928 divided the basin into approximately equal upper and lower segments for water-management purposes. "Lee Ferry," Arizona, defined as "a point 1 mile downstream from the mouth of the Paria River," was selected as the dividing point between the upper and lower basins. Other laws regulating use of Colorado River water are reviewed in this symposium by Harris *et al.*

THE UPPER COLORADO RIVER BASIN

The Upper Colorado River Basin extends about 885 km from north to south, is about 563 km from east to west, and comprises about 283,600 km² of western Colorado, southwestern Wyoming, eastern Utah, northwestern New Mexico, and northeastern Arizona (Iorns *et al.* 1965). Rimmed by some of the highest mountains in America, it includes the Colorado Plateau region and portions of the Middle and Southern Rocky Mountain and Wyoming Basin regions described by Hunt (1974). Hunt (1956,1969,1974) described the geologic history of the basin and the development of the Colorado River. The Upper Colorado River Basin has been sub-divided by several authors into the Green, Upper Main-stem Colorado (or Grand), and San Juan (or San Juan-Colorado) hydrologic sub-basins. The main-stem Colorado River above the confluence with the Green was known as the Grand River prior to 1921. Much of the following descriptive information on the sub-basins is based on the works of LaRue (1916) and Iorns *et al.* (1965).

The Green Sub-basin

The Green Sub-basin has a drainage area of 115,773 km² in Wyoming, Colorado, and Utah. It extends from the source of the Colorado's largest tributary, the Green River, to the confluence of the Green with the Colorado.

The headwaters of the 805-km-long Green River are on the western slopes of the Wind River Range in western Wyoming at an altitude of almost 4,270 m (Frontis.). The Green River has been impounded by Fontenelle Dam in Wyoming and Flaming Gorge Dam in Utah; both impoundments are participating projects of the Colorado River Storage Project, built and operated by the U.S. Bureau of Reclamation. Principal tributaries of the Green River include the Yampa River, the Duchesne River, the White River, the Price River, and the San Rafael River.

The Upper Main-stem Colorado Sub-basin

This sub-basin consists of 68,625 km² in Colorado and Utah; it contains the Colorado River above its confluence with the Green. The Colorado River arises near the eastern slope of Mount Richthofen on the Continental Divide and flows generally southwestward for about 480 km to its confluence with the Green River (Frontis.). Fradkin (1981) stated that seepage from the Grand Ditch, the first major conveyor of water from the basin, now is the source of the Upper Main-stem Colorado River.

Diversion of water out of the Upper Main-stem Colorado River Sub-basin began in 1880, when Eagle River headwaters were diverted to the Arkansas River Basin for placer mining. The Colorado-Big Thompson Reclamation Project, virtually completed in 1956, exports water from the Colorado River headwaters to the South Platte drainage in eastern Colorado (Pennak 1963). Water is stored in Willow Creek Reservoir, Lake Granby, Shadow Mountain Lake, and Grand Lake and is delivered to the eastern slope through the 21-km Adams Tunnel for flood control, irrigation, municipal supplies, hydroelectric power, and recreational facilities.

The Roaring Fork River joins the Colorado River at Glenwood Springs, Colorado. The largest tributary of the Upper Main-stem Colorado, the Gunnison River, enters the Colorado at Grand Junction, Colorado. In Utah, the Dolores River enters the Colorado; it is the last major tributary upstream of the Colorado-Green River confluence.

The San Juan Sub-basin

The San Juan Sub-basin is the drainage between the junction of the Green and Colorado rivers and the Lower Colorado River Basin. Its 99,200 km^2 area is in Colorado, Utah, New Mexico, and Arizona.

The Colorado River below the mouth of the Green River passes through Cataract Canyon and remains entrenched in a deep canyon as it flows about 200 km southwestward to Lee Ferry (Frontis.). Much of the stretch of river below Cataract Canyon is now part of Lake Powell. Glen Canyon Dam and Reservoir (Lake Powell) were authorized by the Colorado River Storage Project Act in 1956; the dam, a few miles below the Utah-Arizona line, was completed in 1964 (Upper Colorado River Commission 1980).

Principal Colorado River tributaries which now enter Lake Powell are the Dirty Devil, Escalante, and San Juan rivers.

