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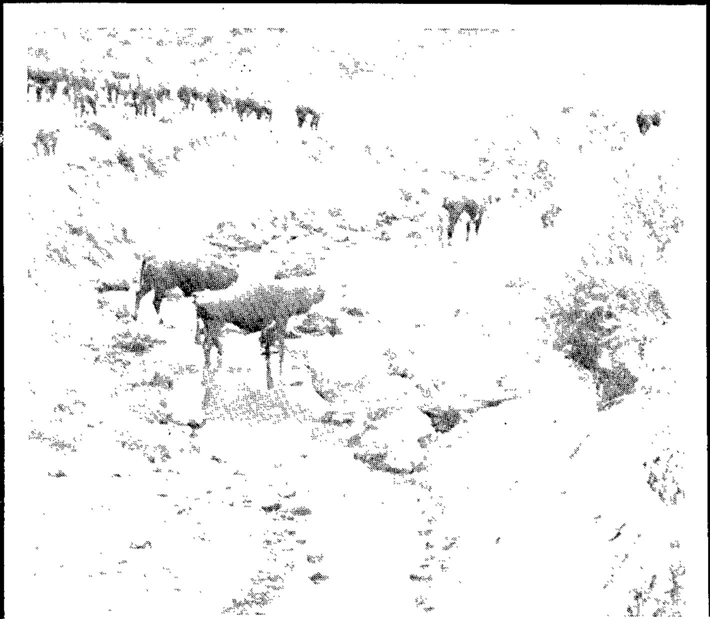
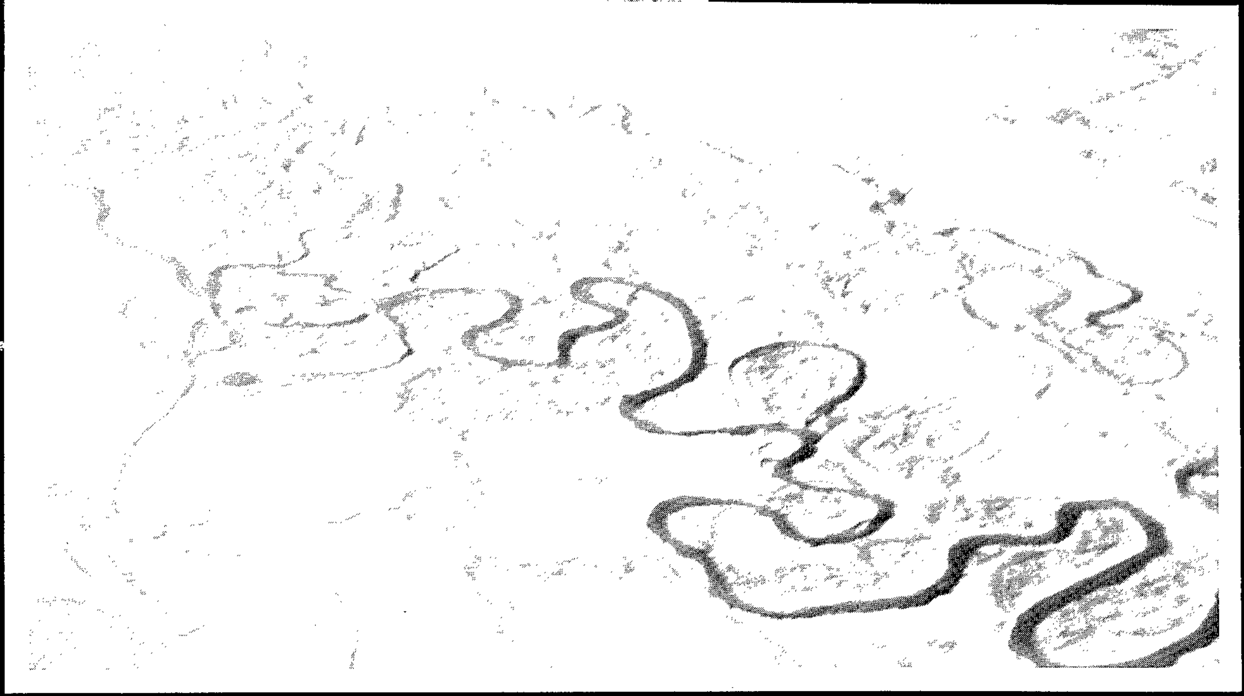


A Community Profile



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THE ECOLOGY OF STREAM AND RIPARIAN HABITATS OF THE GREAT BASIN REGION: A COMMUNITY PROFILE

by

G. Wayne Minshall
Idaho State University
Department of Biological Sciences
Pocatello, ID 83209

Sherman E. Jensen
White Horse Associates
P.O. Box 123
Smithfield, UT 84335

and

William S. Platts
U. S. Forest Service
Intermountain Forest and Range Experiment Station
316 East Myrtle Street
Boise, ID 83702

Project Officer

Walter G. Duffy
U.S. Fish and Wildlife Service
National Wetlands Research Center
1010 Gause Boulevard
Slidell, LA 70458

Performed for

U.S. Fish and Wildlife Service
National Wetlands Research Center
NASA-Slidell Computer Complex
1010 Gause Boulevard
Slidell, LA 70458

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PREFACE

The purpose of this profile is to summarize the ecological information available for and relevant to stream and riparian habitats of the Great Basin. The Great Basin comprises the northern half of the Basin and Range physiographic province and covers most of Nevada and western Utah and portions of California, Oregon, and Idaho. The entire basin actually consists of numerous subbasins and mountain ranges which present an extremely diverse physical setting. Unlike other physiographic regions, drainage patterns in the Great Basin are characteristically toward the interior, which has a major influence on water quality as well as biota within the basin. Surface waters of the Great Basin include perennial, intermittent, and ephemeral streams; freshwater and saline lakes; playa lakes; freshwater and saline wetlands and thermal springs associated with faulting and volcanic activity.

Riparian and stream habitats within the Great Basin have received less attention from ecologists than similar habitats elsewhere in the United States. As a consequence, little is known about certain aspects of ecosystem structure and function within the Great Basin. This profile is intended to serve as a reference to the ecology of riparian and stream habitats of the Great Basin. References cited in the profile should also assist those wishing to learn more about these habitats.

CONVERSION TABLE

Metric to U.S. Customary

Multiply	*By*	*To Obtain*
millimeters (mm)	0.03937	inches
centimeters (cm)	0.3937	inches
meters (m)	3.281	feet
meters	0.5468	fathoms
kilometers (km)	0.6214	statute miles
kilometers	0.5396	nautical miles
square meters (m^2)	10.76	square feet
square kilometers (km^2)	0.3861	square miles
hectares (ha)	2.471	acres
liters (L)	0.2642	gallons
cubic meters (m^3)	35.31	cubic feet
cubic meters	0.0008110	acre-feet
milligrams (mg)	0.00003527	ounces
grams (g)	0.03527	ounces
kilograms (kg)	2.205	pounds
metric tons (t)	2205.0	pounds
metric tons	1.102	short tons
kilocalories (kcal)	3.968	British thermal units
Celsius degrees (° C)	1.8 (° C) + 32	Fahrenheit degrees

U.S. Customary to Metric

inches	25.40	millimeters
inches	2.54	centimeters
feet (ft)	0.3048	meters
fathoms	1.829	meters
statute miles (mi)	1.609	kilometers
nautical miles (nmi)	1.852	kilometers
square feet ft^2)	0.0929	square meters
square miles (mi^2)	2.590	square kilometers
acres	0.4047	hectares
gallons (gal)	3.785	liters
cubic feet (ft^3)	0.02831	cubic meters
acre-feet	1233.0	cubic meters
ounces (oz)	28350.0	milligrams
ounces	28.35	grams
pounds (lb)	0.4536	kilograms
pounds	0.00045	metric tons
short tons (ton)	0.9072	metric tons
British thermal units (Btu)	0.2520	kilocalories
Fahrenheit degrees (° F)	0.5556 (° F - 32)	Celsius degrees

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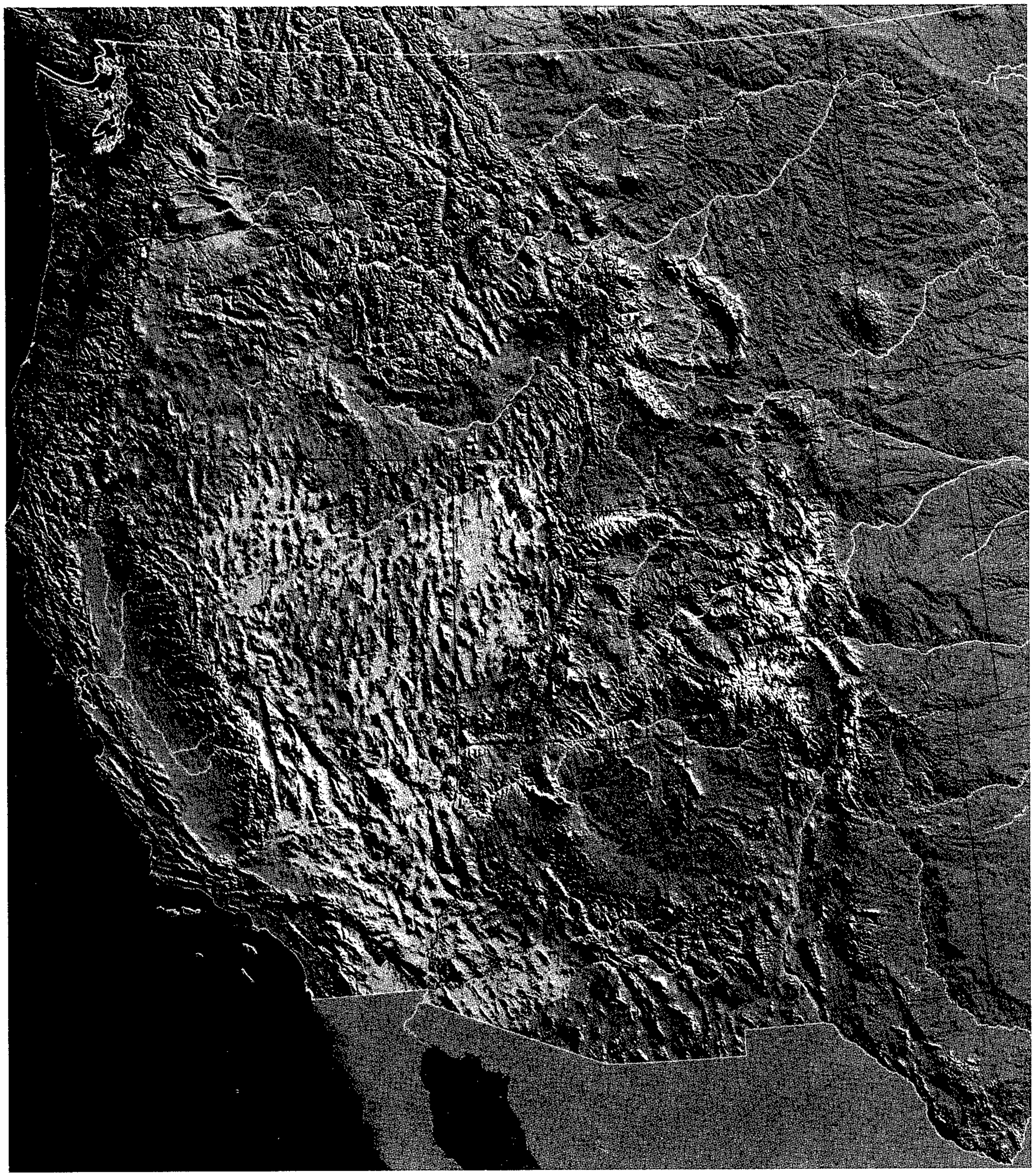


Computer-enhanced photograph from National Oceanic and Atmospheric Administration, Earth Resources Technology Satellite (NOAA ERTS) data showing topography of the Great Basin and surrounding regions including principal water masses (courtesy of Battelle Pacific-Northwest Laboratories, Richland, Washington).

CHAPTER 1. INTRODUCTION

The purposes of this document are to provide a geographical overview of the Great Basin environment and to provide more resolute descriptions of the ecological features of riparian and stream habitats. The overview is focused on the environmental parameters that influence the distribution, magnitude, flux, and qualities of surface water. The distribution, structure, composition, and dynamics of riparian and stream habitats are interpreted as a response to geologic, hydrologic, geomorphic, pedogenic, and biotic processes. The values of stream and riparian habitats are considered to be a measure of the relative effectiveness of these same processes in determining the qualities of each site.

1.1 GREAT BASIN

John C. Fremont, following an expedition through the region in 1843 and 1844, first applied the term "Great Basin" to a vast area of land encompassing most of Nevada and western Utah. The region includes numerous north-to-south trending mountain ranges separated by nearly level basins. Contrary to the singular connotation of the term "Great Basin," the region includes more than 75 elongated basins, most of which are bordered by mountain ranges on the east and west and by low alluvial divides on the north and south. The Great Basin region also includes two irregularly shaped basins that contained extensive lakes during the Pleistocene Epoch (including Lake Bonneville and Lake Lahontan) (Figure 1). Since the time of Fremont, the term "Great Basin" has been used to denote physiographic, floristic, and hydrographic regions, each with somewhat different boundaries.

Fenneman (1931) defined the Great Basin as a section of the Basin and Range physiographic province (Figure 2). The Great Basin section, including portions of Oregon, Idaho, California and most of western Utah and Nevada, makes up the northern half of the physiographic province. The Great Basin physiographic section is bordered to the north by the Columbia Plateau province; to the west by the Sierra-Cascade province; to the east by the Middle Rocky Mountain and Colorado Plateau provinces; and the southern border is the arbitrary latitude of 35°30′ N. Although drainage is to the interior characteristic of the Great Basin physiographic section, three watersheds located along the periphery drain toward the ocean.

The Great Basin floristic division of the intermountain region (Cronquist et al. 1972) includes most of the Great Basin physiographic section and also the Snake River Plains and Owyhee Desert of Idaho and Oregon which drain to the Columbia River (Figure 3). Floristic sections generally correspond with climatic, physical, or edaphic criteria that influence the distribution of plants.

The Great Basin hydrographic region is the watershed area contributing to the closed basins (Figure 4). The hydrographic delineation provides the most discrete and unequivocal boundary and has been used in this report. It includes most of the Great Basin physiographic section (Fenneman 1931), in addition to portions of the Sierra-Cascade, Middle Rocky Mountain, Columbia Plateau, and Colorado Plateau physiographic provinces.

1.2 RIPARIAN HABITAT

For the purposes of this review we have adopted the following working definition

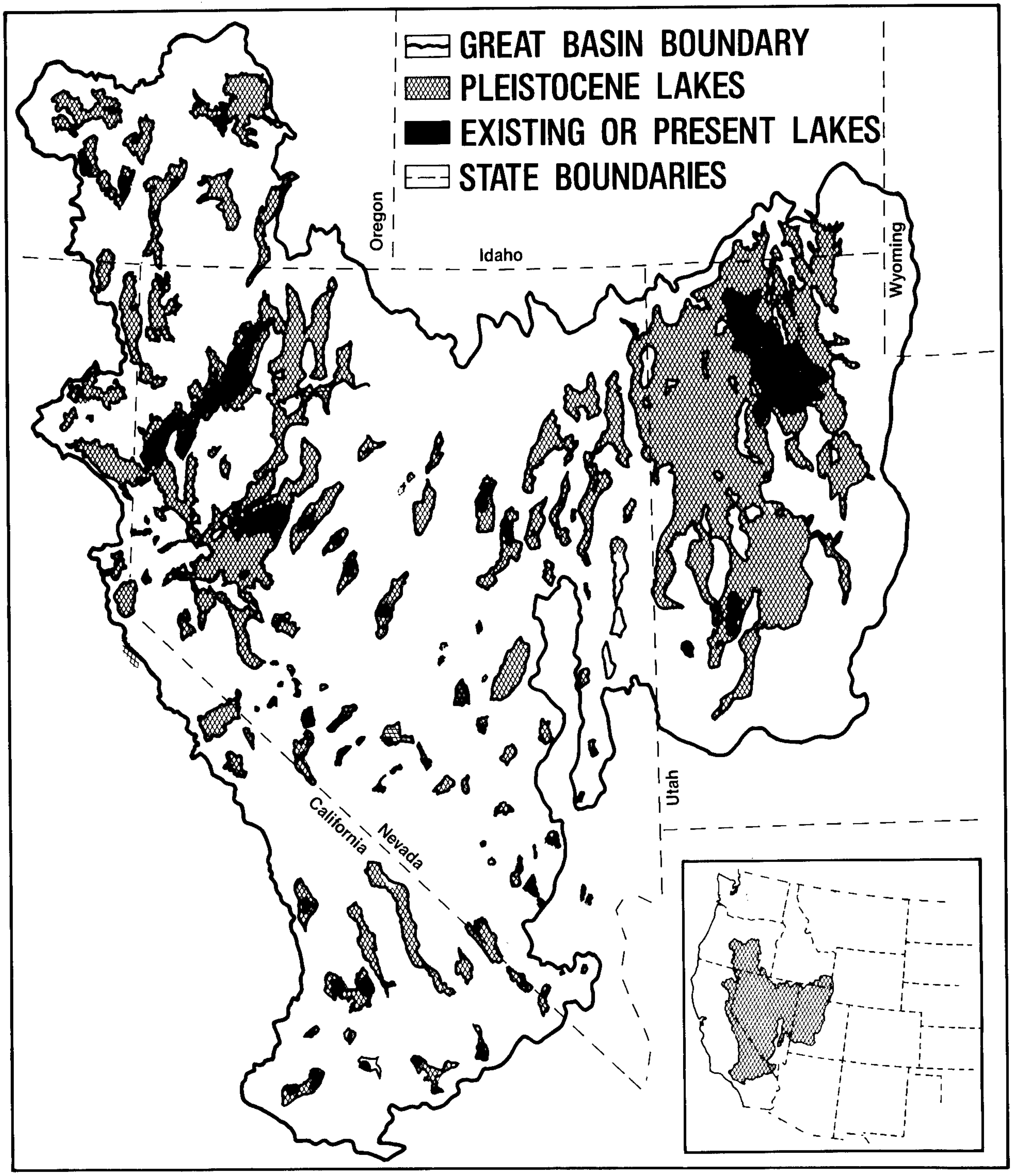


Figure 1. Distribution of Pleistocene lakes in the American Great Basin (after Snyder et al. 1964).

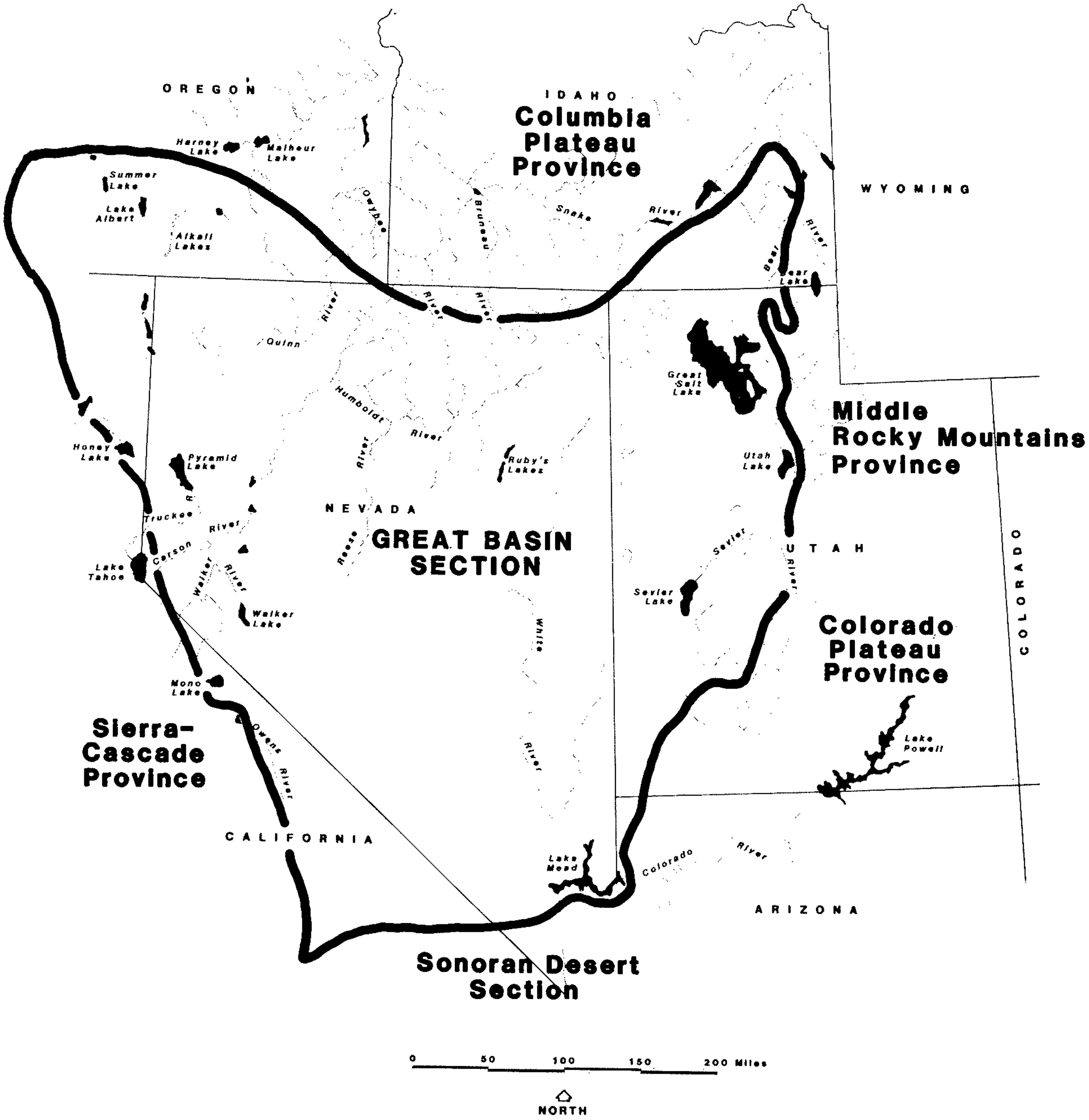


Figure 2. The Great Basin section of the Basin and Range physiographic province.