The San Juan River arises on the southern slopes of the San Juan Mountains in southwestern Colorado, flows southwestward into New Mexico, and then turns back into the southwestern corner of Colorado before entering Utah. It flows through a deep canyon before entering Lake Powell. The Navajo Storage Unit of the Colorado River Storage Project was completed in 1963 to regulate San Juan River flows for irrigation and municipal purposes (Upper Colorado River Commission 1980).

The Paria River joins the Colorado River about 25 km below Glen Canyon Dam and 1.6 km north of Lee Ferry.

Dams, Reservoirs, and Water Diversions

We have not attempted to mention all dams, reservoirs, and water diversions in the Upper Colorado River Basin. Spofford (1980) referred to nine principal federal reservoirs in the basin. A complete list of the 21 participating projects of the Colorado River Storage Project authorized by Congress appeared in the Thirtieth Annual Report of the Upper Colorado River Commission (1978). Some of these are still in planning phases or under construction. Other, non-federal, projects such as the Moffat and Roberts tunnels of the Denver Water Board also exist. A complete list of existing and planned projects is very difficult to develop and keep up-to-date.

Many diversions, like the Colorado-Big Thompson Project, result in export of water from the Colorado River Basin. Water diverted from the Upper Colorado River Basin is used in the Arkansas River, Platte River, and Rio Grande River basins and in the Great Basin. Martin (1981) reported, for example, that 27% of Colorado's legal share of Colorado River water is diverted to eastern-slope cities from Fort Collins south to Pueblo and that water needs of these cities are expected to increase by at least 200% in the next 30 years. Schad (1980) noted the irony in the Colorado River Basin, which drains some of the nation's more arid lands and has the lowest run-off per square mile of any major river basin, being the source of such a large number of interbasin transfers.

Conditions in the Basin

Iorns *et al.* (1965), Joseph *et al.* (1977), and Bishop and Porcella (1980) summarized conditions in the Upper Colorado River Basin. A broad range of climatic and streamflow conditions exist in the basin; annual precipitation varies from over 127 cm in mountains to under 15 cm in desert areas.

Seasonal streamflow is derived primarily from snowmelt in mountainous areas, and historic unit discharge rates decrease rapidly as tributary streams flow from their headwaters into less humid areas (Bishop and Porcella 1980). Significant variations in annual discharge have occurred from year to year and over periods of years (due to long-term climatic trends). Progressive 10-year running averages of estimated "virgin flow" (if the stream were in its natural state and unaffected by the activities of man) at Lee Ferry have ranged from 16.0 to 17.8 billion m^3 since 1970, and the 1896-1980 long-term annual average virgin flow at Lee Ferry is about 18.3 billion m^3 (Upper Colorado River Commission 1980). The Upper Main-stem Colorado Sub-basin contributes the greatest volume of water and the San Juan Sub-basin the least. Joseph *et al.* (1977) and Spofford (1980) summarized flow data from selected U.S. Geological Survey gaging stations in the Upper Colorado River Basin.

Joseph *et al.* (1977) recognized three distinct stream zones in the Upper Colorado River System. Their upper (headwater) zone was characterized by cold, clear water, high gradient, and rocky or gravelly substrate and was regarded as ideal habitat for cold-water fishes. In this zone primary production (mainly by "periphytic" algae) was considered "significant" and benthic invertebrate production "substantial". An intermediate zone occurs as streams flow from the upper zone; there, water warms, discharge increases, waters are turbid during spring runoff and after heavy rains, and substrates are generally rocky with occasional expanses of sand. Benthic invertebrates are generally abundant only where substrates are rocky, and primary production is higher than in other zones. Salmonid fishes are less common than in the upper zone, and cyprinids and catostomids are predominant. The lower (large-river) zone has warm, turbid water and can be subdivided into two distinct subunits—canyon areas of steep gradient and meandering sections with low gradient in flat terrain. Substrates in high-gradient canyons are of sand, gravel, and rubble; in low-gradient canyons or on flats, sand substrates predominate. Primary production is virtually absent in this zone, and production of benthic invertebrates depends on the availability of gravel-rubble substrate. Allochthonous materials are the basic energy source for this zone's aquatic communities. The fish components of large-river communities are cyprinids and catostomids, and the relative abundance of various species differs considerably in the two subdivisions of the zone.