Figure 3. Floristic sections of the Great Basin (modified from Cronquist et al. 1982).

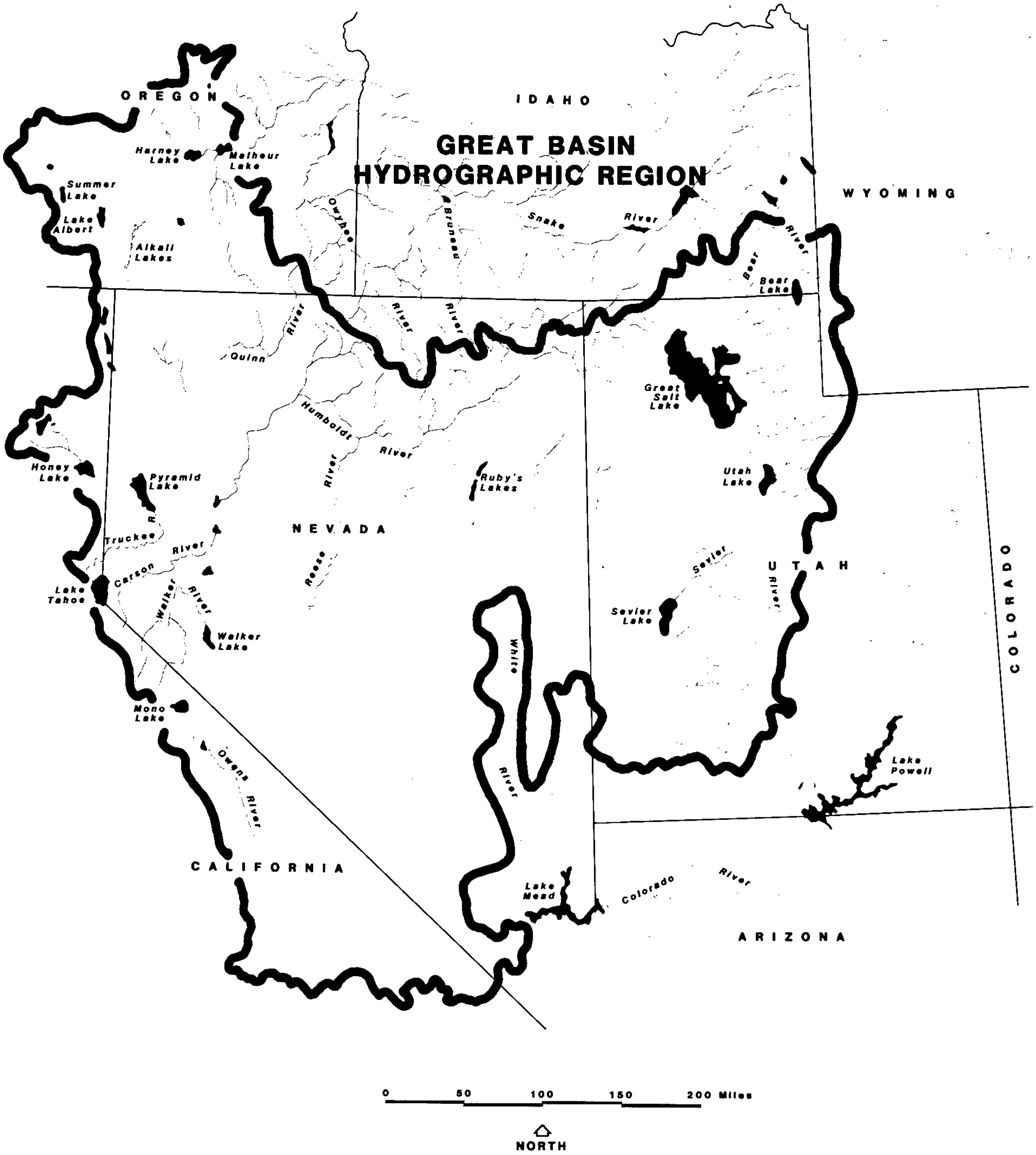


Figure 4. Great Basin hydrographic region.

of riparian habitat: Land inclusive of hydrophytes and/or with soil that is saturated by ground water for at least part of the growing season within the rooting depth of potential native vegetation. This definition includes both vegetated wetlands as defined by the U.S. Fish and Wildlife Service (Cowardin et al. 1979), and more mesic riparian habitats. The extent of riparian versus wetland habitats relative to seasonal variations in ground water level is compared in Figure 5.

The U.S. Fish and Wildlife Service is conducting an inventory of wetland and deepwater habitats of the United States (National Wetlands Inventory) according to the classification developed by Cowardin et al. (1979). While draft and revised map products are available for portions of the Great Basin (U.S. Fish and Wildlife Service 1986a, b), a large portion of the hydrographic region remains to be inventoried. In general, classifications for riparian habitats in the vast majority of the Great Basin hydrographic region are not currently available. A high degree of disparity between methods, criteria, and the resolution of classifications for different regions of the Great Basin limits meaningful comparison or possible integration of existing riparian classifications.

Classifications of riparian community types have been prepared for portions of the Great Basin hydrographic region in Utah (Jensen and Tuhy 1981; Youngblood et al. 1985a,b). A riparian community type is defined as an abstract grouping of riparian communities based upon floristic and structural similarities in both overstory and undergrowth layers (Youngblood et al. 1985a). These classifications, requested by the U.S. Forest Service, are part of a regional effort to identify riparian communities in U.S. Forest Service lands of Idaho, Nevada, Utah, and Wyoming (Region 4). Methods of classification have been summarized by Norton et al. (1981) and by Youngblood et al. (1985c). While these classifications were based primarily on floristic criteria, geomorphic, soil, and hydrologic parameters also were described for each community type.

Streamside types were identified according to location in the watershed and topography for portions of the Malheur National Forest, located along the northern boundary of the Great Basin hydrographic region in east-central Oregon (Claire and Storch 1977). Vegetation types were described for each streamside type. Classifications of riparian habitat in Arizona and New Mexico have been attempted (Brown and Lowe 1974; Dick-Peddie and Hubbard 1977; Pase and Layser 1977).

Several other efforts have been made to classify riparian habitats which may have relevance to the Great Basin. Shaw and Fredine (1956) developed a classification system that identified 20 wetland types, 11

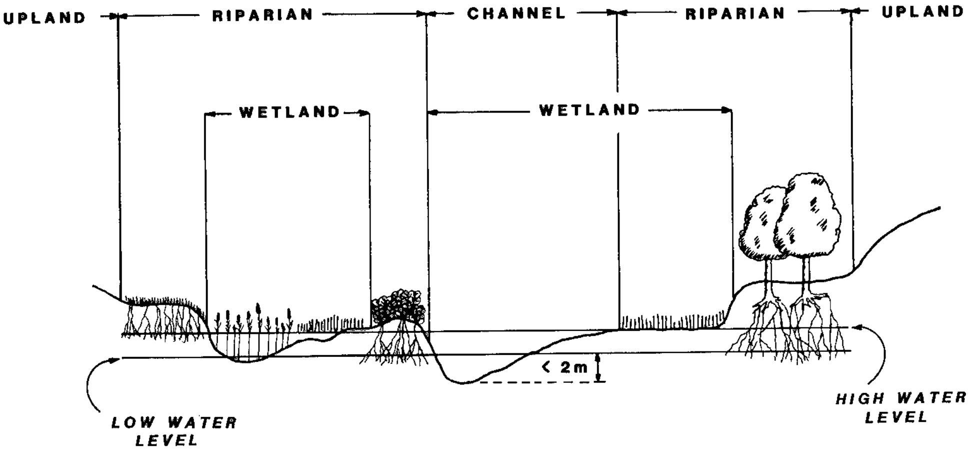


Figure 5. Riparian versus wetland habitat.

of which are represented in the Great Basin hydrographic region, in order to evaluate the importance of wetland habitat to waterfowl. They identified 1,008 km^2 of high quality wetlands considered to be for waterfowl in Utah; 442 km^2 in Nevada; and 996 km^2 in Oregon. The vast majority of wetlands were associated with shallow freshwater and saline lakes. Brown (1982) described biotic communities of the American Southwest, a region including southern portions of the Great Basin (Mohavian Biogeographic Province). Minckley and Brown (1982) suggested a general structure for classification of wetlands in the Southwest. A digitized hierarchical classification system for both upland and riparian habitats of North America, with examples of communities and associations for the Southwest was prepared by Brown et al. (1984). This system uses biogeography, vegetation, structure, and climate as criteria (Brown 1984).

1.3 AQUATIC HABITAT

Aquatic habitat, as used in this review, is any environment covered by water and includes both the wetland and deep water habitats distinguished by Cowardin et al. (1979). Great Basin aquatic habitats include riverine (stream), lacustrine (lake), and palustrine (marsh) systems (Cowardin et al. 1979). We have attempted to include coverage of all of these systems because they have a great deal in common: generally all have associated riparian habitats, they frequently are linked together, and all are of significance to aquatic/riparian resource managers. However, partly because of historic precedent, but mainly because of their greater numbers and extent and because they have been the focus of more studies, streams will be the focus of our coverage.

Stream habitat is considered to be synonymous with the riverine system, as defined by the U.S. Fish and Wildlife Service (Cowardin et al. 1979). The riverine system includes nonvegetated wetland habitat and deepwater habitat contained within a river channel. Stream habitat includes the channel banks, channel bottom, and aquatic habitat (Figure 6). It should be noted that the portion of the channel inundated by streamflow (aquatic habitat) may vary as a function of stream discharge. Streams can be further subdivided into (a) perennial which flow year round and (b) ephemeral streams which flow only for relatively short periods during the wetter months (usually spring). Ephemeral streams appear to be biologically depauperate.

Great Basin aquatic ecosystems have been appropriately characterized as islands of freshwater in a sea of land. These desert oases provide important refuge for a variety of invertebrates, fish, and wildlife many of which have adjusted in a number of interesting ways to the stresses imposed by the environment. Due to the shortage of precipitation over most of the Great Basin and the critical importance of

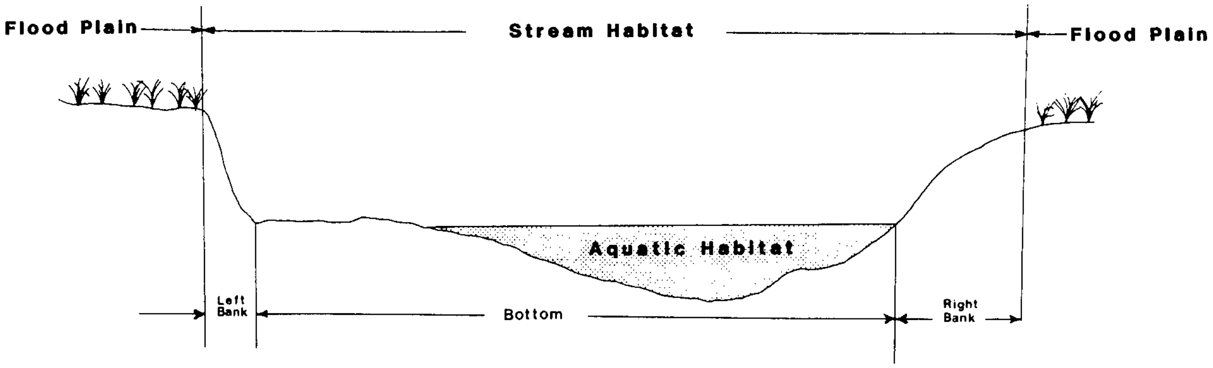


Figure 6. Stream habitat (modified from Platts 1983).

water to humans, the manipulation, alteration, and out-right destruction of waterbodies are among the major perturbations taking place. Many unique and scientifically interesting sites have been or are being destroyed or significantly altered. Thus there is an urgent need to study such environments and the organisms that occupy them before they are altered or removed forever.

Less is known about the structure and function of aquatic systems in the Great Basin than in any other major area in the United States. Furthermore, very little is known of the biology of the many unique species living there or of the adaptations which enable them to persist. Aquatic habitats in the Great Basin are ecosystems, often relatively "closed" or isolated, operating under severe stress conditions especially in regard to temperature, timing and amount of water, and salinity. Many of these systems are extremely fragile; others are surprisingly resilient. The reasons for these differences need to be known for proper management and protection and to make the effects of possible future disturbances predictable.

The current state of study of Great Basin aquatic communities serves to outline how little is known about how they respond to changes and stress. Much can be learned about "strategies for survival" from study of the colonizing species, from patterns of succession, and from study of the food chains and energy sources and their utilization. For example, one of the reasons that temporary waterbodies respond biologically so rapidly after wetting seems to be due to the dehydrated vegetable matter and feces carried in by runoff and stored in the basin. This quickly becomes a nutrient broth for bacteria and algae and in turn provides food for protozoans and newly hatched crustaceans and insects. Thus elimination of this allochthonous input by overgrazing could severely limit the chances for successful completion of life cycles by the resident population. Because of a limited number of taxa, the extreme physical factors, and the relative instability of populations, many Great Basin aquatic systems provide especially favorable sites for functional studies and for the study of non-equilibrium species populations under constantly changing conditions. Few such studies have been made; therefore, Great Basin aquatic ecosystems provide an important opportunity to extend the rather atypical "steady state" ecological concepts to more realistic dynamic conditions.

CHAPTER 2. GEOGRAPHICAL OVERVIEW

2.1 CLIMATE OF THE GREAT BASIN PHYSIOGRAPHIC SECTION

The Great Basin lies in the rain shadow of the Sierra Nevada Mountains. The region is semiarid to arid. High mountains to the west capture most of the moisture associated with the generally eastward-moving air masses from the Pacific Ocean (Morrison 1965). Rain shadow effects also are produced by the numerous ranges oriented transverse to prevailing winds within the Great Basin.

Mean annual precipitation in the Great Basin ranges from less than 10 cm in the lower basins to more than 76 cm on the higher mountain summits; a difference of more than 51 cm over a distance of a few kilometers is common. Most of the winter precipitation falls as snow, while most of the summer precipitation occurs as infrequent torrential showers. Patterns and amounts of precipitation are extremely variable from year to year, while annual temperatures are more consistent. In general, relative humidity is very low.

Mean annual temperature for a given altitude generally differs by about 6.1 °C between southern and northern boundaries of the Great Basin. Average January and July temperatures across the latitudinal gradient are listed in Table 1.

Due to the closed drainage configuration characteristic of the Great Basin hydrographic region, all loss of precipitation is through evapotranspiration. In the northern portion of the region, precipitation generally equals or exceeds evapotranspiration and permanent lakes are maintained at the terminal sinks of larger rivers. In the southeast, potential evapotranspiration exceeds precipitation by a considerable amount and there are no permanent natural lakes.

In the Miocene and Pliocene, the climate of the Great Basin was subhumid, with 63 to 76 cm of precipitation (Axelrod 1950). Botanical evidence indicates that the contemporary climate of the Great Basin began in early Pleistocene time. The more arid climate is thought to have resulted from uplift of the Sierra Nevada by block faulting (Morrison 1965). The Pleistocene climate fluctuated considerably with respect to both temperature and precipitation.

The cooler and wetter climatic periods of the Pleiocene Epoch are called pluvials, and are thought to have been 4.4 to 8.3 °C cooler than interpluvial periods, causing

Table 1. Average January and July temperatures (Morris 1965).

Location	Latitude	Average Temperature (°C) January	July
Burns, OR	43.5	-4	19
Salt Lake City, UT	41	-1	25
Reno, NV	39.5	0	22
Las Vegas, NV	36	7	30

permanent lakes to form in terminal basins. These pluvial intervals were concurrent with glacial intervals in the higher mountains to the east and west of the Great Basin, with studies of deposits showing evidence of several such wet/dry cycles (Morrison 1965). These climatic changes caused biological life zones to move hundreds of kilometers from north to south and many thousands of meters up and down mountainsides.

2.2 STRUCTURAL GEOLOGY OF GREAT BASIN PHYSIOGRAPHIC SECTION

The topography of the Great Basin is characterized by numerous north-to-south trending ranges separated by broad, nearly level basins. The topography is the result of block faulting of folded and thrust-faulted overlapping geosynclines of Paleozoic and early Mesozoic ages, and of the accompanying deposition of mineral debris weathered from upthrust portions of blocks over downthrust block surfaces.

Throughout most of geologic history, the central and eastern areas of the present Great Basin were part of the Cordilleran Geosyncline (see Figure 7a). Sediments were deposited in the ancient sea that passed back and forth over the Paleozoic landscape, and formed the rock strata conspicuous in mountain ranges throughout the region. While calcareous sediments in the eastern and northern areas of the geosyncline were later consolidated as limestone strata, igneous sediments characteristic of more westerly areas of the geosyncline formed sandstone, siltstone, and shale.

A second geosyncline formed in early Mesozoic time along the western flank of the Great Basin (Figure 7b). Mesozoic sediments, derived primarily from volcanic eruptives, overlapped the western flank of the Paleozoic geosyncline, while strata to the east were folded and up-lifted in a geanticline. The Mesozoic sediments are evident in strata of ranges in the western Great Basin.

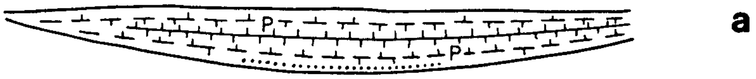
In middle and late Mesozoic time, an extensive batholith intruded into the region of the Sierra-Cascade province, causing folding, thrust faulting, and uplift of the Paleozoic and Mesozoic strata to the east (Figure 7c). During late Mesozoic and early Tertiary time, intrusions of igneous rocks (stocks and laccoliths) penetrated the deformed sedimentary strata of the Great Basin (Figure 7d).

The extensive block faulting responsible for the present topography of the Great Basin began in middle Tertiary time (Figure 7e). Volcanic activity, which was sporadic throughout the early Tertiary, became extensive. As block faulting continued, sediments weathered from upthrust portions of blocks accumulated in the intervening basins. Nolan (1943) suggests that block faulting has been continuous since the Oligocene age.

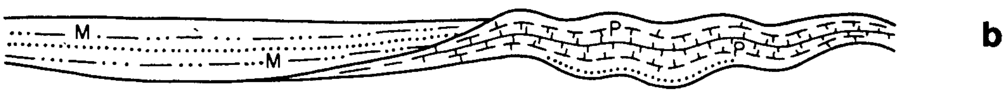
2.3 PHYSIOGRAPHY OF THE GREAT BASIN SECTION

Fenneman (1931) defined the Great Basin as a section of the basin and range province. A latitudinal cross-section through the center of the section resembles a broad, partly-collapsed arch (Morrison 1965) having its highest part in eastern Nevada and dipping towards both the east and west. The longitudinal profile of the section dips southward. Dutton (1880) likened the pattern of discontinuous, sub-parallel ranges to that of an "army of caterpillars marching to Mexico." Hunt (1967) further divides the Great Basin physiographic section into five subdivisions based on structure, topography, hydrography, and surface deposits (Figure 8).

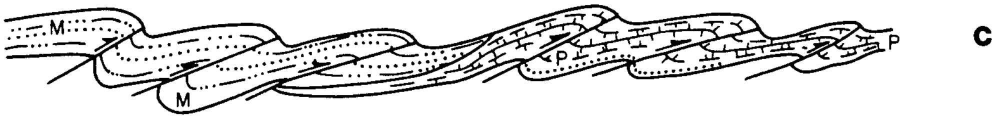
The central subdivision of the Great Basin physiographic section is topographically and structurally elevated relative to surrounding parts of the Great Basin. Basins in eastern Nevada range from 1,615 to 1,838 m in elevation (Morrison 1965). During the Pleistocene, at least 21 pluvial lakes formed in the Central Basin, some overflowing to adjacent basins (Meinzer 1922). Two basins within the subdivision overflowed to the Colorado River during late Pleistocene time (Morrison 1965); the White River and Meadow Valley Wash have maintained this external drainage. Dry lake beds and playas make up



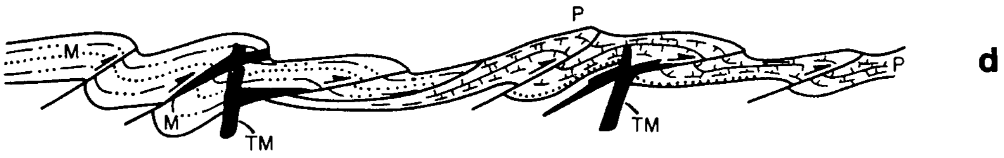
Paleozoic (P) geosyncline



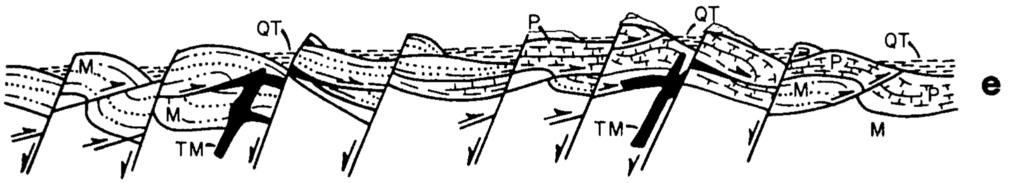
Early Mesozoic geosyncline (M), and Paleozoic formations folded



Middle and Late Mesozoic folding and thrust faulting



Late Mesozoic and Early Tertiary (TM) stocks and laccoliths intruded



Middle and Late Cenozoic block faulting, with sediments (QT) deposited in the basins; Great Basin arched. Much volcanic action (not shown).