Bishop and Porcella (1980) identified water-quality problems in the Upper Colorado River System by determining where federal or state water-quality standards were exceeded. Problems were considered primarily local and included acid mine drainage and heavy metals pollution, energy impact, reservoir eutrophication and sedimentation, biochemical oxygen and dissolved oxygen interactions below treatment facilities, and potential health problems associated with municipal sewage discharge. The most serious water-quality problem, in a general sense, is increasing salinity (total dissolved solids). Salinity increases downstream because of concentration of salt in subsurface waters by range and forest tracts and evapotranspiration by phreatophytes and marshy areas along the river. Man's activities have also contributed salts, and salts have been concentrated by irrigation of crops, reservoir evaporation, water diversions, and municipal and industrial water uses. In 1974, at the behest of the Environmental Protection Agency, the seven states of the Colorado River Basin agreed to maintain salinity in the Lower Basin at or below levels measured in 1972. The U.S. also agreed in 1974 to deliver Colorado River water to Mexico at Morales Dam in an amount that does not exceed the average salinity at Imperial Dam (north of Yuma, Arizona) by more than 115 (± 30) mg/liter.

Total sediment load has decreased substantially since construction of Colorado River Storage Project dams on the Upper Colorado River; Lake Powell and Navajo, Fontenelle, Flaming Gorge, Blue Mesa, and Morrow Point reservoirs trap about 75-80% of the sediment that normally flowed into Lake Mead on the lower Colorado (Joseph *et al.* 1977). These and other reservoirs have also significantly altered stream temperatures and discharge in the Upper Colorado River Basin. Joseph *et al.* (1977) discussed temperature, pH, and dissolved oxygen and summarized voluminous U.S. Geological Survey records on carbonates, calcium, chloride, conductivity, magnesium, phosphate, potassium, silica, sodium, sulfate, and turbidity in the Upper Colorado River Basin.

STUDIES OF FISHES OF THE UPPER COLORADO RIVER SYSTEM

The present Colorado River drainage has existed since the Pliocene and has had no broad connections with surrounding river basins for millions of years (Behnke 1980). This long period of isolation has led to a high degree of endemism in the fish fauna of the river (Behnke 1980; Behnke and Benson 1980). Miller (1959) stated that the Colorado River drainage system was second of seven centers of endemism studied in degree of endemism of fish species. It ranked highest (87%) in endemism of primary (strictly freshwater) fishes. Miller listed 35 species, 22 genera, and 11 families of native fishes for the Colorado River System. Hubbard (1980) reported 30 species, 18 genera, and 6 families of native freshwater fishes in the Colorado River Basin, with 73% of the species and 39% of the genera being endemic.

Some disagreement regarding numbers of native and introduced fishes in the Upper Colorado River System is reflected in recent reports. Wydoski (1980) referred to an unpublished 1976 Colorado Wildlife Council list of 50 species and 4 subspecies of fish in the Upper Colorado River. Twenty species and 4 subspecies were said to be native to one or more states in the Upper Basin. Raleigh (1980) cited a 1975 unpublished report of the Utah Water Research Laboratory listing 13 native and 31 introduced fish species in the Upper Colorado River drainage system. Joseph *et al.* (1977) and Behnke and Benson (1980) listed 13 species of fishes native to the Upper Basin. The report by Tyus *et al.* in this symposium contains the most recent and authoritative data on this subject.

Fishes of the Green Sub-basin

Fontenelle and Flaming Gorge reservoirs have had a profound effect on flow and water quality in the Green River; lower summer water temperatures have resulted, and spawning of native fishes in these areas has virtually ceased. The changed habitat immediately downstream favors introduced salmonids which compete with native species (Joseph *et al.* 1977). Generally, introduced fishes appear to be thriving in the Upper Colorado River Basin.