Figure 7. Evolution of geologic structure in the Great Basin (from Hunt 1967).

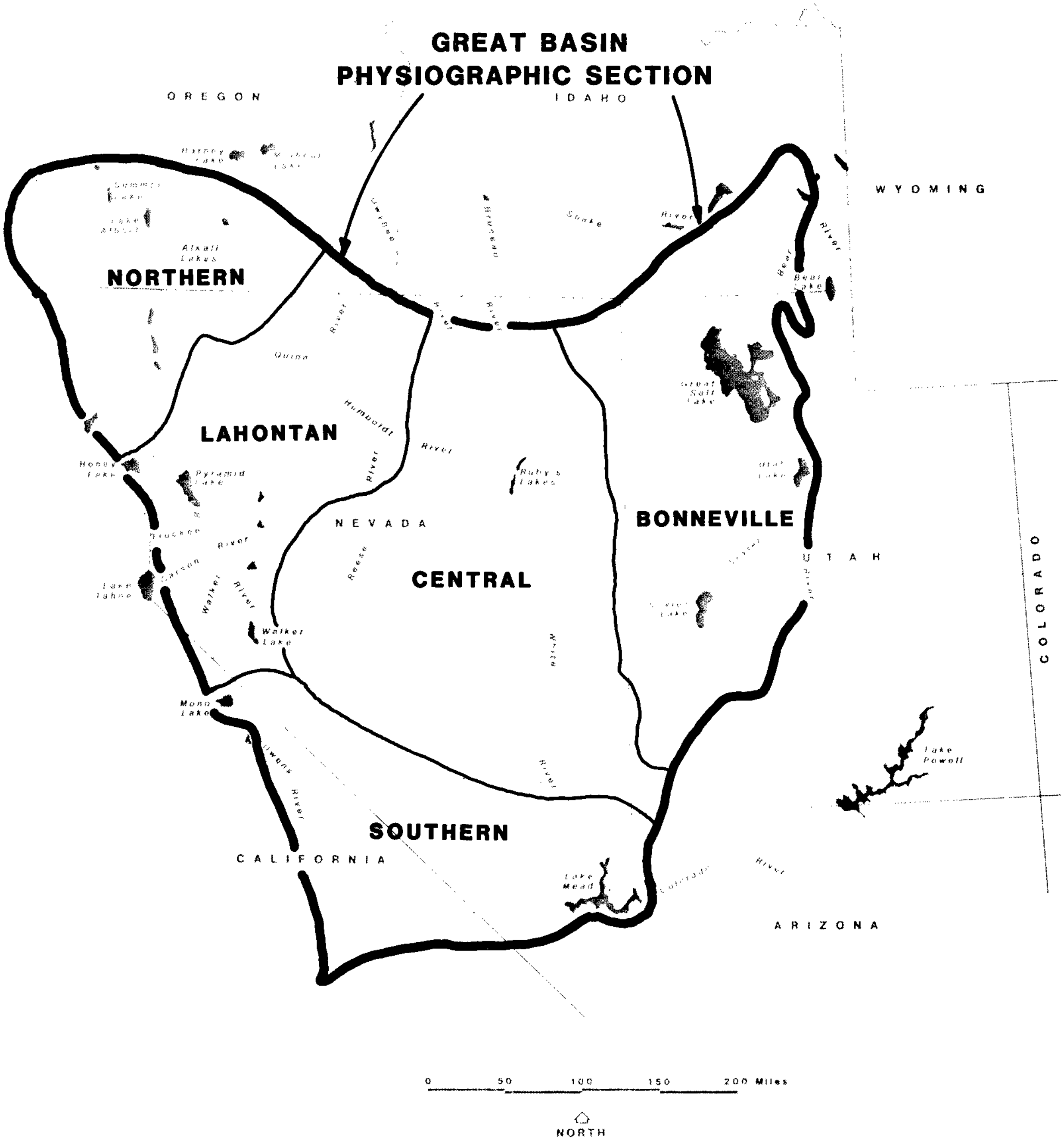


Figure 8. Subdivisions of the Great Basin physiographic section (modified from Hunt 1967).

about 10% of the central subdivision, and mountain ranges and alluvial fans about 45% of the area (Hunt 1967). A major part of the subdivision drains to the Lahontan Basin via the Humboldt River.

The Bonneville subdivision is topographically lower than the central subdivision to the west, with basin floors commonly 1,158-1,524 m in elevation. The subdivision is bordered to the east by the Middle Rocky Mountain and Colorado Plateau physiographic provinces. The Great Salt Lake, covering an area of about 6,030 km^2 in 1985 (U.S. Department of Interior, Bureau of Land Manangement 1986), is the modern relict of Lake Bonneville. Lake flats and playas are extensive and constitute about 40% of the Bonneville subdivision. Mountain ranges occupy about 25%, and alluvial fans and bajadas make up about 35% of the area (Hunt 1967). Delta terraces, and beaches skirting the feet of mountain ranges in the Bonneville subdivision reflect several relatively stable levels of Lake Bonneville.

The Lahontan subdivision is situated between the elevated central subdivision and the Sierra-Cascade province. Lake Lahontan covered an area of about 22,442 km^2 at its maximum level during Pleistocene time (Morrison 1965). Russell (1885) determined that the pluvial lake never overflowed its basin. Honey, Pyramid, and Walker Lakes are relicts of Lake Lahontan. The proportional extent of alluvial flats, playas, alluvial fans, bajadas, and mountain ranges in the Lahontan Basin is similar to that described for the Bonneville subdivision (Hunt 1967).

The northern subdivision is north of the Lahontan subdivision and includes portions of southeastern Oregon, northeastern California, and northwestern Nevada. The subdivision is characterized by many high volcanic cones and thickblock-faulted lava beds that are thought to be underlain by the folded and faulted Mesozoic strata characteristic of the Lahontan subdivision (Hunt 1967). While topographically higher than the Lahontan subdivision because of the thick layers of volcanic sediments, the subdivision is structurally depressed, possibly as a result of the overlying mass of Quaternary lava. At least 13 major pluvial lakes filled basins in Pleistocene time: several overflowed to the Snake River, another drained to the Pacific via the Pit River drainage and a few in the vicinity of Honey Lake drained to the Lahontan basin. Most of the pluvial lakes lacked external drainage (Morrison 1965). Many shallow lakes, remnants of the more extensive pluvial bodies, are distributed throughout the northern subdivision.

The southern subdivision is both structurally and topographically lower than the Lahontan and central subdivisions. The northern boundary corresponds with the Las Vegas shear zone, which runs parallel to the diagonal southwestern boundary of Nevada and extends from the vicinity of Lake Mead to the vicinity of Walker Lake. Blocks on the southwestern side of the shear zone have moved northwesterly relative to blocks on the northeastern side; the extent of displacement appears to have been several kilometers along the southeastern part of the shear zone (Hunt 1967). The shear displacement is marked by a northwest trending belt of low hills. Strata exposed in the mountain ranges of the southern area include intricately folded and faulted Precambrian beds of a geosyncline which preceded the Cordilleran Geosyncline. Paleozoic strata and more isolated early Mesozoic beds, granitic intrusions related to the Sierra-Cascade batholith, and a thick series of Tertiary and Quaternary volcanic rocks also are present. A series of pluvial lakes inundated parts of the southern basin during the Pleistocene Epoch. Lake Russell, of which Mono Lake is a relict, and two other sizable pluvial lakes overflowed to Owens Lake via the Owens River. Owens Lake drained through several pluvial basins on its course to pluvial Lake Manly in Death Valley. The Amargosa River carried overflow from three additional basins to Lake Manly, now a desert playa. The southern subdivision includes much of the Mojave Desert and is transitional to the Sonoran Desert section of the basin and range province (Fenneman 1931).

2.4 GEOMORPHOLOGY

Mountain ranges and basins are the major geomorphic features of the Great Basin. The land forms of the Great Basin are a response to weathering and erosion acting upon diastrophic features. Lake terraces and beaches skirting the flanks of the Bonneville and Lahontan subdivisions are evidence of climatic changes since the Pleistocene age. Glacial land forms also are evident in the highest mountain ranges of the central subdivision.

2.4.1 Mountain Ranges

The mountain ranges of the Great Basin are typically fault-block ranges that are relatively narrow and oriented in a north-to-south direction, with steep escarpments on the upthrust aspects and somewhat gentler slopes on the down-dip aspects. About three-fourths of Great Basin ranges fit this generalized description (Bostick et al. 1975).

Fenneman (1931) describes the "typical" mountain range as 80-120 km long, 10-24 km wide, 914-1524 m above the base, 2133-3048 m in elevation and north-to-south trending with a slight deviation to the east. Generally, the crests of the ranges are relatively level with few prominent peaks, although ridgelines may be very jagged.

Mountain slopes usually are nearly uniform in angle from crest to base, thus enhancing an appearance of steepness. The angles of mountain slopes appear to remain constant as escarpments recede (Hunt 1967), which may be more a response to rock type than to any other characteristic (Fenneman 1931). The sideslopes of some ranges consist entirely of deep ravines, forming V-shaped gorges that are separated by acute ridge spurs (Gilbert 1890). Ravines are apt to be cut into bare rock with little or no rock detritus in their beds. The slope of ravines is normally as steep near the base of the mountain ranges as at the summit instead of flattening out towards the foot as is characteristic of most stream profiles. In many cases, the ridge spurs between the ravines do not taper gradually to the base of slopes but rather are cut off abruptly in terminal facets, which are thought to be the result of relatively recent faulting. The transition from residual mountain slopes to alluvial basins generally is marked by an abrupt change in slope angle. Successional stages of geomorphic development of fault-block mountains are illustrated in Figure 9.

While glacial (U-shaped) valley forms are evident along the crests of some ranges, fluvial (V-shaped) canyons are typical of the vast majority of Great Basin ranges. In headwater segments, fluvial erosion is headcutting towards ridgelines, resulting in dendritic patterns of steep ravines.

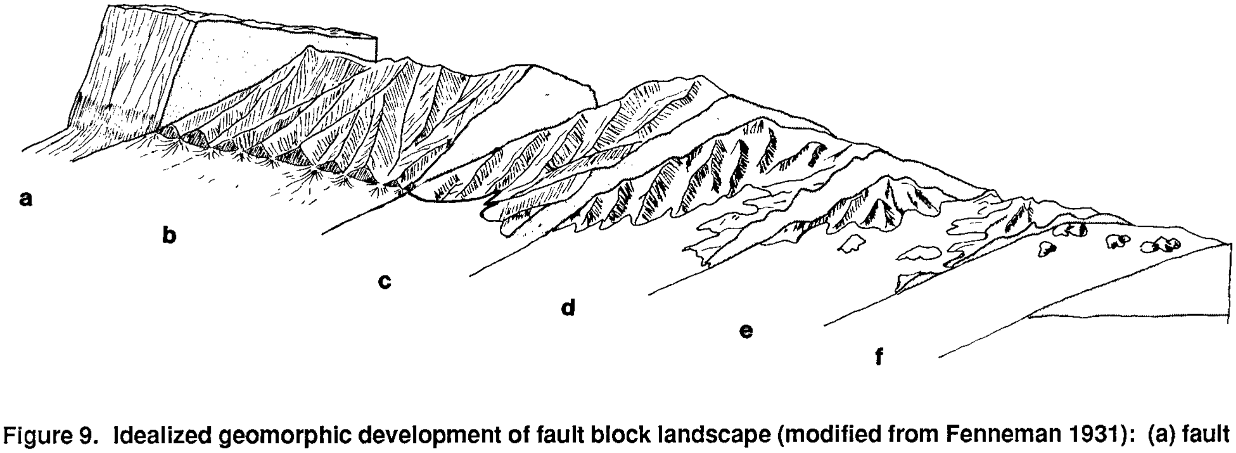


Figure 9. Idealized geomorphic development of fault block landscape (modified from Fenneman 1931): (a) fault block; (b) ravines developed sufficiently to divide the face into spurs; triangular facets at base of slope indicate continued upthrust of fault; (c) lower portions of spurs are buried by mineral detritus (fan-bayed stage); (d) mineral detritus extends considerable distances up major drainages (fan-frayed stage); (e) some of the former spurs appear detached from the major face due to inundation by unconsolidated mineral detritus (fan-wrapped stage); (f) the mountains are practically buried in their own detritus (pan-fan stage).

Sediments are transported primarily during brief episodes of high runoff and are eventually deposited as alluvial fans splaying from the mouths of canyons.

2.4.2 Basins

Basins are diastrophic troughs that are in the process of being filled with alluvium transported from surrounding mountain ranges. In contrast to mountain slopes, basins appear quite level. Although the flanks of basins may exceed 15% slope, a slope of less than 7% is more common. The fall from the edge of the basin to its center is commonly 90 to 200 m (Fenneman 1931). The depth of alluvial fill is more than 1,524 m in some basins (U.S. Bureau of Land Management 1986).

Alluvial landforms commonly form a broad skirt at the bases of mountain ranges. Near the mouths of drainages, alluvial fans may be distinct and broadly convex in form or may merge into gently undulating bajadas. Upper portions of alluvial fans and bajadas often are dissected as a result of altered stream regimen or from local uplift by block faulting (Morrison 1965). Pediments are land forms consisting of a veneer of alluvium over solid rock. These land forms are primarily the result of erosion in contrast to the deposition characteristic of alluvial fans and bajadas. In general, pediments are narrow in the northern Great Basin and become progressively wider toward the south.

Alluvial landforms may extend toward the center of basins to merge with those arising from the opposite slope, the line of coalescence marked by a dry wash. Alternately, alluvial landforms may grade towards the basin interior until they merge into alluvial flats and finally, level playas. Some basins have been breached and now drain to lower basins.

Lake beds are relict of relatively recent geologic time, although contemporary influences are locally evident. The West Desert in the Bonneville Basin was separated from the main body of the Great Salt Lake by a rise in a neck of land about 5,000 years ago (Eardley 1962). Successive flooding caused evaporites to collect at the surface of the lower western half of the desert, forming the Bonneville Salt Flats. Wind erosion of the salt crust resulted in the formation of gypsum sand dunes on the elevated east flank of the ancient lake bed. Dry lake beds are extensive throughout the Bonneville and Lahontan subdivisions.

Playas are places where water may accumulate on a seasonal basis or following precipitation that results in runoff. Water is depleted from playas mostly through evaporation and slow percolation through underlying strata. The proportion of evaporation versus percolation influences the degree to which salts delivered in surface runoff accumulate at the playa surface.

2.5 SOIL OF THE GREAT BASIN PHYSIOGRAPHIC SECTION

Soils of the Great Basin are mostly aridisols, entisols, and mollisols (U.S. Soil Conservation Service (SCS) 1975). Salt and mud flats (i.e., nonsoil) are also extensive in the Bonneville and Lahontan subdivisions. The distribution of contrasting soils generally corresponds with the geomorphic characteristics of the Great Basin landscape.

On mountain slopes, residual soils usually are shallow to moderately deep. Areas of exposed bedrock are common. Soils on mountain slopes in western Utah typically have a dark-colored surface horizon and a subsurface horizon characterized by an accumulation of illuvial clay (argillic horizon) or lime (calcic horizon) (Wilson et al. 1975). Runoff from mountain slopes is typically moderate to rapid.

Soils on alluvial fans and bajadas are generally skeletal near the foot of mountain slopes and grade to a finer texture towards the medial axes of basins. Desert pavement, characterized by a smooth surface of tightly fitting pebbles, is believed to be a result of wind deflation and is a common feature in the southern Great Basin. Lime- and silica-cemented hardpans are common at variable depths of the alluvial fans and bajadas (U.S. Air Force 1980). While surface runoff is typically moderate to slow, subsurface lateral flow along cemented horizons may be sustained following precipitation.

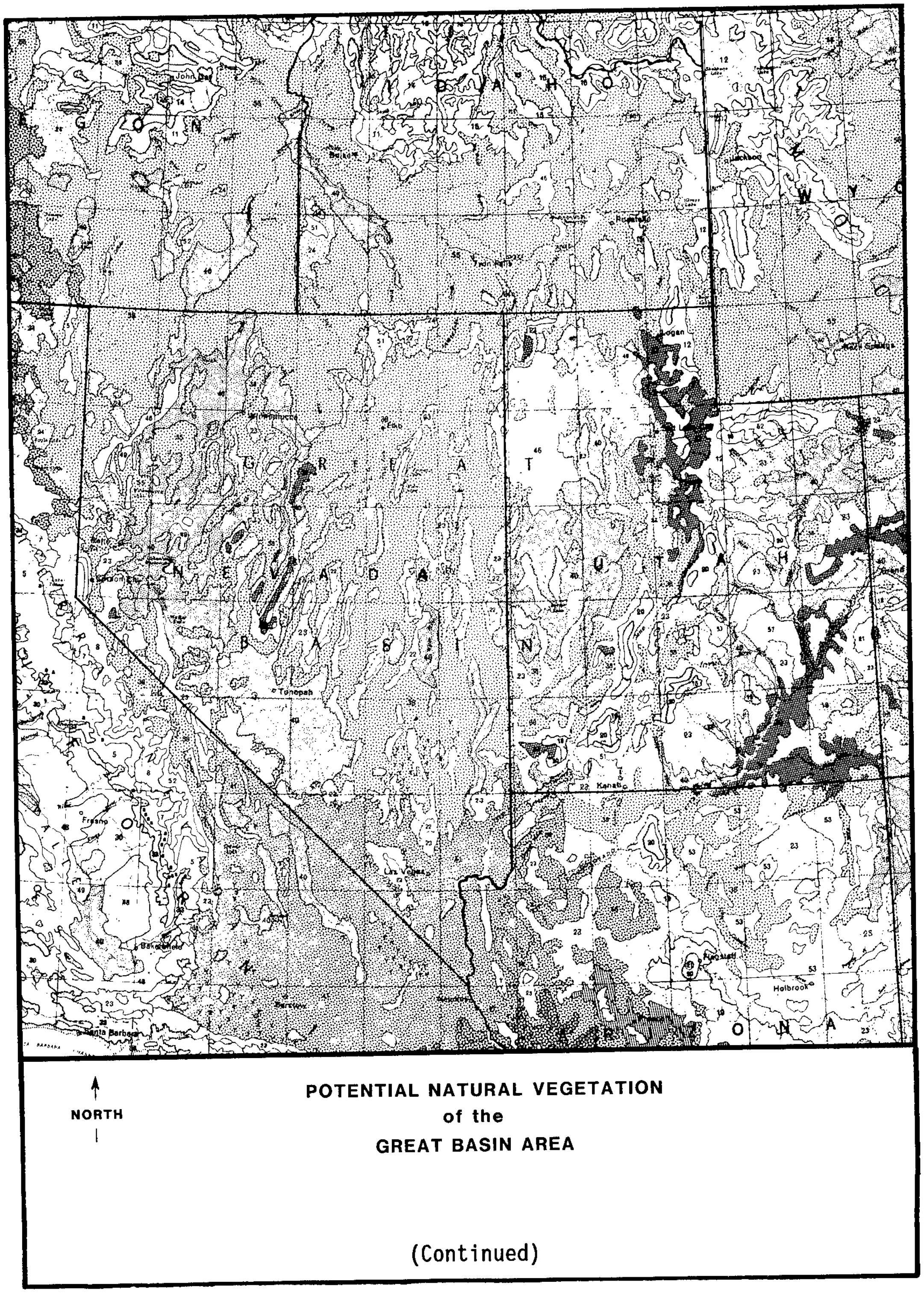


Figure 10. Potential natural vegetation of the Great Basin area (from Kuchler 1964).

KEY TO VEGETATION TYPES

WESTERN FORESTS

NEEDLELEAF FORESTS

1	Spruce-cedar hemlock forest *(Picea-Thuja-Tsuga)*
2	Cedar-hemlock-Douglas fir forest *(Thuja-Tsuga-Pseudotsuga)*
3	Silver fir-Douglas fir forest *(Abies-Pseudotsuga)*
4	Fir-hemlock forest *(Abies-Tsuga)*
5	Mixed conifer forest *(Abies-Pinus-Pseudotsuga)*
J J J J	the same, with junipers *(Juniperus)*
6	Redwood forest *(Sequoia-Pseudotsuga)*
7	Red fir forest *(Abies)*
8	Lodgepole pine-subalpine forest *(Pinus-Tsuga)*
■	Pine-cypress forest *(Pinus-Cupressus)*
10	Ponderosa shrub forest *(Pinus)*
11	Western ponderosa forest *(Pinus)*
12	Douglas fir forest *(Pseudotsuga)*
13	Cedar-hemlock-pine forest *(Thuja-Tsuga-Pinus)*
14	Grand fir-Douglas fir forest *(Abies-Pseudotsuga)*
15	Western spruce-fir forest *(Picea-Abies)*
■	Eastern ponderosa forest *(Pinus)*
17	Black Hills pine forest *(Pinus)*
18	Pine-Douglas fir forest *(Pinus-Pseudotsuga)*
19	Arizona pine forest *(Pinus)*
20	Spruce-fir-Douglas fir forest *(Picea-Abies-Pseudotsuga)*
21	Southwestern spruce-fir forest *(Picea-Abies)*
22	Great Basin pine forest *(Pinus)*
23	Juniper-pinyon woodland *(Juniperus-Pinus)*
Y Y Y Y	the same, with Joshua trees *(Yucca brevifolia)*
24	Juniper steppe woodland *(Juniperus-Artemisia-Agropyron)*

BROADLEAF FORESTS

■	Alder-ash forest *(Alnus-Fraxinus)*
26	Oregon oakwoods *(Quercus)*
■	Mesquite bosques *(Prosopis)*

BROADLEAF AND NEEDLELEAF FORESTS

28	Mosaic numbers 2 and 26
29	California mixed evergreen forest *(Quercus-Arbutus-Pseudotsuga)*
30	California oakwoods *(Quercus)*
31	Oak-juniper woodland *(Quercus-Juniperus)*
▥	Transition between 31 and 37

WESTERN SHRUB AND GRASSLAND

SHRUB

33	Chaparral *(Adenostoma-Arctostaphylos-Ceanothus)*
34	Montane chaparral *(Arctostaphylos-Castanopsis-Ceanothus)*
35	Coastal sagebrush *(Salvia-Eriogonum)*
▥	Mosaic of numbers 30 and 35
37	Mountain mahogany-oak scrub *(Cercocarpus-Quercus)*
38	Great Basin sagebrush *(Artemisia)*
J J J J	the same, with junipers *(Juniperus)*
Y Y Y Y	the same, with Joshua trees *(Yucca brevifolia)*
■	Blackbrush *(Coleogyne)*
40	Saltbush-greasewood *(Atriplex-Sarcobatus)*
41	Creosote bush *(Larrea)*
Y Y Y Y	the same, with Joshua trees *(Yucca brevifolia)*
■	Creosote bush-bur sage *(Larrea-Franseria)*
Y Y Y Y	the same as 42, with Joshua trees *(Yucca brevifolia)*
43	Palo verde-cactus shrub *(Cercidium-Opuntia)*
44	Creosote bush-tarbush *(Larrea-Flourensia)*
45	Ceniza shrub *(Leucophyllum-Larrea-Prosopis)*
46	Desert: vegetation largely absent

GRASSLANDS

47	Fescue-oatgrass *(Festuca-Danthonia)*
48	California steppe *(Stipa)*
49	Tule marshes *(Scirpus-Typha)*
50	Fescue-wheatgrass *(Festuca-Agropyron)*
51	Wheatgrass-bluegrass *(Agropyron-Poa)*
52	Alpine meadows and barren *(Agrostis, Carex, Festuca, Poa)*
53	Grama-galleta steppe *(Bouteloua-Hilaria)*
54	Grama-tobosa prairie *(Bouteloua-Hilaria)*

SHRUB AND GRASSLANDS COMBINATIONS

55	Sagebrush steppe *(Artemisia-Agropyron)*
J J J J	the same, with junipers *(Juniperus)*
56	Wheatgrass-needlegrass shrubsteppe *(Agropyron-Stipa-Artemisia)*
57	Galleta-three awn shrubsteppe *(Hilaria-Aristida)*
58	Grama-tobosa shrubsteppe *(Bouteloua-Hilaria-Larrea)*
Y Y Y Y	the same, with Joshua trees *(Yucca brevifolia)*
59	Trans-Pecos shrub savanna *(Flourensia-Larrea)*
J J J J	the same, with junipers *(Juniperus)*
60	Mesquite savanna *(Prosopis-Hilaria)*
61	Mesquite-acacia savanna *(Prosopis-Acacia-Andropogon-Setaria)*
■	Mesquite-live oak savanna *(Prosopis-Quercus-Andropogon)*

J = *Juniperus spp.* (juniper, red cedar)

• = *Sequoia wellingtonia* (giant sequoia)

Y = *Yucca brevifolia* (Joshua tree)

Figure 10. (Concluded).

Lower portions of the basins are commonly smooth to gently undulating with deep soil. The texture of surface horizons ranges from loam to silty clay loam. Subsoils are generally a finer texture. These soils are mostly saline, sodic, or saline-sodic. Permeability ranges from very slow to moderate and drainage often is impaired.

Playas and lake beds typically consist of light-colored sediment with high salinity. Runoff usually ponds on the surface and salt crusts may form during dry periods. The depletion of ponded water occurs through evaporation and infiltration into underlying strata. Playas generally are devoid of vegetation.

2.6 FLORA

Bailey (1978) includes the Great Basin in the intermountain sagebrush and American desert provinces. The intermountain sagebrush province is characterized by sagebrush (Artemisia) and salt-tolerant plants on lower elevations and forested habitat at higher elevations. Bailey (1978) suggested that sagebrush habitats may be a disclimax resulting from overgrazing. The American desert province is characterized by sparse vegetation inclusive of cacti and thorny shrubs. Bailey further identifies five sections within the provinces: sagebrush-wheatgrass section for the Snake River plain, Owyhee Desert, and Northern subdivision; Lahontan sagebrush-greasewood section in the Lahontan subdivision; Great Basin sagebrush section for the central subdivision; Bonneville saltbrush-greasewood section in the Bonneville subdivision; and creosote bush section for the southern subdivision.

A more detailed survey of vegetation types in the Great Basin was prepared by Kuchler (1964) (see Figure 10). Kuchler identified 14 major vegetation types in the Great Basin physiographic section and several additional vegetation types within the high mountain areas bordering the Great Basin physiographic section on the east and west.

Along the crests of high ranges in the central subdivision, spruce-fir-Douglas fir (Picea-Abies-Pseudotsuga) forests are prevalent. Juniper-pinyon (Juniperus-Pinus) woodland is common at lower elevations in the mountains and foothills throughout the Great Basin. Other vegetation types common in the mountains include juniper steppe woodland (Juniperus, Artemisia, Agropyron) in the northern subdivision, Mountain mahogany-oak scrub (Cercocarpus-Quercus) and blackbrush (Coleogyne).

Shrub-dominated communities are common on alluvial deposits. Great Basin sagebrush (Artemisia) type is common on deep, well-drained soil throughout the central subdivision and, less extensively, in the Bonneville subdivision. The sagebrush steppe (Artemisia-Agropyron) type is extensive in the northern subdivision. In lower portions of the Bonneville and Lahontan subdivision with saline-alkali soil and impaired drainage, saltbrush-greasewood (Atriplex-Sarcobatus) vegetation type is common. Creosote bush (Larrea) vegetation type is extensive south of 37 °N latitude.

Vegetation is largely absent on saline lake beds in the northwestern portion of the Bonneville subdivision and the Black Rock Desert in northwestern Nevada. Less extensive, nonvegetated areas correspond with playas and lake beds distributed throughout the Great Basin.

Axelrod (1973) suggested that riparian vegetation in western North America is a reduced vestige of an Arcto-Tertiary geoflora, a zone of diverse forests that once covered extensive areas of the Northern Hemisphere. When the geoflora was destroyed in the late Tertiary and Quaternary periods by spreading cold and drought, some of the elements that already were adapted to riparian conditions were able to survive along stream courses (Axelrod 1977). The origin and distribution of many modern riparian species including maple (Acer spp.), alder (Alnus spp.), birch (Betula spp.), ash (Fraxinus spp.), walnut (Juglans spp.), sycamore (Platanus spp.), cottonwood (Populus spp.), oak (Quercus spp.) and willow (Salix spp.) are discussed by Holstein (1984).

CHAPTER 3. RIPARIAN ECOSYSTEMS

Riparian habitats associated with the Great Basin hydrographic region are distributed across a broad geographic continuum having wide variations in precipitation and elevation. The degree of diversity in the form, composition, and dynamics of riparian habitats is expected to be as broad as that of the region's characteristics.

Riparian ecosystems of the Great Basin hydrographic region are distributed along at least three environmental gradients: a North to South latitudinal gradient; an elevational gradient consisting of river headwaters to the oceanic or basin sink; and a lateral gradient of stream channel to upland ecosystems. The latitudinal gradient of the Great Basin hydrographic region extends from about 35° to 44 °N latitude. Climate is principally responsible for variations in the structure, composition, and dynamics of riparian ecosystems along the latitudinal gradient. For a given elevation, net climatic inputs (i.e., precipitation minus evaporation) are generally highest in the northern latitudes. As a result, perennial streams are more frequent in northern latitudes and riparian ecosystems are often dominated by obligate hydrophytes. In southern latitudes, ephemeral, intermittent, and interrupted streams are more common and riparian communities typically are dominated by facultative hydrophytes, often complemented by upland plant species.

The elevational extremes of the Great Basin hydrographic region range from 4,418 m on the summit of Mount Whitney to 75 m below sea level in Death Valley, sink of the Amargosa River. The distribution of contrasting riparian habitats along the elevational gradient of watersheds is thought to generally correspond with the geomorphic form of river valleys (Vannote et al. 1980, Cummins et al. 1984, Minshall et al. 1985). The watershed of a single stream may include glacial headwater basins, broad (U-shaped) glacial valleys, fluvial (V-shaped) canyons, alluvial valleys, and lacustrine basins transitional to terminal lakes or playas. Although a single mechanism may be the principal influence on the geomorphology of a valley segment, the concomitant influence of subordinate mechanisms may impart a considerable degree of diversity to the riparian habitat along the length of a given valley-form. Climate may also impart diversity to the distribution of riparian communities along the elevational gradients of watersheds.

The lateral gradient between the stream (aquatic) and upland ecosystems also has been termed the transriparian gradient (Minckley and Brown 1982). The distribution of riparian communities along the lateral gradients of valleys is primarily a response to water regime, as influenced by topographic position relative to the dynamics of streamflow and alluvial ground water, and the frequency and intensity of flooding.

3.1 HIERARCHICAL CLASSIFICATION OF RIPARIAN ECOSYSTEMS

We propose a hierarchical framework for classification of riparian ecosystems of the Great Basin hydrographic region: hydrologic unit, geomorphic valley form, water regime, physiognomy of the community, community type, and decriptors. The purpose of this approach is to demonstrate the dynamic relationships responsible for the structure, composition, and values of riparian ecosystems of the Great Basin.

The approach may also be useful for predicting the distribution of riparian communities and the effects of land and water management upon the dynamic qualities of riparian ecosystems. The objects of this hierarchical classification are riparian communities, which are grouped as community types, the fundamental units.

Hydrographic units may be useful for identification of watersheds at any degree of resolution. Preliminary hydrographic units, arranged in order of increasing resolution, are region, subregion, basin, subbasin, and tributary basin. Hydrographic regions (i.e., Great Basin region) are characterized by diverse geology, climate, and geomorphology. Subregions are watersheds of similar hydrologic character. Basins denote the watershed draining to a particular sink. Subbasins are used to distinguish major watersheds draining to a single sink while tributary subbasins may be used to identify still more resolute divisions of watersheds.

Geomorphic valley-form could be useful for subdividing hydrographic units along the elevationalÑ5Xgradientsof watersheds. Valley-forms are named for the principal geomorphic mechanism responsible for its genesis. Preliminary classes of geomorphic valley-form are glacial valleys (alpine and subalpine); fluvial canyons (V-shaped and notch-shaped); alluvial valleys (confined and unconfined floodplains); and lacustrine basins (open and closed). Geomorphic valley-forms may be further distinguished based on geographic parameters (e.g., elevation or geology) and/or based on the relative effectiveness of specific geomorphic processes (i.e., erosion, transport, and deposition of sediments) characterizing a given valley segment. Water-regimes are used to indicate the temporal dynamics of hydrologic parameters. Preliminary classes of water-regime are amended from those used to classify wetland ecosystems (Cowardin et al. 1979). In order of decreasing duration of flooding, preliminary classes of water-regime are: (1) permanently flooded; (2) semi-permanently flooded; (3) saturated; (4) seasonally flooded; and (5) sub-irrigated (Figure 11). The distribution of contrasting riparian communities along the lateral gradients of valleys is primarily a response to variations in water-regime.

The physiognomy of riparian communities is based on the life form of the uppermost stratum of vegetation with an areal cover of at least 30 percent, or upon the composition of the substrate, if vegetation covers less than 30 percent of the

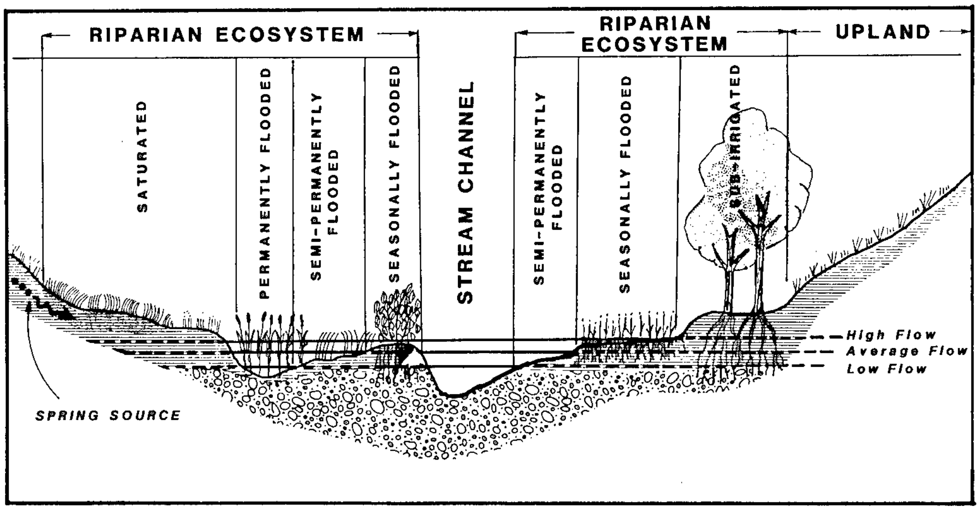


Figure 11. Preliminary classes of water regimes.

community (Cowardin et al. 1979). Preliminary physiognomic classes for vegetated communities are: forest, shrub, herbaceous, and moss/lichen. Non-vegetated physiognomic classes include cobble bars, gravel bars, sand bars, and silt bars.

Community types are based on floristic similarities in both the overstory (if present) and the understory of riparian communities (Youngblood et al. 1985a). While the description of riparian communities should include detailed geologic, climatic, hydrologic, geomorphic, soil, and floristic parameters, the identification of riparian communities is generally based on the presence/absence and coverage of a few indicator species with high constancy. Although floristic parameters generally are the focus of riparian community types, more fundamental soil, hydrologic, and geomorphic parameters are often of greater interpretive value for management.

A search of the literature for descriptions of riparian communities in the Great Basin hydrographic region has been somewhat futile. While relatively thorough descriptions of riparian communities are available for portions of some watersheds (Clair and Storch 1977; Jensen and Tuhy 1981; Youngblood et al. 1985a, b), most descriptive information pertains to the discrete aspects of riparian ecology (e.g. fish and wildlife parameters) and does not address parameters needed to interpret the functional attributes and multiple values of riparian habitats (e.g., geologic, climatic, hydrologic, geomorphic, pedogenic, and biotic).

As an alternative, the major hydrographic units of the Great Basin Region are discussed, followed by general interpretations of riparian ecosystems occurring in discrete geomorphic valley forms arranged along the continuum from headwaters to basin sinks. Hydrologic, soil, and floristic parameters are discussed with respect to specific geomorphic valley-forms. The intent of this approach is to develop a framework in which subsequent investigations of riparian ecosystems in the Great Basin may be integrated.

The emphases of the following discussions are upon the functional attributes of riparian ecosystems. The approach is designed to facilitate interpretations of the flux of water and sediments along elevational and lateral gradients of watersheds. It is believed that these fundamental processes are of paramount importance for understanding the dynamics and proper management of riparian and stream ecosystems.

3.2 HYDROGRAPHIC UNITS

Surface waters of the Great Basin include perennial, intermittent, and ephemeral streams; freshwater and saline lakes; playa lakes; freshwater and saline wetlands sustained by springs; and thermal springs associated with faulting and volcanic activity. The primary emphases of hydrographic descriptions presented here are upon perennial streams and rivers. Discussions are subsequently presented with respect to the central basin, Bonneville basin, Lahontan basin, northwest basin, and southern basin hydrographic subregions as delineated in Figure 12. Subregions of the Great Basin denote watersheds of similar hydrologic character, such as basins and subbasins. Hydrologic features, major dams, diversions, and the locations of selected stream gauging stations are illustrated on the relief map in the Appendix.

3.2.1 Central Basins Hydrographic Subregion

The central basins contain no major rivers or lakes. However, many minor streams are distributed throughout the area. Some of these streams are spring-fed and perennial and a few sustain short courses through basins before being depleted. Most of the streams diverge into numerous channels upon leaving the mountains and crossing alluvial fans, resulting in substantial depletion through infiltration and evaporation (U.S. Air Force 1980). That portion of runoff reaching the center of closed basins may collect in playa lakes. Streamflow parameters at U.S. Geological Survey gauging stations in the central basin subregion are summarized in Table 2.

Ephemeral streams are numerous throughout the Central Basin. They are characterized

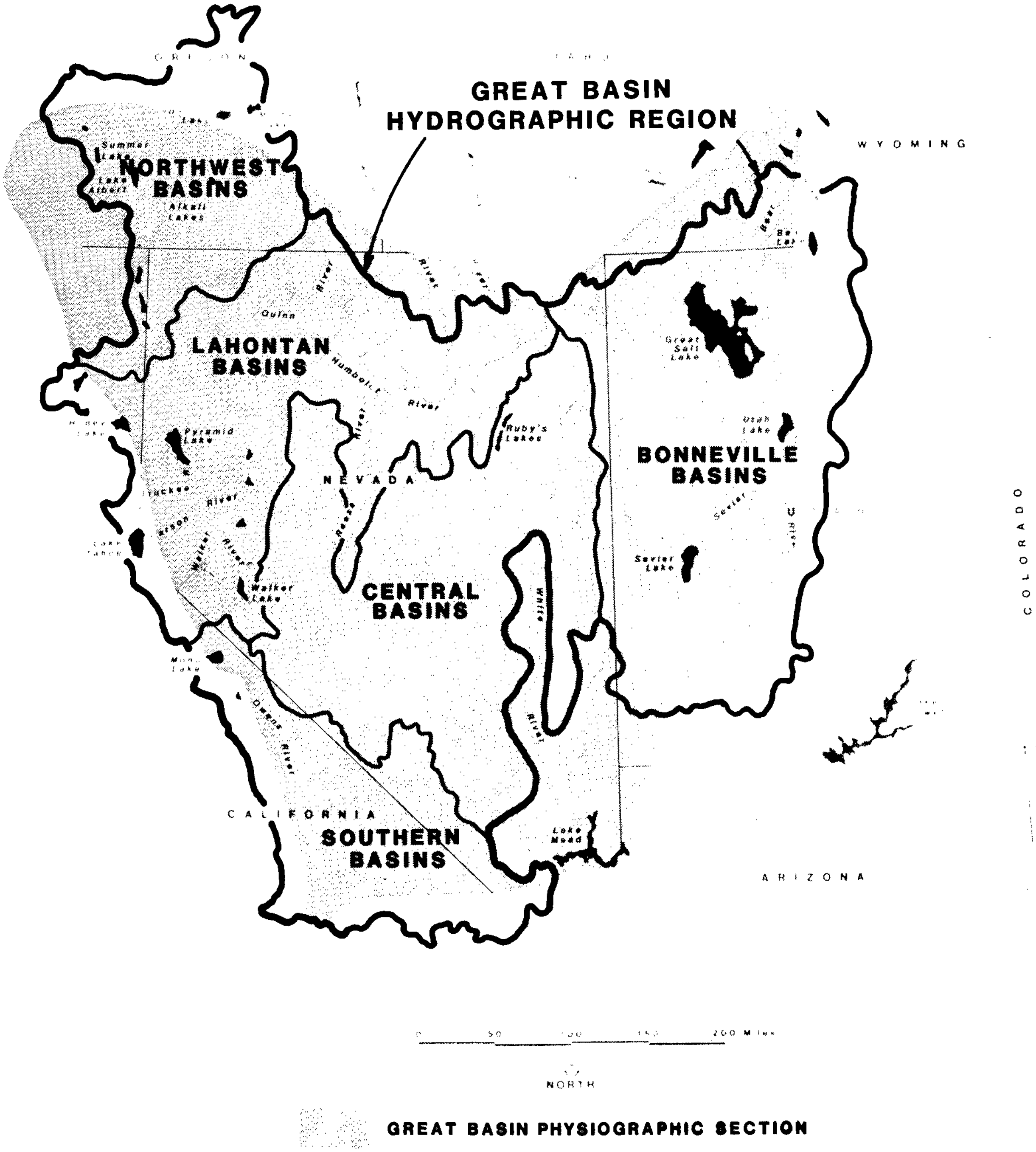


Figure 12. Subregions of the Great Basin hydrographic region.