Banks (1974) discussed the fishery resource of the Green River in the Fontenelle tailwater (between the Fontenelle and Flaming Gorge impoundments), where a very productive trout fishery competes with industry, agriculture, and municipal interests for river water. The impact of reduced flows on fish and wildlife was evaluated, and flows to meet most production and survival needs for all sizes of trout and to ensure winter survival were recommended. Wiley and Mullan (1975) evaluated consequences of four flow regimes to help the public allocate their basic water supply. When discharges released from Fontenelle Reservoir resulted in excessive water velocities in relation to available shelter, low use, low yield, and modest standing crop of trout were realized (Mullan *et al.* 1976). Wiley and Dufek (1980) discussed standing stocks and mortality rates of rainbow and brown trout in the Fontenelle tailwater; growth was excellent because of the productive environment. The main factor limiting standing stock was lack of instream cover. Early data collected after some instream cover (large boulders) was provided suggested increased stock in the improved areas.

Gaufin *et al.* (1960) conducted an aquatic survey of the Green River and its tributaries in the Flaming Gorge Reservoir Basin. A checklist of native and introduced fishes was included in their report.

In early September 1962, prior to the closure of Flaming Gorge Dam, the Green River and its tributaries for 362 km above the damsite were treated with rotenone to cause a large-scale reduction of "coarse" fish populations and allow reservoirs and rivers to realize their full potential as trout fisheries (Dexter 1965). The result of introduction of rotenone into the complex river ecosystem was a biological catastrophe. However, Dexter reported a gradual increase in river biota, aided by the stocking of "desired" fish species, by the time his paper was written. Binns (1967) substantiated Dexter's report and discussed devastation of the invertebrate community and its subsequent inability to recover.

Vanicek *et al.* (1970) analyzed the effect on the Green River in Utah of the closure in November 1962 of Flaming Gorge Dam. They studied changes in the river environment; determined species composition, distribution, and abundance of fishes; and compared 1963-1966 distribution of fishes with preimpoundment collections. Seasonal flows changed from high spring and low winter flows to a relatively stabilized seasonal flow pattern, and temperatures and temperature fluctuations decreased. Native fish populations were replaced by rainbow trout in a 42-km section below the damsite. Stalnaker and Holden (1973) stated that no native species were reproducing in the 105-km area from the dam to the mouth of the Yampa River and that trout had replaced native species to the confluence of the Yampa. Four native species (humpback chub, Colorado squawfish, bonytail chub, and razorback sucker) were considered rare. These authors suggested that the Yampa River, the Green and Colorado rivers in the Canyonlands section of southeastern Utah, and Desolation Canyon on the middle Green River appeared to be the only areas in this sub-basin ecologically suitable for maintaining reproducing populations of the large-river endemic fishes.

The tailwater fishery of Flaming Gorge Reservoir had discharge and shelter components that resulted in an exceptional trout yield prior to dysfunction by lowered water temperatures (Mullan *et al.* 1976). In 1978, the U.S. Bureau of Reclamation installed an inlet modification to aid the failing tailwater trout fishery. Warmer water drawn from higher reservoir levels to enhance trout production has elevated stream temperatures and may restore successful reproduction of Colorado squawfish below the dam (Holden 1979).

Miller (1965) discussed the fishes of Dinosaur National Monument and reviewed changes resulting from the closure of Flaming Gorge Dam. Seethaler *et al.* (1979) reviewed earlier work and emphasized the importance of waters in Dinosaur National Monument for the continued existence of endemic fishes. They listed stream alteration (due to dams, irrigation, dewatering, channelization, and unstable banks), increases in competition and predation (due to introduction of non-native fishes), pollution, eutrophication, and other factors as possible causes of declines of endangered and threatened endemic fishes.

Three sampling areas of Holden and Stalnaker (1975a) were on the Green River below its confluence with the Yampa. Flannelmouth and bluehead suckers were predominant in this area.

Joseph *et al.* (1977) stressed the importance of the Yampa River for maintenance of Green River spawning temperatures; recent evidence demonstrates that the Yampa itself provides spawning habitat for rare native fishes. An extensive review of the literature on fishes of the Yampa was done by Carlson *et al.* (1979). Holden and Stalnaker (1975b) concluded that the Yampa River was of extreme importance to the preservation of rare and endangered fishes in the Colorado River Basin; all of the rare forms were then present in the Yampa, and some were apparently reproducing. Carlson *et al.* (1979) presented data on fishes collected in the Yampa River from 1975 to 1978 between Lily Park Pool near Cross Mountain and Hayden, Colorado. Fish distribution, relative abundance, reproduction, growth, food, and habitat were discussed. In 1981, Tyus *et al.* (1982) discovered the first spawning ground of Colorado squawfish in lower Yampa Canyon. Radiotelemetered fish moved into this location from the upper Yampa and middle Green rivers. This discovery links the decline of the Colorado squawfish with blockage of spawning migrations.