Table 2. Streamflow parameters for the Central Basins subregion (U.S. Geological Survey 1981).

Stream gauge	Period of record (yr)	Drainage area (km^2)	Average annual discharge (m^3/s)	Average annual discharge (x10^6 m^3/yr)	Daily extremes max. (m^3/s)	Daily extremes min. (m^3/s)
Spring Valley						
2437	14	82	0.28	8.49	3.54	0.06
Ruby Valley						
244720	16	27	0.34	10.27	5.58	0.03
244745	23	12	0.34	10.55	4.30	0.00
Steptoe Valley						
24494	14	29	0.20	6.28	1.05	0.06
Little Smoky and Newark Valleys						
2458	18	407	0.01	0.18	8.24	0.00
Hot Creek and Railroad Valleys						
246846	16	33	0.20	3.21	10.37	0.00
Big Smoky Valley						
24928	14	61	0.23	7.46	4.25	0.03
2493	15	52	0.20	5.86	3.62	0.06
Smith Creek Valley						
29411	17	6	<0.01	0.05	5.07	0.00
Fish Lake Valley						
2499	20	97	0.25	7.83	14.92	0.03

by short periods of high discharge punctuating long periods of little or no flow. Flooding may occur as a response to snowmelt, rain on snow, or thunderstorms. Snowmelt generally occurs from April through June; rain on snow may occur between November and March; thunderstorms occur most frequently during the summer and fall months. Thunderstorms cause the most catastrophic and frequent flood events. The rate of precipitation may be as high as 18 cm (7 inches) per hour over an area of less than 260 ha (U.S. Air Force 1980).

Ruby Marsh (also called Ruby Lake) and Franklin Lake are on the eastern flank of the Ruby Mountains in the northern portion of the central basin area. Managed as a National Wildlife Refuge, Ruby Marsh covers about 8,100 ha and is fed by about 135 springs at a rate of 1,208 to 1,850 hectare-meters per year (U.S. Air Force 1980). Another 12,500 hectare-meters are contributed annually by precipitation and runoff, yet there is no outlet. Franklin Lake, located 8 km north of Ruby Marsh, is comparable in size and resembles Ruby Marsh during wet years. Most of Franklin Lake is privately owned and intensively managed for hay and livestock production.

Pahranagat Valley in Lincoln County contains a wetland in the bed of the White River which is sustained by many springs.

Several large thermal springs (Ash, Crystal, and Hiko) have been designated as fish sanctuaries by the Nevada Department of Wildlife and have been recommended for national landmark status (Bostick et al. 1975).

3.2.2 Bonneville Basins Hydrographic Subregion

The Bonneville basins encompass the northeastern portion of the Great Basin, and include parts of the Middle Rocky Mountains, Colorado Plateau, and Wyoming basin physiographic provinces. During the Pleistocene, Lake Bonneville covered nearly 52,000 km^2 to a maximum depth of about 335 m (Houghton 1976). The lake was about the size of Lake Michigan. Lake Bonneville overflowed from the northern extreme of Cache Valley to the Snake River drainage for a brief interval of Pleistocene time (Gilbert 1890). The alluvial sill of the outlet was rapidly eroded over 110 m to the Provo Lake level. The brief, catastrophic discharge through the erosion cut is believed to have been primarily responsible for the Snake River Gorge in Southern Idaho.

According to Broecker and Kaufman (1965), four low levels of Lake Bonneville occurred between 8,000 and 22,000 years ago. One period of complete desiccation was followed by a refilling of the basins about 11,000 years ago resulting in 10 or 12 independent lakes. By the end of the pluvial period about 10,000 years ago, most of the lakes had dried up.

The three major bodies remnant of Lake Bonneville are distributed along the eastern flank of the Bonneville basin: The Great Salt Lake, Utah Lake, and Sevier Lake. These lakes are dependent on drainage from the western flanks of the Middle Rocky Mountains and Colorado Plateau. Streamflow parameters for major rivers of the Bonneville basin subregion are summarized in Table 3. Hydrologic features and the location of stream gauging stations are illustrated on the relief map (Appendix).

3.2.2.a Great Salt Lake basin. The Great Salt Lake has no outlet. It is constantly fluctuating in response to evaporation and precipitation over its 1.3 million square kilometer watershed. Since 1851, the total annual inflow to the lake has varied from 1.36×10^9 to 11.25×10^9 m^3 causing the lake level to vary as much as 6.1 m (U.S. Bureau of Land Management 1986). The average annual input to the lake is about 3.70×10^9 m^3; 2.59×10^9 m^3 from surface runoff; 1.01×10^9 m^3 from direct precipitation; and 1.01×10^9 m^3 from ground water (U.S. Bureau of Land Management 1986). At its normal level (about 1,280 m) the surface area of the lake is about 4,370 km^2 with an average depth of 4 m and volume of 1.9×10^{12} m^3 (U.S. Bureau of Land Management 1986).

The Great Salt Lake contains about 4.72 billion metric tons of salt (Bureau of Land Management 1986). Since 1963, the volume of the lake has fluctuated from a minimum of 7.07 million hectare-meters in 1963 (27.5% salt by weight) to a maximum of 23.97×10^{12} m^3 in the spring of 1986 (10% salt by weight). The flat shores result in a very high degree of lake expansion corresponding with a small rise in lake level. An increase in lake level from 1,281.7 m to 1,282.2 m corresponds to a 971 km^2 increase in surface area (U.S. Bureau of Land Management 1986).

High runoff associated with record precipitation over the Bonneville basin since 1983 has resulted in record lake levels and considerable damage to industries, residential areas, highways, railroads, and public utilities. Eight waterfowl management areas administered by the Utah Department of Wildlife Resources, the Bear River Migratory Bird Refuge managed by the U.S. Fish and Wildlife Service, and over 30 private waterfowl hunting areas also have sustained significant damage. Alternatives are currently being considered to reduce the potential of future flooding (U.S. Bureau of Land Management 1986).

The principal drainages contributing directly to the Great Salt Lake are the Bear River and Weber River. The Jordan River drains from Utah Lake to the Great Salt Lake. Peak flow for streams originating along the Wasatch Front corresponds with snowmelt in May and June, and minimum flow occurs during winter months (U.S. Geological Survey 1979 a-d).

Table 3. Streamflow parameters for major rivers of the Bonneville Basins subregion (U.S. Geological Survey 1985).

Stream gauge	Period of record (yr)	Drainage area (km^2)	Average annual discharge (m^3/s)	Average annual discharge ($\times 10^6$ m^3/yr)	Daily extremes max. (m^3/s)	Daily extremes min. (m^3/s)
Great Salt Lake Basin						
Bear River						
0104	12	124	1.61	50.94	24.27	0.11
0395	48	6,439	12.69	400.40	138.20	0.68
0750	31	10,287	20.28	639.83	180.68	1.16
1260	29	18,205	54.09	1,625.79	418.29	2.04
Weber River						
1285	80	420	6.29	198.35	118.09	0.42
1305	53	1,127	5.92	186.76	62.02	0.17
1410	19	5,389	16.31	514.75	286.03	0.00
Provo River						
1542	21	420	6.34	200.20	71.37	1.19
1595	31	1,417	10.54	332.44	64.00	0.00
1630	49	673	5.78	182.32	71.37	0.45
Spanish Fork River						
1505	13	1,689	4.87	203.78	141.60	0.17
Jordon River						
1670	71	7,796	11.33	357.48	85.81	0.00
1710	41	8,904	4.08	128.66	127.72	2.52
Sevier Lake Basin						
Sevier River						
1745	62	881	3.60	113.50	45.20	0.57
2050	70	8,741	3.03	95.62	67.97	0.00
2190	73	13,377	7.19	226.97	146.98	0.00
2240	47	15,451	6.66	210.07	142.17	0.06
West Desert Basins						
Dunn Creek						
17952	10	23	0.20	5.88	4.25	<0.01
Trout Creek						
172870	26	21	0.17	5.34	5.01	0.01
South Willow Creek						
1728	21	11	0.20	6.32	2.61	0.05
Vernon Creek						
1727	26	65	0.11	3.18	23.36	0.01

(1) Bear River subbasin. The Bear River drains an area of 18,324 km^2 including portions of three physiographic provinces (Middle Rocky Mountains, Wyoming basin, and minor portions of the Great Basin). It contributes the principal hydrologic input to the Great Salt Lake, averaging 59% of the annual inflow. While the headwater source of the Bear River is only about 145 km from the Great Salt Lake, it wanders over 800 km before entering its sink.

The Bear River originates in glaciated alpine basins on the northern flank of Hayden Peak in the Uinta Mountains. After flowing a relatively short distance through glacial (U-shaped) valleys to the foot of the mountains, the river flows northward along the southwestern flank of the Wyoming basin province, an uplifted series of structural basins separated by low anticlines. Near the Wyoming-Idaho-Utah border, the Bear River turns westward through structural valleys and passes near the northern shore of Bear Lake. While the Bear River once flowed through Bear Lake, the drainage was diverted to the northwest several thousand years ago (Mansfield 1927). The Bear River has been artificially linked with Bear Lake through Dingle Marsh at the north end of Bear Lake while outflow back to the Bear River is regulated through a diversion channel.

The Bear River continues northward to the vicinity of Soda Springs, Idaho, where a lava flow obstructed discharge to the Snake River drainage about 34,000 years ago (Morrison 1966). The lava flow caused the river to turn south and overflow a low divide of the Bonneville basin along the northern extremity of Cache Valley. Numerous tributaries arising in fluvial (V-shaped) canyons incised in the Bear River range merge with the Bear River along its slow, meandering course through Cache Valley. Streamflow is impounded in Cutler Reservoir on the western flank of Cache Valley. The Malad River, the only major tributary, converges with the Bear River near Brigham City, Utah.

Extensive diking near the mouth of the Bear River once sustained expansive freshwater wetlands operated by the U.S. Fish and Wildlife Service as the Bear River Migratory Bird Refuge. Brackish waters of the Great Salt Lake overflowed the dikes in 1984 and inundated most of the freshwater wetlands. Several privately operated waterfowl areas located upslope sustained less extensive damage.

(2) Weber River subbasin. The Weber River drains 5,390 km^2 located mostly within the Middle Rocky Mountains (U.S. Geological Survey 1979). It contributes about 20% of the annual surface inflow to the Great Salt Lake. The river originates in glacial lakes near the western flank of Hayden Peak. Its headwater tributaries flow through glacial (U-shaped) valleys to the foot of the Uinta Mountains. A portion of its flow is diverted to the Provo River drainage through an overland diversion near Kamas, Utah. Beaver, Chalk, Echo, and Lost Creeks converge along lower steep-gradient segments of the Weber River. The Ogden River, originating in a contiguous drainage of the Wasatch Front, unites with the Weber along the western flank of the Great Basin.

Discharge through the Weber River is controlled by several impoundments along both the main stem and its tributaries. The Ogden Bay Waterfowl Management Area, operated by the Utah Division of Wildlife Resources, was regulated by diking the river west of Ogden, Utah. Most of the management area is now inundated by the brackish waters of the Great Salt Lake.

(3) Utah Lake subbasins. Utah Lake covers an area of about 337 km^2 and historically contained fresh water. Currently, the lake is hypereutrophic due to inflow of industrial, urban, and agricultural effluent. In summer months, total coliform levels along the eastern shore make water unfit for all but irrigation and industrial use. Marshy land around Provo Bay, the principal inlet, is thought to reduce water-quality degradation (U.S. Bureau of Reclamation 1979a).

The Provo and Spanish Fork Rivers are the principal drainages to Utah Lake. The lake drains to the Great Salt Lake via the Jordan River.

The watershed of the Provo River is about 1,760 km^2 located mostly within the Middle Rocky Mountains. Its three headwater tributaries originate in glacial lakes on the south slope of the Uinta Mountains.

Flow is augmented by several steep-gradient tributaries along its 121-km course through the Wasatch Mountains to Utah Lake. The Provo River contributes about 70% of the average annual inflow to Utah Lake. Flow in the Provo River is increased by diversions from the Duschesne River via a tunnel, and from the Weber River via an overland diversion canal. Two dams on the main stem and numerous diversions reduce annual streamflow to 57% of upstream discharge (U.S. Bureau of Reclamation 1979a). Construction of several additional reservoirs and diversions are planned as part of the Central Utah Project.

The Spanish Fork River drains a watershed of about 1,800 km^2 of a transitional area between the Colorado Plateau and the South and the Middle Rocky Mountains to the north. Thistle Creek and Diamond Fork are its principal tributaries. Flow in Diamond Fork is expanded by water diverted from the Strawberry River via a tunnel excavated under its headwater divide. The channel of Diamond Fork is severely degraded for some kilometers below the inlet of the Strawberry Tunnel because of extreme fluctuations in flow (U.S. Bureau of Reclamation 1979a). In 1984, a major landslide along a steep slope above the Spanish Fork River created Thistle Lake, named for the town it flooded. Many irrigation diversions along the lower segment of the Spanish Fork River reduce annual discharge to about 65% of upstream flow. During summer months, flow to Utah Lake often is limited to seepage, irrigation return flow, and drainage from septic tanks (U.S. Bureau of Reclamation 1979a).

The Jordan River flows out of Utah Lake and collects additional drainage from seven canyons along the Wasatch Front before terminating in the Great Salt Lake (U.S. Forest Service 1978). It contributes about 13% of the average annual surface flow to the lake.

3.2.2.b <u>Sevier Lake basin.</u> During the time of early settlement in the late 1800's, Sevier Lake covered an area of 487 km^2 (Houghton 1976). Today the lake is intermittent due to dams and diversions along the Sevier River and its tributaries.

The Sevier River originates as two forks along the western flank of the Colorado Plateau physiographic province. Draining an area of 19,956 km^2 it flows northward and is joined at obtuse angles by Otter Creek and the San Pitch River, both flowing to the south. The Sevier turns westward and flows towards the Sevier Desert near the town of Leamington, and its historic course continues through 115 km of desert to Sevier Lake. The Beaver River, draining ranges along the high western flank of the Great Basin, is intermittent along its lower course and is normally a dry channel at its confluence with the Sevier River.

While several dams along the tributaries and the main stem of the Sevier River regulate flow to lower segments, numerous diversions for irrigation of the Sevier Desert are thought to be primarily responsible for depletion. Sevier Lake is a dry playa except following periods of exceptionally high runoff.

3.2.2.c <u>West Desert basins.</u> Numerous minor tributaries originate in the ranges along the Utah-Nevada border in the western portion of the Bonneville basin. While some of these drainages maintain perennial flows in the mountains, they dissipate upon entering basins and fail to achieve a continuous network.

In Fish Springs Flat, Fish Springs National Wildlife Refuge is sustained by three major and many minor springs (U.S. Air Force 1980). These springs have a combined flow of 1.27 to 1.42 m^3/s (Bolen 1964) and have inundated an area of about 50 km^2.

3.2.3 <u>Lahontan Basins Subregion</u>

During the Pleistocene, Lake Lahontan covered an area of about 22,015 km^2 (about the size of Lake Erie) to a maximum depth greater than 267 m (Hubbs et al. 1974). The Pleistocene Lake had a watershed of about 116,550 km^2. About 8,000 years after the last glaciers melted (11,000 years ago), the climate became warm and dry, and the ancient lake was depleted; only Pyramid and Walker Lakes remain (Gerstung 1982).

Three major lakes distributed along the western flank of the Lahontan basin (Pyramid Lake, Carson Lake, and Walker Lake) are dependent on the drainage originating in the Sierra-Cascade province to the west. The Truckee, Carson, and Walker Rivers are of similar origin, starting as swift, clear streams in the Sierra Mountains and terminating as turbid, sluggish rivers at their terminal sinks. The Humboldt River, originating in the high mountains of northeastern Nevada, normally terminates at Humboldt Sink, a short distance north of Carson Lake. The minor rivers of the Lahontan basin include the Quinn and King Rivers that unite and terminate in a playa in the Black Rock Desert. The Quinn River normally shrinks more than 160 kilometers toward its source during the summer (Russell 1885). The Susan River drains intermittently to Honey Lake. Streamflow parameters for the Lahontan basin subregion are summarized in Table 4. Hydrologic features and the locations of gauging stations are illustrated on the relief map (appendix).

3.2.3.a <u>Truckee River basin.</u> The Truckee River drains an area of over 5,000 km^2. Originating from Lake Tahoe at about 1,900 m elevation, it follows a course of about 161 km to its terminus, Pyramid Lake, over 730 m below (Houghton 1976). Lake Tahoe is a large (499 km^2), high altitude (1,897 m), deep (maximum, 502 m; mean, 313 m) alpine lake of an extremely oligotrophic nature. Throughout most of its course, the river is incised in a narrow channel and is notable for alternating cascades and pools. Streamflow is seasonal, with peak flow occurring in late spring due to snowmelt. Donner, Prosser, Little Truckee, and Dog Creeks are tributary drainages.

Three reservoirs provide flood control on tributaries of the Truckee River upstream from Reno (Prosser Reservoir, Stampede Reservoir, and Martis Creek Reservoir). Numerous diversion dams used for irrigation and electric power deplete the river along its lower course. Derby Dam, a part of the Newlands Project enacted in 1903, diverts a major portion of streamflow through a 51 km canal to the Lahontan Reservoir on the Carson River. In the early 1960's, the Truckee River from Reno to Nixon was channelized and all streamside vegetation eliminated (Klebenow and Oakleaf 1984). Commercial logging, gravel operations, and severe overgrazing also have resulted in the demise of riparian habitat.

The act creating the Newlands Project guaranteed a minimum of 500x10^6 m^3 of water

Table 4. Streamflow parameters for major rivers in the Lahontan Basins subregion (U.S. Geological Survey 1981).

Stream gauge	Period of record (yr)	Drainage area (km^2)	Average annual discharge (m^3/s)	Average annual discharge (x10^6 m^3/yr)	Daily extremes max. (m^3/s)	Daily extremes min. (m^3/s)
			<u>Truckee River Basin</u>			
Upper Truckee						
3366	20	86	1.78	56.48	75.22	0.06
Truckee River						
3460	81	2,414	22.29	703.35	495.60	0.79
3480	54	2,764	17.05	591.59	589.06	0.00
3500	52	3,706	22.26	702.49	535.25	0.20
3516	61	4,341	9.29	293.08	521.09	0.00
351650	15	4,475	14.90	470.09	249.78	0.08
3517	23	4,732	12.18	384.24	407.81	0.23

(Continued)

Table 4. (Concluded).

Stream gauge	Period of record (yr)	Drainage area (km^2)	Average annual discharge (m^3/s)	Average annual discharge (x10^6 m^3/yr)	Daily extremes max. (m^3/s)	Daily extremes min. (m^3/s)
Carson River Basin						
East Fork Carson River						
3082	20	715	9.91	312.82	427.63	0.28
3090	54	922	10.87	343.17	498.43	0.34
Carson River						
310405	7	1,480	*	*	95.72	0.03
3110	41	2,295	11.21	353.90	849.60	0.06
3120	69	3,372	10.25	323.43	433.30	0.00
Walker River Basin						
East Walker River						
2930	57	930	3.94	124.22	39.36	0.00
29305	6	1,210	4.42	139.41	40.21	0.14
2935	31	2,849	4.02	126.93	67.40	0.06
West Walker River						
2960	42	469	7.28	229.68	176.15	0.11
3000	41	2,497	5.30	167.20	76.46	0.11
Walker River						
3015	55	6,700	4.42	139.39	92.89	0.00
Humboldt River Basin						
Marys River						
3155	37	1,075	1.78	56.21	119.23	0.00
North Fork Humboldt River						
3174	15	28	0.31	9.74	4.81	0.00
Humboldt River						
3185	43	7,252	6.77	213.60	200.22	0.00
3210	37	11,160	9.86	310.97	174.45	0.00
3225	73	12,980	10.56	333.30	174.45	0.06
3235	34	19,400	9.60	302.95	169.92	0.00
3250	38	22,970	10.00	315.41	164.26	0.00
3275	66	31,300	8.38	264.59	165.96	0.00
3330	41	40,660	5.98	188.61	172.19	0.00
3350	66	41,700	5.81	183.18	125.17	0.00
Quinn River Basin						
East Fork Quinn River						
3530	32	361	0.74	23.68	35.97	0.00
Quinn River						
35365	7	9,117	0.06	1.90	6.43	0.00

annually from the combined flows of the Truckee and Carson Rivers. Transfers from the Truckee Basin have averaged about 29,000 hectare-meters annually (Houghton 1976). The level of Pyramid Lake dropped 18.3 m between 1930 and 1960 as a result of upstream water use and prolonged drought (U.S. Bureau of Reclamation 1975).

3.2.3.b <u>Carson River basin.</u> Carson River arises as two forks along the Sierra Crest and terminates in Carson Sink about 193 km away. The eastern fork begins near the base of Sonora Peak at nearly 3,500 m and descends to the northeast. Streams adjoining this fork include Silver King, Wolf, and Markleville Creeks. The western fork starts in Lost Lake south of Kit Carson Pass. The two forks of the Carson River merge near Genoa, Nevada. The upper reaches of the Carson River are steep and turbulent. The lower course of the river is through Lahontan Lake beds. Streamflow is impregnated with soda salts as it passes through Carson and Eagle Valleys (Russell 1885).

Lahontan Reservoir, completed in 1915, retains about 360×10^6 m^3 at maximum capacity and covers about 4,050 ha. It is about 27 km long and 30 m deep. Inflow to the reservoir is augmented by water diverted from the Truckee River via the Truckee Canal. Lahontan Reservoir is managed as storage for numerous irrigation diversions as part of the Newlands Project. Several small reservoirs and Carson Lake are maintained below Lahontan Reservoir. The excess drainage discharges into Carson Sink, a playa lake.

3.2.3.c <u>Walker River basin.</u> The Walker River originates on the Sierra Crest and ends in Walker Lake, draining an area of about 10,900 km^2 (U.S. Bureau of Reclamation 1975). For more than half its length, the Walker River exists as two separate and nearly equal forks. The East Walker originates in Twin Lakes Basin below the northeastern rim of Yosemite and meanders about 137 km northward, receiving tributaries from the Sweetwater and Walker Ranges. The west fork originates in Kirkwood and Tower Lake located near the Sierra Nevada divide. It is regulated by gates at Topaz Lake (Bostic et al. 1975). Major tributaries of the West Walker are Little Walker, Leavitt, and Silver Creeks. The northerly trending forks merge near the town of Yerington, Nevada, after which the Walker River turns southeastward, flowing about 50 km to Walker Lake. The lower portions of the Walker River are slow moving and heavy with suspended sediment.

Russell (1885) reported extensive use of the Walker River for irrigation in Mason Valley as early as 1885. Today three reservoirs are distributed along upper portions of the Walker River and its tributaries: Topaz, Wilson, and Bridgeport Reservoirs. The Weber Reservoir impounds water along the lower course of the Walker River, less than 33 km upstream from Walker Lake. Extensive diversions for irrigation occur along the lower segments of the river. Wells, springs, and streams in the basin yield 407×10^6 m^3/yr of which 179×10^6 m^3 are consumed; 85% is used for irrigation (U.S. Bureau of Reclamation 1975). The average annual decline in Walker Lake is about 0.61 m though increases in lake level commonly are recorded in wet years.

3.2.3.d <u>Humboldt River basin.</u> The Humboldt River drains an area of about 41,700 km^2 of northern and eastern Nevada. Headwater tributaries include the Mary's River from the Jarbidge Mountains, the North Fork Humboldt River from the Independence Mountains, and the South Fork from the Ruby Mountains, all of which converge near Elko, Nevada. Pine Creek, Reese River, and Little Humboldt River converge with the Humboldt River past Elko. The Reese River sinks before it joins the Humboldt except during periods of high runoff. The Humboldt River channel is incised in lacustrine deposits throughout much of its lower course. Discharge to Humboldt Sink has varied from 0 to 125 m^3/s. The average annual discharge is 182,000 m^3 (U.S. Geological Survey 1979b). Russell (1885) noted that Humboldt Lake overflowed to North Carson Lake during winter months.

Rye Patch Reservoir, located on the Humboldt River about 50 km northwest of Lovelock, Nevada, impounds an area of about 4,452 ha to a maximum depth of about 18 m. The reservoir is rapidly filling with sediments (Rivers 1962).

3.2.4 Northwest Basins Hydrographic Subregion

The northwest basins hydrographic subregion includes part of southeastern Oregon, northwestern Nevada, and northeastern California. It is characterized by many shallow lakes, most of which are saline. The subregion is bordered to the north by the crest of the Blue Mountains; to the west by the watershed divide of the South Cascade Mountains, on the east by the Snake River drainage, and by the Lahontan basin to the south. Eight troughs in the region bear evidence of pluvial lakes. One of these spilled to the Snake River, and another drained to the Pacific Ocean by way of the Pit River. At the end of the last pluvial period these basins became closed. In contrast, pluvial Lake Klamath overflowed to the Klamath-Trinity River system, and the watershed now drains to the ocean (Houghton 1976).

Among the most notable lakes in the subregion are Malheur Lake, Harney Lake, Lake Albert, Summer Lake, Goose Lake, Horse Lake, Eagle Lake, and the Warner Lakes. Extensive wetlands are associated with some of the lakes. The major rivers of the Northwest Basin are Silvies River and the Donner and Blitzen Rivers, which flow to Malheur Lake, and Silver Creek, which empties to Harney Lake. Paulina Marsh and Chewaucan Marsh also are noteworthy. Streamflow parameters for the northwest basin subregion are summarized in Table 5. Hydrographic features and the locations of stream gauging stations are illustrated on the relief map (Appendix).

Malheur and Harney Lakes are remnants of pluvial Lake Malheur that filled Harney Basin to become the third largest of the Great Basin Pleistocene lakes (Houghton 1976). At its maximum, the lake covered 2,383 km^2 and overflowed to the Snake River. The Silvies River originates on the south flank of the Blue Mountains and drains a 3,500 km^2 watershed northward to Malheur Lake. The Donner and Blitzen Rivers drain a 2,600-km^2 watershed southward from the Steens Mountains to Malheur Lake. Silver Creek, a 2,330-km^2 drainage, flows to Harney Lake. Overflow of Malheur Lake flows to Harney Lake. While the former lake maintains relatively fresh water, the latter is saline. Extensive wetlands surrounding Malheur Lake are managed as the Malheur National Wildlife Refuge, the largest freshwater marsh in the western United States (U.S. Bureau of Reclamation 1975).

Goose Lake straddles the California-Oregon border and covers about 635 km^2. During the pluvial period, it drained to the Sacramento River via the Pit River. For the many thousands of years since it has been a terminal sink.

Honey Lake is a playa that fluctuates with annual variation in climate but seldom goes dry. The Susan River drains to Honey Lake.

3.2.5 Southern Basins Hydrographic Subregion

A series of pluvial lakes inundated parts of the southern basins subregion during the Pleistocene Epoch. Lake Russell, of which Mono Lake is a relict, and two other sizable pluvial lakes overflowed to Owens Lake via the Owens River. Owens Lake overflowed from lakes in Indian Wells, Salt Wells, Searles, and Panamint Basins to Lake Manly in Death Valley. Predecessors of the Amargosa and Mojave Rivers contributed additional drainage to Lake Manly, now a desert playa. Streamflow parameters for the southern basin subregion are summarized in Table 6. Hydrographic features and the locations of gauging stations are illustrated on the attached map.

3.2.5.a Mono Lake basin. Lake Russell covered 692 km^2 to a maximum depth of 29 m. Mono Lake, the relict of Lake Russell, is 16 to 23 km in diameter and so full of salts (e.g., borax, sodium chloride, and calcium carbonate) that macroscopic aquatic invertebrate life is limited to brine shrimp (Artemia) (Melack 1983). The shores of Mono Lake feature columns, arches, and battlements which are like the ruins of an ancient Roman city (Houghton 1976). The strange tufa deposits were formed by algae along the submerged shelves of Lake Russell. Two volcanic islands rise from Mono Lake.

Rush, Parker, Walker, and Lee Vining Creeks originate at 3,200 to 3,960 m along

Table 5. Streamflow parameters for major streams in the Northwest Basins subregion (U.S. Geological Survey 1984).

Stream gauge	Period of record (yr)	Drainage area (km^2)	Average annual discharge		Daily extremes	
			(m^3/s)	(x10^6 m^3/yr)	max. (m^3/s)	min. (m^3/s)
Warner Lakes Basin						
3660	48	502	1.50	44.99	103.93	0.00
3785	57	440	0.88	27.52	311.52	0.00
Summer Lake Basin						
388001	35	Unknown	2.58	81.41	5.32	0.08
Silver Lake Basin						
390001	64	466	0.88	27.52	509.76	0.00
Malheur and Harney Lakes Basin						
3935	70	2,419	4.96	156.41	140.47	1.22
3960	53	518	3.54	111.71	120.93	0.11
Alvord Lake Basin						
4065	52	228	0.45	14.38	13.31	0.00
Eagle Lake Basin						
3593	19	585	0.59	18.95	23.39	0.00
Surprise Valley Basin						
3609	21	66	0.59	19.12	19.31	0.03
Honey Lake Basin						
Susan River						
3565	37	477	2.61	82.21	65.67	0.00

the Sierra Nevada east of Yosemite National Park. These streams emerge from bedrock canyons at elevations ranging from 2,130 to 2,440 m and flow 11 to 16 km across alluvial, lacustrine, and aeolian sediments to the shores of Mono Lake. This flow historically accounted for about 75 percent of the surface inflow to the Lake (Stine et al. 1984). As the streams cross alluvial fans and piedmont slopes at the flank of Mono Basin, a substantial amount of flow percolates through the coarse substrate and is slowly returned to stream channels in their lower reaches, acting to maintain perennial flow even through prolonged drought. Lower reaches of these perennial streams historically supported luxuriant riparian habitats. Several shallow depressions along these lower courses sustained more than 200 ha of wet meadow and marshland.

In the early twentieth century, irrigation dams were constructed to impound water in the previously cited shallow depressions. Then in 1941, Los Angeles began diverting water from Mono Basin through an extension of the Los Angeles Aqueduct, and over the next 30 years about 60% of the basin's waters were diverted.

Table 6. Streamflow parameters for major streams in the Southern Basins subregion (U.S. Geological Survey 1982).

Stream gauge	Period of record (yr)	Drainage area (km^2)	Average annual discharge (m^3/s)	(x10^6 m^3/yr)	Daily extremes max. (m^3/s)	min. (m^3/s)
Mono Lake Basin						
Mill Creek 28707	11	47	0.79	25.39	3.99	0.00
Rush Creek 28279	11	60	1.56	49.24	11.92	0.03
Owens Lake Basin						
Bishop Creek 27121	11	269	2.83	88.92	22.91	0.91
Death Valley Basin						
Amargosa River 2513	20	8,000	0.08	2.90	2.12	0.00
2774	10	15,087	*	*	26.03	0.14
Closed Basin						
Oak Creek 2646	24	41	0.03	.88	49.28	0.00

In 1970, with the completion of a second aqueduct, Los Angeles increased diversions of Mono Basin waters to the extent that nearly the entire flow of Rush, Parker, Walker, and Lee Vining Creeks was diverted (Stine et al. 1984). Today the marshes and wet meadows that once lined the basin stretches of these streams have vanished entirely and have been replaced by sagebrush (Artemisia) and rabbitbrush (Chrysothamnus).

3.2.5.b Owens Lake basin. Owens Valley is a long, narrow graben bordered on the west by the towering Sierra Nevada and on the east by the White and Inyo Ranges. The valley is about 160 km long, 25 to 30 km wide, and covers about 8,500 km^2. Numerous tributaries originate in the glacial basins of the Sierra Nevada at 3,350 m above the valley floor, and supply most of the flow to the Owens River, the largest perennial stream of the southern basin subregion. The Owens River is fed almost entirely by runoff from the Sierra Nevada, but even before man altered the hydrologic regime, only about a third of the Sierra tributaries maintained perennial flow to the river. The rest of the tributaries normally disappeared before reaching the river channel due to percolation and evaporation. Much of the Sierra runoff reaches the river as subsurface flow (Dileanis et al. 1981).

The Owens River originates in remote, snow-fed lakes along the Sierra Divide. Glass, Deadman, Hot, McGee, and other creeks merge above Crowley Lake, a reservoir with a capacity of 226.3x10^6 m^3. Below the reservoir, the river descends abruptly through a lava rim, dropping 732 m in 32 km. Along this route there are numerous penstock diversions to serve power stations in Owens Gorge. Below Owens River Gorge, the river is a meandering, low-gradient stream, winding over a floodplain ranging from less than 100 m to over 1 km wide (Brothers 1984). The river channel is incised and bounded by abrupt bluffs along much of its course. After merging with several other tributaries originating from the Sierras, the river flows to the Tinemaha Reservoir near the town of Aberdeen, California.

Several wetland areas in Owens Valley historically were sustained by springs. Perkins et al. (1984) described the effects of ground water pumping on the demise of Little Black Rock Spring, Fish Springs Lake, the Springfield, Fish Slough, and Collins Warm Springs. Attempts to mitigate the effects of pumping by diversion of surface flow have resulted in floral and faunal distributions quite different from original populations. Alteration of hydrologic relationships and introduction of exotic fish species have resulted in the decline of endemic fish species in Fish Slough (Pister and Kerbavaz 1984).

Most irrigation diversions in Owens Valley began before 1890. By 1904 it was estimated that over 75% of the annual flow was diverted for irrigation (Brothers 1984). Los Angeles bought much of the land in Owens Valley and in 1913 began diverting streamflow through an aqueduct from the Tinemaha Reservoir to the city, 625 km away. Long Valley and Pleasant Valley Dams were constructed along upper portions of the Owens River drainage. In the 1920's and 1930's, Los Angeles began pumping about 170 wells in Owens Valley to supply the aqueduct during seasons of low flow. An extension of the Los Angeles Aqueduct began diverting water from Mono Basin to the Owens River in 1941, and diversions increased following construction of a second aqueduct in 1970. More wells were drilled after completion of the second aqueduct. Today, Owens Lake, the terminal sump of the Owens River, has been reduced to a dry playa.

3.2.5.c <u>Death Valley basin.</u> Death Valley is a deep and narrow graben that formed between 1 and 2 million years ago. Lake Manly, the fourth largest of the Pleistocene lakes, covered 1,600 km^2 of the basin, reaching a maximum depth of about 183 m at its peak about 65,000 years ago. Unconsolidated sediments are now as deep as 2,286 m below the valley surface. The Pleistocene lake was fed by the predecessors of the Owens, Mojave, and Amargosa Rivers. The Mojave River now sinks outside the boundary of the Southern Basin and the Owens River terminates at Owens Lake. The Amargosa River is the only drainage reaching Death Valley (albeit infrequently).

The Amargosa River arises in the Timber Mountains above Beatty, Nevada, and follows a channel about 282 km long to Death Valley. Near its headwaters, the river is perennial and of good quality. It is fed by several warm springs along its course; the most notable are Saratoga Springs and springs in Ash Meadows. In the middle and lower segments, the drainage has been described as "an artery of salt running through the desert" (Hubbs and Miller 1948). The river is intermittent along most of its lower course.

Ash Meadows, located about 60 km east of Death Valley, is sustained by more than 30 springs and seeps with a total annual discharge of about $21x10^6$ to $25x10^6$ m^3 (Williams 1984). The unique and biologically rich ecosystem encompasses about 16,200 ha of the Amargosa Desert and exhibits the greatest biological endemism of any area in the United States. More than 25 organisms, including 8 plants, 2 insects, 10 or more molluscs, 5 fish, and 1 mammal, are indigenous to the area. Between 1910 and 1930, Carson Slough, an extensive marsh in the western portion of Ash Meadows, was drained for mining of peat and clay. In the mid-1940s several exotic species were introduced to the springs, resulting in a decline of the native populations (Miller 1948). In the 1960s, ground-water pumping for irrigation reduced the discharge of several springs. Although litigation to establish minimal water levels needed for the survival of endemic fishes was successful, Ash Meadows faced the threat of major residential, industrial, and mining development both within and adjacent to the site (Williams 1984). However, the Ash Meadows Wildlife Refuge was established in 1984 by the U.S. Fish and Wildlife Service with the acquisition of a 4,525 ha unit (Anonymous 1984), the first of several parcels that eventually will make up the refuge's total 9,513 ha.

3.3 GEOMORPHIC VALLEY-FORMS

Processes influencing the flux of sediments along the lateral and elevational gradients of stream corridors are evident in the geomorphology of river valleys. The relationships between stream and alluvial ground-water levels often can be interpreted as a function of valley-form. These relationships further influence the dynamics of hydrologic parameters and the qualities of riparian communities. Hydrologic, soil, and physiognomic characteristics of riparian communities in glacial, fluvial, alluvial, and lacustrine valley-forms are subsequently discussed.

3.3.1 Glacial Valley-Forms

At least three episodes of Pleistocene glaciation, many with interstadials, scoured the headwaters of most of the major drainages in the Great Basin (Morrison 1965). Blackwelder (1931) examined glacial till along the eastern divide of the Sierra Mountains, origin of the Truckee, Carson, Walker, Owens, and Susan Rivers. In this area, terminal moraines are distributed near the mouths of major drainages, 1,800 to 2,400 m below the summit (Hunt 1967). Similarly, tributaries of major streams of the Bonneville basin (Bear, Weber, Provo, and Sevier Rivers) originate in glaciated portions of the Wasatch Front and Uinta Mountains (Atwood 1909). Blackwelder (1934) noted glacial features in 17 of the interior ranges of the Great Basin.

Glaciers formed along the Ruby Mountains and East Humboldt Range at an average altitude of about 3,050 m extended down to an average altitude of about 2,225 m along the west side of the range (Humboldt River drainage) and down to about 2,195 m on the east side contributing to the watershed of Ruby and Franklin Lakes (Sharp 1938). The most extensive glacier in the central basins was about 24 km long.

Glaciated lands generally coincide with high elevations. Weathering is dominated by mechanical rather than chemical mechanisms. High precipitation falls mostly as snow, which may endure throughout summer months. Evaporation is generally low. The gradual melting of snowpack and slow percolation of meltwater through surface strata results in sustained water yield throughout much of the short growing season.

Erosion was prevalent at the headwaters of glaciated drainages. Sediments were transported through lower valleys and deposited as moraines as the glaciers receded. Discussions of glaciated headwater basins (zone of erosion) and glacial valleys (zone of transport and deposition) are subsequently presented.

3.3.1.a Zone of glacial erosion. Cirques, scree slopes, shallow basins, and extensive exposures of scoured bedrock are characteristic of glaciated headwaters. The melting of snowfields is generally the primary source of drainage. In alpine environs, snowmelt may percolate through scree slopes and follow a course over bedrock to oligotrophic glacial lakes; riparian habitat may be limited to isolated communities along the toe of scree slopes.

In subalpine environs, glacial basins may develop into fens and riparian habitat may extend considerable distances up side slopes. The distribution of riparian habitat thought to be typical of more mesic glacial basins is illustrated in Figure 13.

The dispersed flow characteristic of glacial basins is conducive to the proliferation of organic matter. Saturated riparian habitats are thought to be prevalent. Prolonged saturation may limit the decomposition of organic matter. Organic soils are extensive in glaciated headwaters of streams in the Bonneville basins subregion (Jensen 1981). The morphologies of soils thought to be typical of subalpine glacial basins are illustrated in Figure 14.

Soils on sloping positions of glaciated headwaters (Figure 14a) may be saturated throughout most of the growing season. Surface horizons may be relatively undecomposed (fibric) organic matter originating as bryophytes and the fibrous roots of herbaceous vegetation. Subtending organic horizons may be in a moderately (hemic) to completely (sapric) decomposed condition.

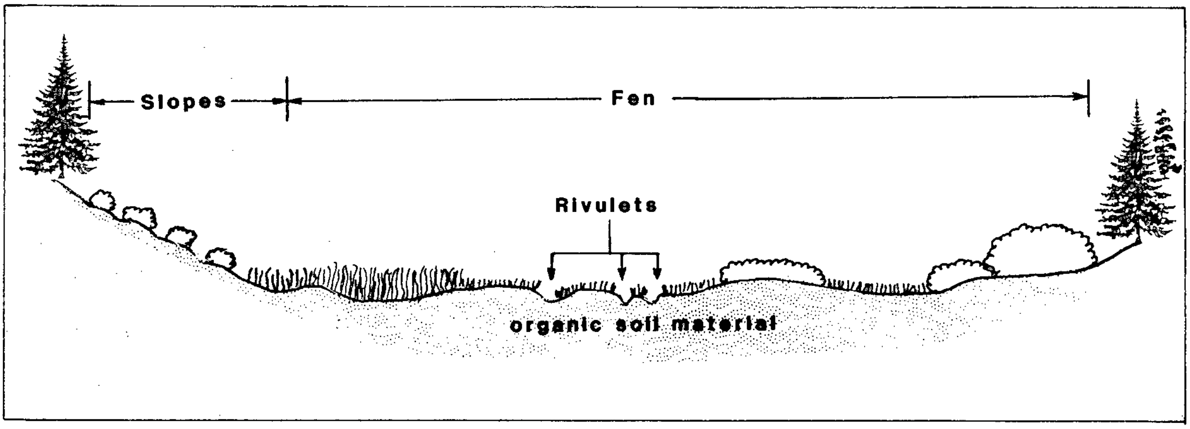


Figure 13. Typical form of eutrophied glacial basins.