Joseph *et al.* (1977) reviewed the history of the White River Basin and stated that changes in the White River due to potential oil shale development will significantly affect the Green River. Carlson *et al.* (1979) provided an extensive literature review on the White River fishes and a report on fishes collected in Colorado from 1975 to 1978. Lanigan and Berry (1979) provided an in-depth report on the endemic fishes of the White River in Utah.

Fishes of the San Rafael River system were discussed by McAda *et al.* (1980). Native fishes were dominant in the tributary streams and middle section of the San Rafael River, while introduced fishes were dominant near the mouth of the river.

Fishes of the Upper Main-stem Colorado Sub-basin

Joseph *et al.* (1977) considered native and introduced fishes of the Upper Main-stem Colorado and factors affecting area streams. Introduction of non-native fishes and waterflow reductions were the main factors involved in declines of native species, and oil shale development will surely add another major obstacle to their survival.

The Gunnison River at one time contained all threatened or endangered fishes of the Upper Colorado System except the Kendall Warm Springs dace and the humpback chub. With the introduction of non-native fishes, the abundance and distribution of these native fishes was drastically curtailed (Joseph *et al.* 1977). Part of the Gunnison River was once a world-famous trout fishery. Wiltzius (1978) reviewed many studies done on the Gunnison after 1927 and discussed the quality and quantity of the trout fisheries since the 1880's. Introduction of several species, together with continued stocking and other factors, played a role in changing the fish fauna. Wiltzius also considered the effects of Blue Mesa and Morrow Point reservoirs on the fishery of the Gunnison. The fisheries in the tailwaters of dams forming these and other major reservoirs in the Upper Basin were discussed by Mullan *et al.* (1976).

Holden and Stalnaker (1975b) discussed the native and introduced fishes of the Dolores, including their abundance and distribution. The Dolores River System appeared to have little importance regarding preservation of rare and endangered fish species and was far from its natural state due to irrigation and severe pollution.

General notes on fishes of the Upper Main-stem Colorado near Moab, Utah, were provided by Taba *et al.* (1965). Holden and Stalnaker (1975a) collected near Moab, at three other sites on the Upper Main-stem Colorado, and at one station on the Gunnison River.

Fishes of the San Juan Sub-basin

Joseph *et al.* (1977) stated that many of the native large-river endemics of the San Juan River were much reduced in distribution and abundance and that some were probably extirpated. Navajo Dam construction appeared to exert the major impact, and competition from introduced species was another significant factor. Koster (1960) and Minckley and Carothers (1979) reported Colorado squawfish captures from the San Juan River.

Fish encountered in the Glen Canyon area on the Colorado River before construction of Glen Canyon Dam included 17 species; only six were native (Woodbury 1959). Major faunal collections came from the tributaries as the river at this point was rapid, showing much scouring and providing little habitat for flora and fauna.

Water impoundment behind Glen Canyon Dam began in January 1963. Largemouth bass were stocked in the resultant Lake Powell in 1963 and 1964, and abundant stocks have been maintained by natural reproduction (Miller and Kramer 1971). Rainbow trout were also introduced in 1963; yearly stocking continued but in later years was restricted to the lower reservoir (May 1973). Introduction of other fishes occurred in part to provide an abundant, vulnerable food source for the four major centrarchids (largemouth bass, black crappie, bluegill, and green sunfish) in the reservoir (May and Thompson 1974; May *et al.* 1975). All resident species experienced changes in their food habits as feeding on introduced threadfin shad increased. Introductions of striped bass in 1974 and 1975 have provided another species to the fishery. May and Gloss (1979) studied depth distribution of major gamefishes in Lake Powell in relation to oxygen and temperature profiles. They referred to earlier, largely-unpublished research on physical, chemical, and biological characteristics of the reservoir. Diversity of habitat in Lake Powell and of its community of endemic and introduced fishes was emphasized. Potter (1980) provided an ecological description of Lake Powell, stressing management of the resource.