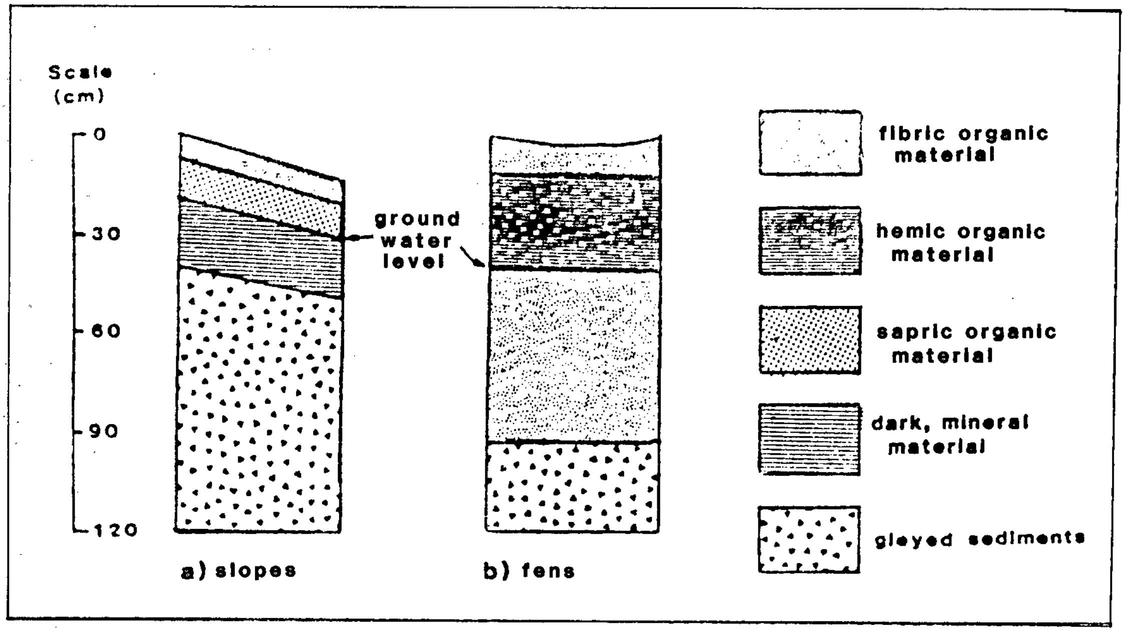


Figure 14. Soil morphologies typical of riparian communities in eutrophied glacial basins.

The thickness of organic horizons on slopes is expected to vary as a complex function of factors affecting biological production and decomposition. The mineral substrate may be alluvial sediment, colluvium, or residuum underlain by weathered bedrock and normally is gleyed.

The sum thickness of organic materials in fens (Figure 14b) may range from as little as a few centimeters to more than 2 m. Thin layers of mineral sediments washed in from contiguous uplands often are stratified between organic layers. Organic materials generally are subtended by fine-grained, gleyed mineral sediment with slow to very slow permeability.

Although the level of ground water may be well below the surface throughout much of the growing season, absorption of water by organic soils normally results in saturated surfaces throughout most of the growing season. The accretion of organic matter may extend the vertical (and consequently the horizontal) limits of capillary rise. The accretion of organic matter may result in the encroachment of fens toward lateral margins. The presence of conifers surrounded by boggy communities is indicative of organic matter accretion.

The distribution of riparian communities in glacial headwaters appears to be a response to microtopographic position and hydrologic regime (Tuhy and Jensen 1982). Herbaceous and shrub riparian communities are common in glaciated headwaters of the Uinta Mountains, Utah (Jensen and Tuhy 1981). Riparian habitats on slopes in this area are dominated by sedges (Eleocharis pauciflora and Carex spp.) and wet-site herbs complemented by low willows (Salix wolfii and Salix planifolia). Fens are a mosaic of saturated shrub communities on low hummocks, monotypic herbaceous communities in swales and more diverse herbaceous communities in even locations.

The organic soils thought to be typical of riparian habitats in glaciated headwaters are expected to be effective in regulating the flux of water and sediments to lower drainage positions. The high degree of biotic activity and dispersed flow associated with glacial basins also may affect the chemical qualities of effluent water. Organic detritus may serve as a nutrient source to downstream aquatic habitats (Cummins 1974; Knight and Bottorff 1984).

3.3.1.b Zone of glacial transport and deposition. Broad glacial valleys often extend considerable distances below cirque basins. Along the upper segments of glacial valleys (zone of transport), bottoms generally are even to concave and bordered by residual slopes. Along the lower valley segments (zone of deposition), bottoms may be undulating and bordered by lateral moraines. Seasonal flooding, displacement of stream channels across the floodplain, and the encroachment of alluvial landforms arising from contiguous uplands lend an additional degree of geomorphic diversity in the forms of stream bars, levees, swales, and alluvial fans. The form thought to be typical of glacial valleys is illustrated in Figure 15.

Fragmental glaciofluvial fill normally underlies glacial valleys at approximately the level of normal streamflow. The high permeability of this substrate is conducive to rapid equilibration of alluvial ground water and streamflow levels. An increase in stream stage may correspond with a rise in alluvial groundwater level without bank overflow. In contrast, a decrease in water-level elevation due to channel downcutting or reduced streamflow may result in drainage of alluvial ground water toward the stream channel. The relationship between alluvial ground water and streamflow geometries may be complicated by spring sources, obstructions to flow, and/or lenses of finegrained sediments. Discussions of riparian habitats in glacial valleys are subsequently presented for the specific features depicted in Figure 15.

(1) Stream bars. Gravel bars may be considered as both the initial state from which habitats develop and the limit to which they may regress. The process dominating the morphology of stream bars is fluvial erosion and sedimentation. The progressive development of soils thought to be typical of stream bars is illustrated in Figure 16.

The "primal state" of stream bars (Figure 16a) is a severely eroded condition subtended by fragmental glaciofluvial fill (gravel bars). While the alluvial groundwater level is normally near the surface, vegetation may be dominated by mesic species due to the low water storage capacity and negligible capillary rise characteristic of the substrate. Although vegetation generally covers a negligible proportion of gravel bars, the species diversity often is very high relative to other riparian habitats (Tuhy and Jensen 1982). The frequent disturbance and coarse substrate characterstic of gravel bars appear to have an equal potential for initial establishment of both upland and riparian species. Deposition of somewhat

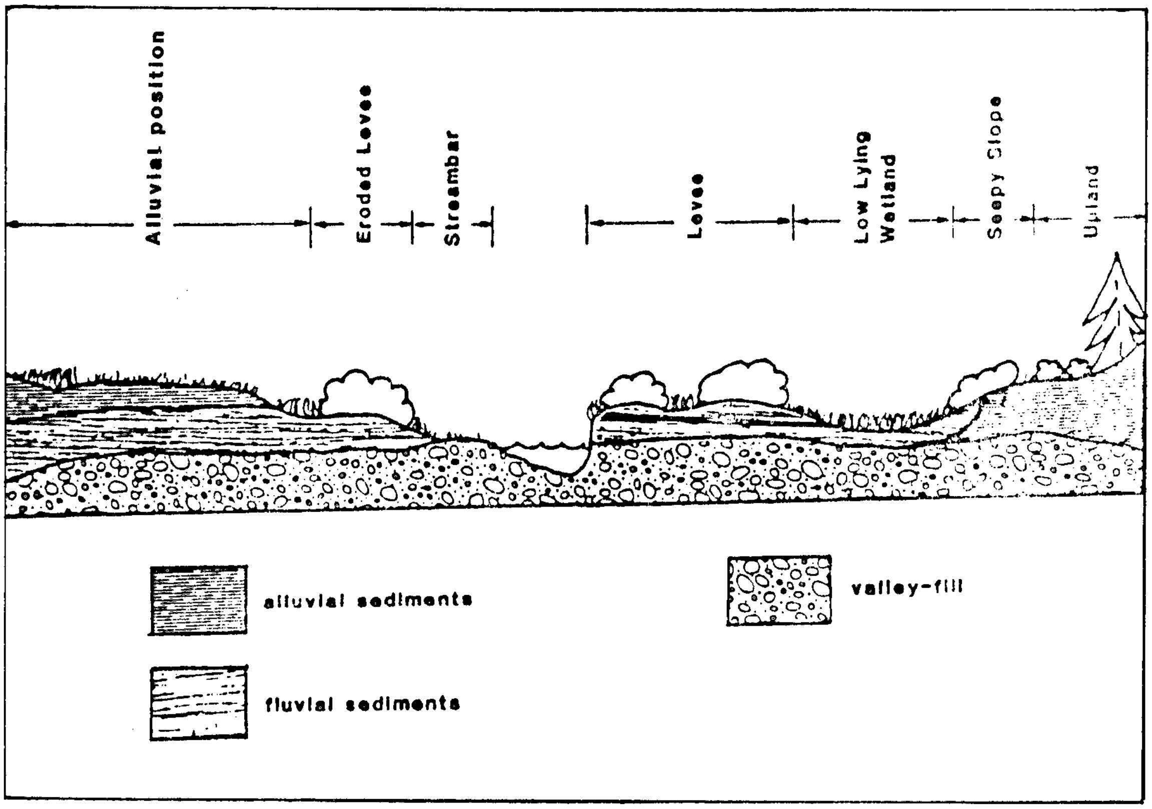


Figure 15. Typical form of glacial valleys.

finer grained sediments (generally sand) may lead to establishment of more vigorous vegetation (often Carex spp.) that tends to stabilize the bar. Mineralized organic matter may accumulate in dark-colored surface horizons (Figure 16b), and subsequent deposition may result in sandwiching of dark surface horizons between layers of fresh sediments (Figure 16c).

Assuming that the flux of sediments through glacial valleys approaches a state of dynamic equilibrium (sediment production approximately equals sediment transport), the area of stream bars should remain relatively constant. An increase in the number or extent of stream bars could be interpreted as a response to degradation of streambanks or to decreased waterflow through established channels. Accelerated rates of streambank degradation have been caused by livestock grazing, mining, roads, construction, and recreation. A decrease in stream discharge resulting from drought, retention, or diversion also may bring about a reduction in stream width and, consequently, more extensive stream bars.

(2) Channel levees. These features develop adjacent stream channels or stream bars, but may occur throughout glacial valleys due to the lateral displacement of channels. The surfaces of levees are convex and generally slightly higher than adjacent land. The lateral migration of stream channels and creation of new levees may result in wide areas of undulating or hummocky relief. The morphology of soil thought to be typical of channel levees is depicted in Figure 17.

Surface soil horizons usually are darkened by mineralized organic matter. Subtending material may include thin layers of contrasting texture and/or organic matter content indicative of several episodes of deposition. Soil texture is usually coarser with increasing depth.

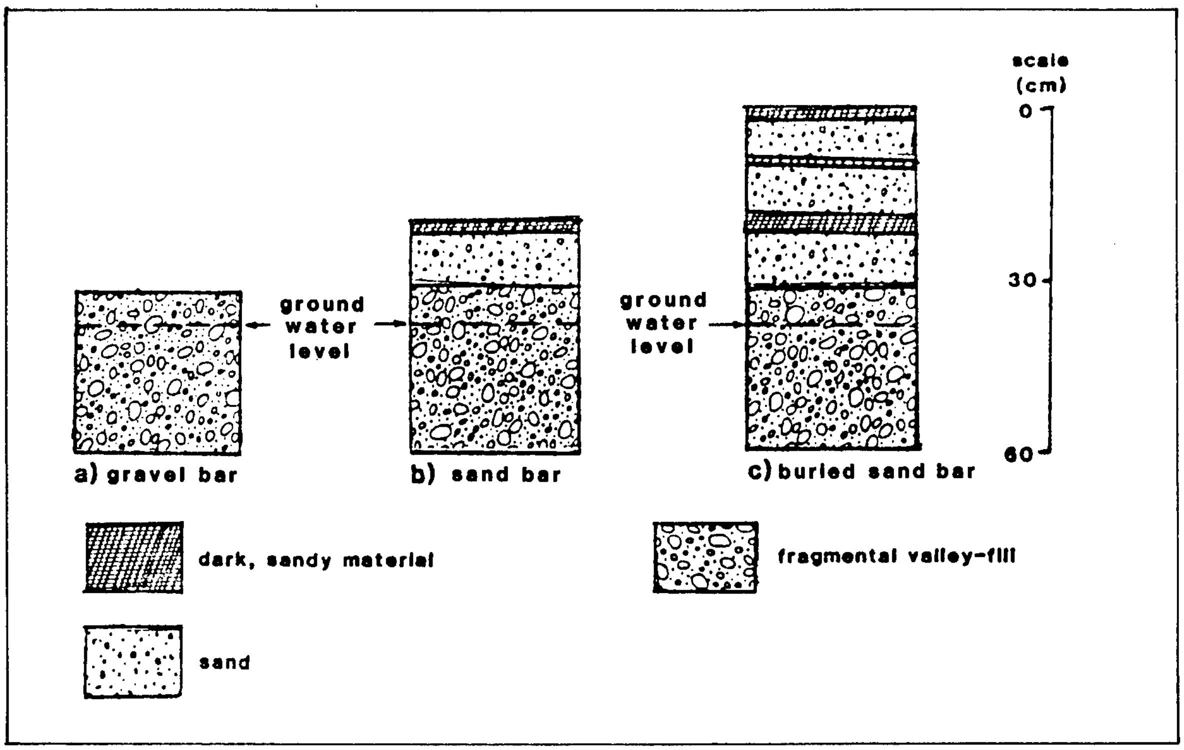


Figure 16. Progressive development of streambar soil.

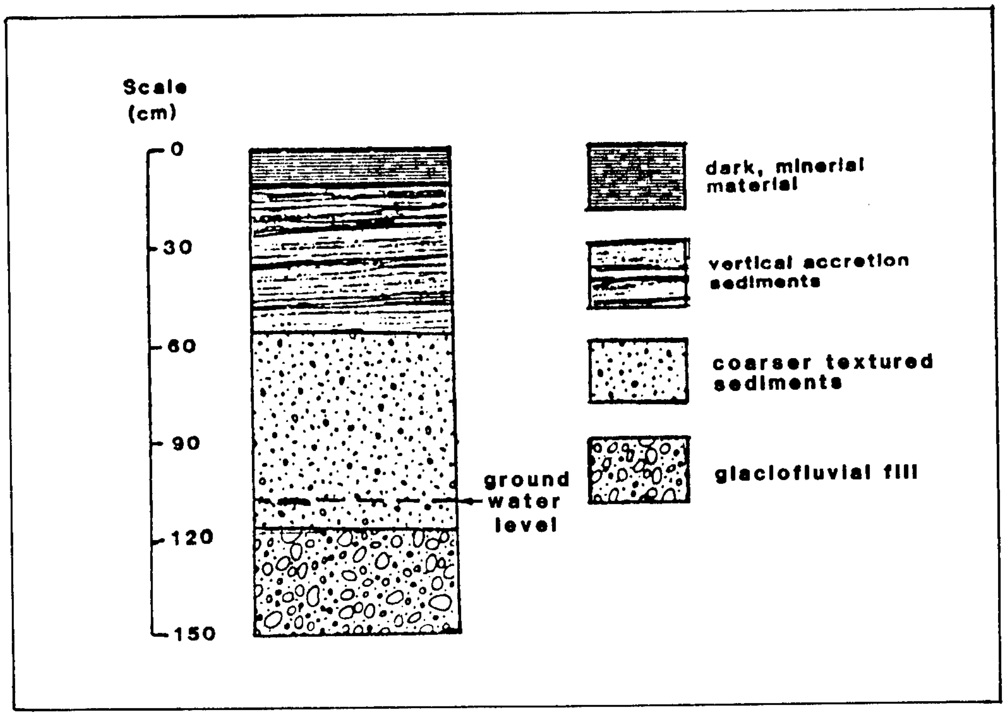


Figure 17. Soil morphology typical of channel levees.

Glaciofluvial fill underlies stream levees at approximately the level of normal streamflow. The high permeability of the glaciofluvial fill allows rapid equilibration between stream stage and alluvial ground-water levels.

Channel levees typically support temporarily flooded shrub communities. Willows (Salix) are a common overstory, while the herbaceous layer may be dominated by sedges (Carex), grasses, and/or forbs. A reduction in the cover or vigor of vegetation may promote streambank sloughing and degradation of levees.

Channel levees function to regulate the rate at which water is distributed across floodplains during active flood stages. As stream levels rise, channels between hummocks disperse water over the floodplain in a regulated manner. Shrubs characteristic of channel levees also function to maintain the integrity of stream channels by reducing fluvial erosion and creating conditions favorable to deposition of sediments.

(3) Low-lying wetlands. Wetlands commonly are concave in form and are at or near the ground-water level. These riparian communities may be a response to inundation resulting from a rise in ground-water level or a response to sedimentation and eutrophication of permanently flooded positions. Beavers often cause flooding of low-lying areas. The morphology of soils thought to be typical of low-lying wetlands in glacial valleys is depicted in Figure 18.

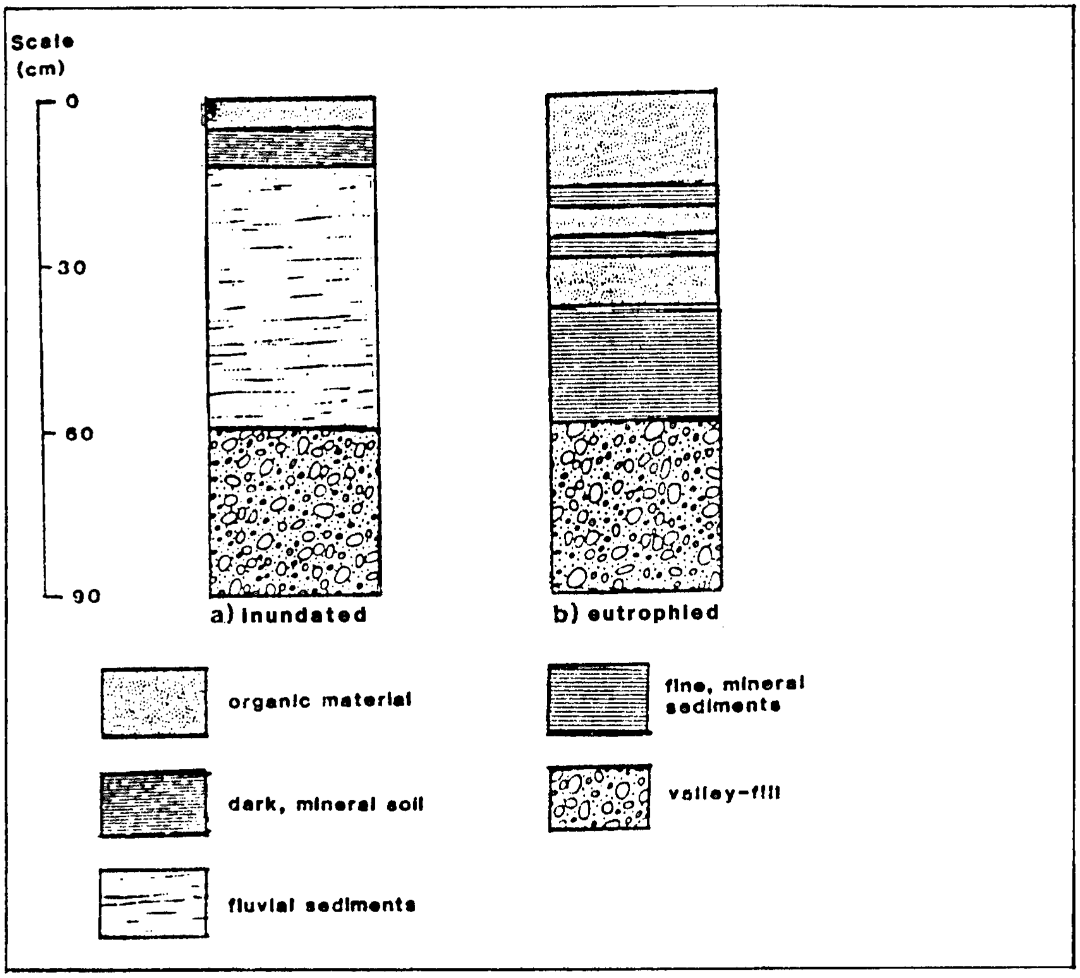


Figure 18. Soil morphology typical of low-lying positions.

Areas inundated by ground water (Figure 18a) normally contain mineral soil, with organic strata generally confined to thin surface horizons. The influence of periodic deposition and in situ pedogenesis during earlier hydrologic regimes may be apparent in subtending strata. In eutrophied soils (Figure 18b), surface materials are generally organic. Subtending strata often show alternating layers of mineral and organic materials, indicative of repeated inundation by low-velocity floodwaters and intervals of relative stability. Glaciofluvial fill underlies these positions at about the level of normal streamflow.

Low-lying wetlands are typically permanently flooded, semipermanently flooded, and saturated water regimes of herbaceous and shrub communities. Herbaceous vegetation commonly includes sedges (Carex), grasses, and wet-site forbs. Harris et al. (1985) noted *Juncus nevadensis*, *Carex* spp., and *Helenium bigelovii* on semipermanently flooded positions in the high Sierra-Nevada. Willows (Salix) are common in the overstory although other shrub species may be dominant.

These riparian communities may function to regulate the discharge and sediment flux along the lateral gradients of valley bottoms to streams. Low-lying wetlands may overflow directly to streams through rivulets, or may drain through glaciofluvial fill. High levels of biotic activity associated with these positions may assimilate nutrients and reduce their discharge to streams.

(4) Alluvial features. Alluvial features are a response to deposition of sediments eroded from contiguous uplands. These features are thought to have been formed by outwash of relatively finegrained sediments from contiguous lateral moraines. Surfaces generally are convex and inclined toward the medial axis of the valley. While surface strata may be wet throughout runoff periods, they seldom are flooded.