Holden and Stalnaker (1975a) collected just below Glen Canyon Dam and reported on fishes of that area. Minckley and Carothers (1979) reported collection of razorback suckers near the mouth of the Paria River.

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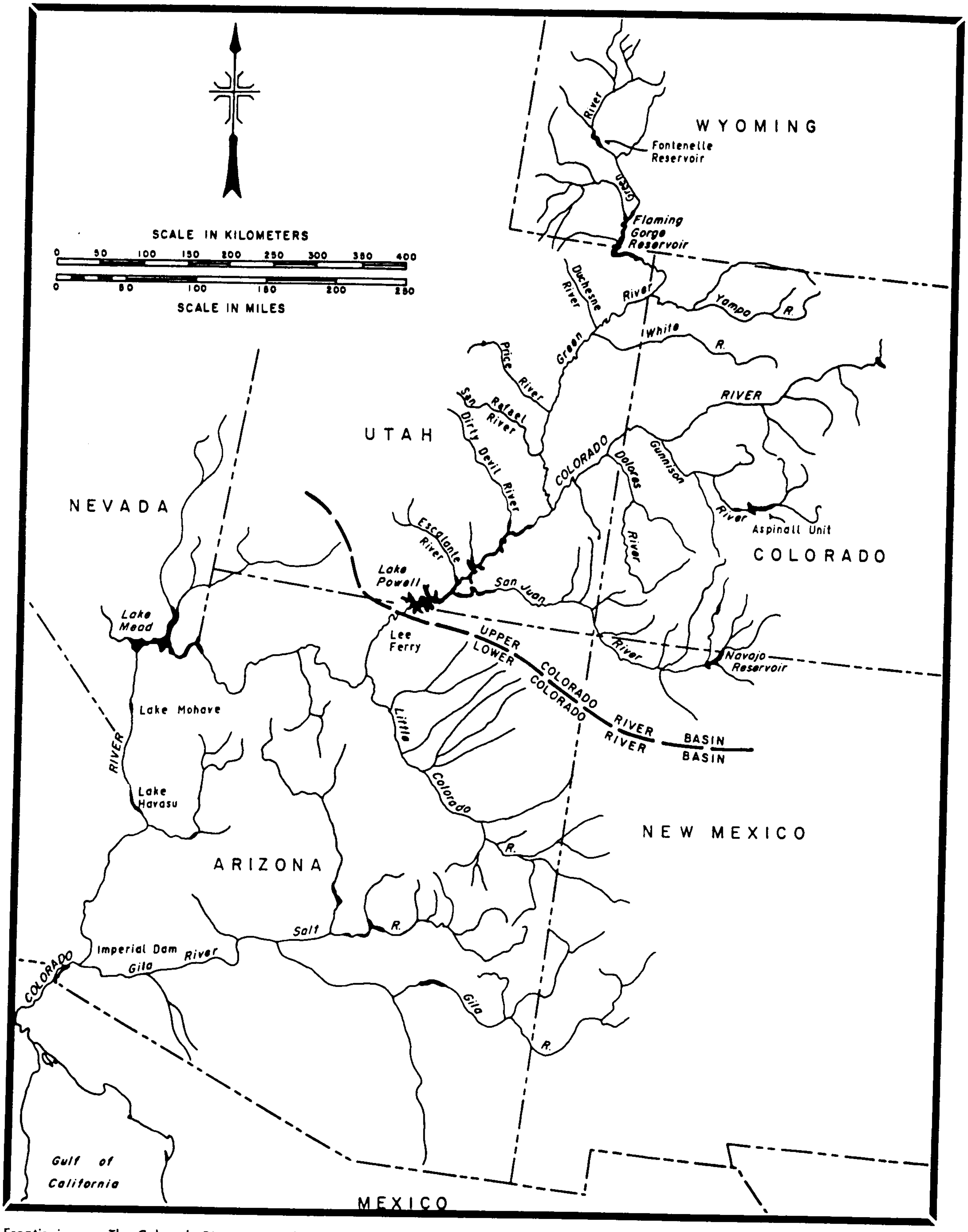

Frontispiece — The Colorado River Basin, showing Upper and Lower sections.