Soils typical of alluvial positions (see Figure 19) show a relatively high degree of in situ pedogenesis. Surface mineral

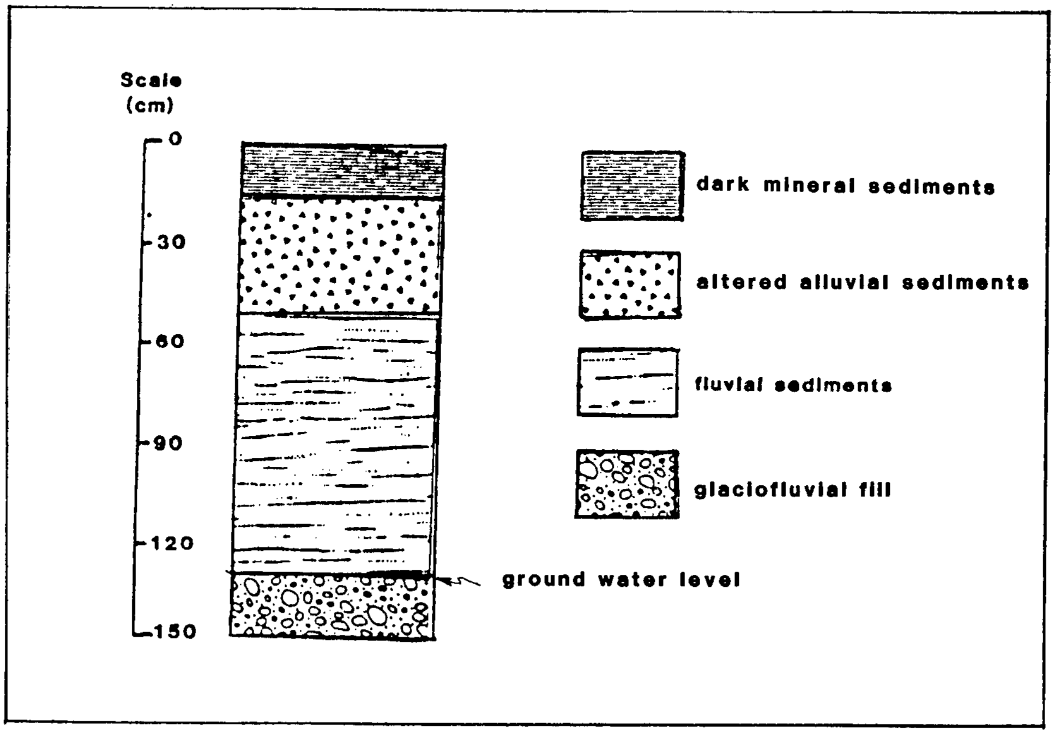


Figure 19. Soil morphology typical of alluvial positions in glacial valleys.

horizons generally are darkened by mineralized organic matter and are flocculated into moderate to strong ped structure. The subtending stratum may be altered by an accumulation of alluvial clay (argillic horizon) or aggregated into strong ped structure (cambic horizon). While surface soil horizons may be gravelly, coarse fragments seldom make up move than 35% of the soil volume. Fluvial sediments normally occur below the level of the floodplain. Fragmental glaciofluvial fill commonly occurs below the level of normal streamflow.

Mesic shrub and herbaceous riparian communities are common on alluvial positions. These communities generally include upland plant species in addition to facultative and obligate hydrophytic plant species. Youngblood et al. (1985a) described Artemisia cana/Poa pratensis communities, Potentilla fruticosa with Deschampsia cespitosa and P. pratensis understories, and herbaceous communities on these positions.

Alluvial features constitute the final stage in the geomorphic succession of riparian habitats in glacial valleys and are transitions to upland habitat. Erosion may result in regression to more fundamental states. Where cut by streams, the high banks associated with alluvial features are very susceptible to sloughing.

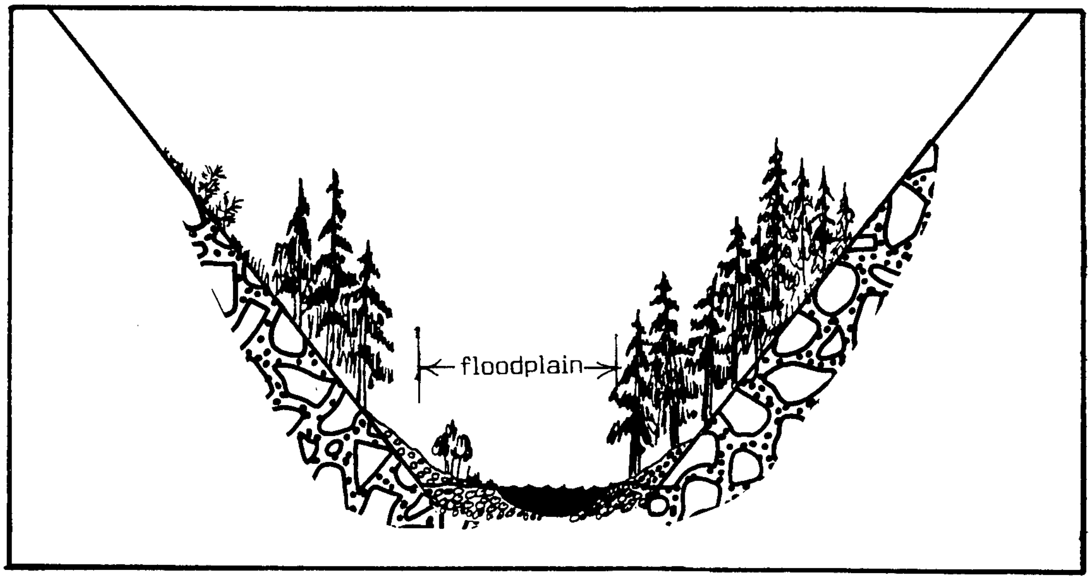
3.3.2 Fluvial Canyons

Where the rate of fluvial erosion and transport is less than or equal to that of colluvial and alluvial deposition, V-shaped canyons form. Fluvial canyons normally are associated with steepgradient, low-order streams. Major drainages originating in the mountains to the east and west of the Great Basin physiographic section flow through fluvial canyons along some part of their route to basin sinks. The vast majority of minor streams draining interior ranges of the Great Basin originate in fluvial canyons and dissipate soon after leaving their confines. These minor drainages include perennial streams (often spring-fed), intermittent drainages, and ephemeral washes. The consistency and intensity of streamflow may influence both the shape of fluvial canyons and characteristics of riparian habitats. Along upper segments of drainages, erosive mechanisms may be predominant; fluvial and alluvial deposition may be concomitant along lower segments of fluvial canyons.

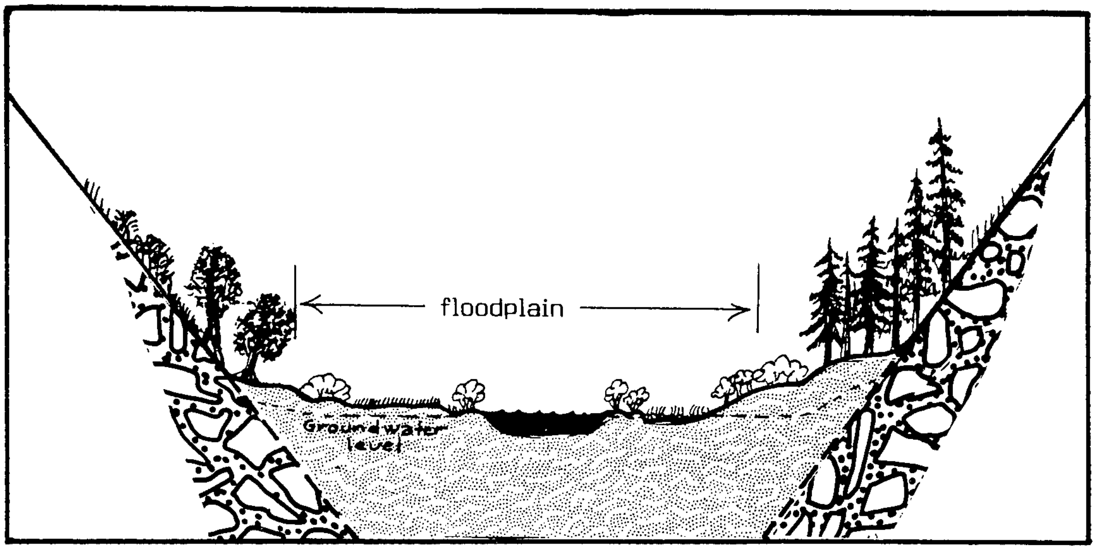
3.3.2.a Zone of erosion. Along upper segments of canyons (see Figure 20a), erosion may be actively downcutting through consolidated bedrock and headcutting toward drainage divides (or upstream glacial valleys). Alluvial/colluvial slopes commonly rise abruptly and confine channels to narrow, relatively straight courses. Riparian communities are mostly temporarily flooded, intermittently flooded, and non-flooded water regimes. The lateral extent of alluvial aquifers may be limited by residual slopes. Channel substrate may be a jumbled assemblage of rubble, often angular, and ranging in size from gravel to boulders. Riparian habitats are usually restricted to narrow bands along stream channels. The form thought to be typical of erosive segments of fluvial canyons is illustrated in Figure 20a.

Thin surface horizons of soils are generally mineral sediments darkened by organic matter. Subtending strata may include angular rock fragments eroded from contiguous slopes. Buried surface horizons indicative of mass wasting also may be present. Mottles often are prevalent at and below the high water level. Although normally contiguous to stream channels, these soils may be excessively drained throughout most of the growing season and typically have low water-storage capacity.

Riparian vegetation generally is restricted to deep-rooted species. Needle-leaved evergreen-forested habitats extend to the edge of stream channels along upper elevations throughout much of the northwest basins subregion (Claire and Storch 1977). Deciduous forest riparian communities dominated by alder (Alnus) or birch (Betula) commonly form a narrow band immediately contiguous to channels in the Bonneville basins subregion (Youngblood et al. 1985a). Harris et al. (1985) noted Rhododendron occidental, Fraxinus latifolia, and Alnus occidental on steep gradient positions along the western slope of the Sierra-Nevada. Willow (Salix), birch (Betula), and aspen (Populus) were noted along steep gradient drainages in the central portion of the region (Dobkin and



a. Zone of erosion



b. Zone of deposition

Figure 20. Form and distribution of riparian habitat in a structural mountain valley (modified from Jensen 1983).

Wilcox 1985). In the southern Great Basin, "xeroriparian" vegetation along the headwaters of arroyos is ordinarily dominated by upland species of pronounced vigor and stature (Warren and Anderson 1985).

The form of erosive segments of fluvial canyons is conducive to the high velocity stream discharge capable of transporting a wide range of sediment sizes. Thus, effectiveness of riparian habitats for flood and erosion control is low and the influence upon chemical water quality insignificant.

3.3.2.b Zone of deposition. Sediments eroded from headwater segments of fluvial canyons generally are sorted from coarse to fine along lower stream segments. Alluvial mechanisms may transport additional sediments toward the medial axis of fluvial bottoms (see Figure 20b). The depth of these sediments generally increases in a downstream direction. At the mouths of fluvial canyons, sediments are splayed in the form of broad alluvial fans.

Surface discharge may be depleted by percolation through the mixed fill deposited along lower segments of fluvial canyons. Minor streams of the interior ranges may sustain only intermittent or ephemeral flow. Larger streams arising from the high mountains to the east and west and from high ranges in the central basins may sustain more continuous flow, though surface flow is frequently diminished by infiltration through underlying sediments. Seasonally flooded, intermittently flooded, temporarily flooded, and sub-irrigated riparian communities are common. A high degree of disparity between maximum and minimum stream discharge often results in extensive scoured floodplains or incised channels.

Riparian soils within the floodplain are characterized by a mineral surface horizon darkened by organic matter, subtended by mixed fluvial sediments. Surface horizons on stream terraces may be considerably thicker than those within the floodplain.

Deciduous forest communities often dominate stream terraces. Shrub and herbaceous communities are more typical within the active floodplain although channels characterized by frequent catastrophic flooding may be essentially unvegetated. Coniferous forests, often complemented by a mixed assemblage of broadleaf shrubs, are common along lower segments of narrow bottoms in the northern portion of the Great Basin hydrographic region (Claire and Storch 1977). Aspen (Populus tremuloides), often complemented by conifer species, also is common in the northern part and, less extensively, in the central part of the region (Dahlem 1979; Platts et al. 1985; Youngblood et al. 1985a,b). Oakleaf et al. (1977) observed riparian groves of aspen being replaced by sagebrush communities throughout Nevada and attributed the response to livestock grazing. Communities dominated by cottonwoods with mixed shrub and herbaceous understrata have been described in the Bonneville basin (Youngblood et al. 1985a). In the southern part of the region, cottonwood-willow associations may dominate stream terraces sustained by subsurface alluvial flow (Pase and Layser 1977; Minckley and Brown 1982). Other commonly associated plants in this region include alder (Alnus), birch (Betula), dogwood (Cornus), and willow (Salix). Brady et al. (1985) describe an orderly successional sequence of riparian habitats that generally is correlated with the degree of fluvial deposition and the periodicity of flooding.

Springs and seeps are common along the flanks of lower segments of fluvial canyons in the Lahontan basins subregion (Platts and Jensen current investigation). Where discharge is consistent, saturated herbaceous communities dominated by sedges (Carex) are common; intermittent springs sustain more mesic communities, often dominated by bluegrass (Poa pratensis).

During base flow, a significant fraction of streamflow may percolate through fluvial substrate, resulting in reduced surface flow and deposition of suspended sediments. At flood stage, bedloss may be insignificant relative to surface flow, and sediments may be resuspended and transported downstream. Along ephemeral drainages the floodplain may be scoured seasonally of fine-grained sediments, leaving broad expanses of rubble substrate. Entrenchment of stream channels may result in draw-down of alluvial aquifers responsible for sustenance of deep-rooted riparian communities. While deposition mechanisms are apparent in the geomorphology of the lower portions of fluvial canyons, land uses (e.g., grazing) may be increasing the effectiveness of erosive mechanisms. The high porosity and low biotic activity common to coarse- textured soils may limit the effectiveness of these riparian habitats in altering the chemical qualities of streamflow.

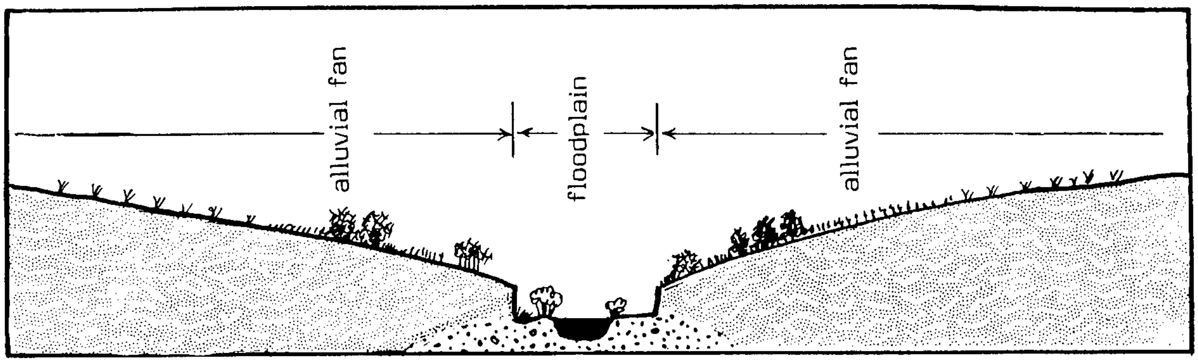
3.3.3 Alluvial Valleys

Where alluvial transport and deposition along the lateral gradients of watersheds outpace the rate of fluvial erosion and transport, alluvial valleys form. Alluvial mechanisms are evident in structural valleys in the high mountains on the eastern and western flanks of the Great Basin hydrographic region. All drainages of the hydrographic region flow toward broad structural basins that are filled to considerable depths with alluvial and lacustrine sediments. The transitions from depositional segments of fluvial canyons to alluvial valleys are often diffuse.

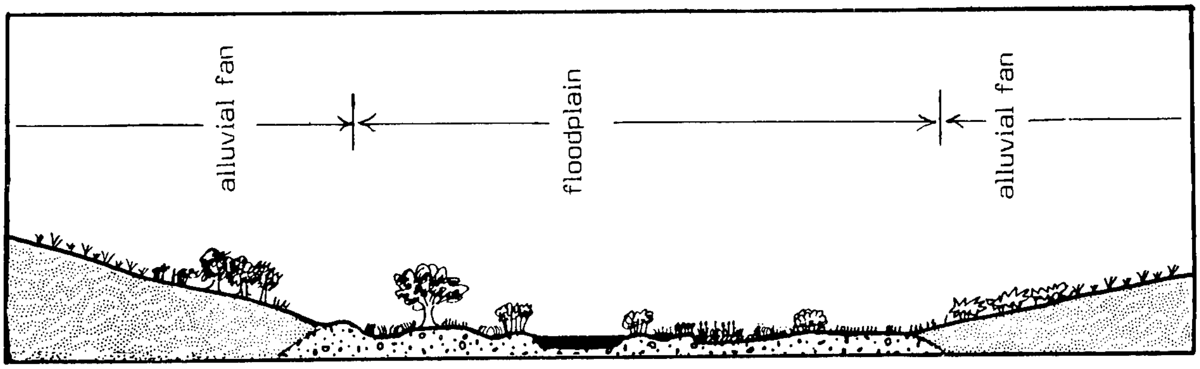
The vast majority of minor interior streams of the Great Basin dissipate within or shortly after leaving the confines of fluvial canyons. Surface discharge generally retreats as the summer progresses, although brief episodes of streamflow commonly follow storm events. The intermittent and ephemeral character of minor streams may be attributed to percolation through underlying substrate (bedloss) and to evapotranspiration.

Within alluvial valleys, two types of floodplains may be distinguished: confined floodplains and unconfined floodplains.

3.3.3.a Confined floodplains. Where alluvial features arising from opposite sides of a valley meet, the juncture is often an entrenched floodplain, channel, or dry wash (see Figure 21a). Confined



a. Confined floodplain



b. Unconfined floodplain

Figure 21. Forms of typical alluvial valleys.

floodplains are most common along the upper segments of watersheds and near the inlets and outlets of structural valleys, where the distance between opposing mountain slopes is narrow. Floodplains of rivers emerging from fluvial canyons may be confined by lacustrine landforms (deltas and terraces) remnant of Pleistocene lakes. Streamflow through narrow floodplains confined by alluvial landforms may be depleted primarily through bedloss.

Forested, shrub, and herbaceous riparian communities normally are restricted to the floodplain. In the northwest basins subregion, communities dominated by willow, cottonwood, hawthorn (Crategus), creek birch (Betula), snowberry (Symphoricarpus), chokecherry (Prunus), and alder (Alnus) occur on narrow floodplains (Claire and Storch 1977). Unstable streambanks dominated by sagebrush (Artemisia) also were described in this subregion. Historically, groves of cottonwoods with shrub understories of buffaloberry (Shepherdia argentea) and willow were common along lower segments of the Truckee River (Klebenow and Oakleaf 1984). Aspen (Populus tremuloides), black cottonwood (P. trichocarpa), and willows are common along lower segments of streams in the Mono Lake basin (Stine et al. 1984). Similarly, dense stands of cottonwood (Populus fremontii), thickets of mesquite (Prosopis), willow, and tamarisk (Tamarix) are dominant in riparian communities along perennial segments of the Amargosa River (Williams et al. 1984). Non-vegetated streambars, reflecting the high disparity between maximum and minimum stream discharge, are often extensive in confined floodplains. Alluvial positions are generally upland habitat dominated by sagebrush (Artemisia).

3.3.3.b Unconfined floodplains. Near the center of alluvial valleys, floodplains typically are flanked by gentle transitions to uplands (see Figure 21b). While alluvial features (e.g., fans and bajadas) may encroach, they terminate before reaching the medial axes of valley bottoms. Streams commonly flow over fine-grained sediments washed in from upstream watersheds and eroded from the surface of alluvial features. Springs discharging through upslope alluvial sediments may augment streamflows (Brothers 1984; Stine et al. 1984). Evaporation, in addition to bedloss, may reduce streamflow through unconfined floodplains of alluvial valleys.

3.3.4 Lacustrine Basins

Major streams of the Great Basin wander through broad landscapes of fine-grained, lacustrine sediments with relatively low permeability on their course toward desert sinks. Transitions between alluvial valleys with unconfined floodplains and lacustrine basins may be diffuse.

Evapotranspiration may be the most significant process reducing streamflow through lacustrine basins. Where hydrologic inputs are consistent, permanent lakes or extensive areas of wetland riparian communities are prevalent. Desert playas and saline soils are common in basins with less consistent hydrologic input.

Streams arising in the Rocky Mountains on the eastern flank of the Great Basin hydrographic region and those arising in the Sierra Mountains on the west flow perennially to terminal lakes in the Bonneville and Lahontan basins subregions. The Bear River is bordered by extensive sloughs on its course through Cache Valley. Wetlands dominated by cattail (Typha latifolia), bulrush (Scirpus), and sedges (Carex) are common.

Streams originating in ranges interior to the Great Basin are generally intermittent or ephemeral along lower segments due to bedloss and evapotranspiration. Dry lake beds and playas occur at the terminus of these streams. Brothers (1984) noted Nevada saltbush (Atriplex torreyi), greasewood (Sarcobatus vermiculatus), rubber rabbit brush (Chrysothamnus nauseosus), salt grass (Distichlis stricta), and alkali sacaton (Sporobolus aroides), all salt tolerant species, along lower segments of the Owens River.

Curtois (1984) described the succession and retrogression of short-lived riparian habitats on dry lake playas associated with the Mojave River. With the flooding of playas, planktonic and algal communities developed within the shallow littoral zone. Establishment of salt cedar (Tamarix), heliotrope (Heliotropium curassavicum), and sea purslane (Sesuvium verrucosum) followed with the evaporation of surface water. Alkali shrub communities became reestablished upon further drying of the playa surface. High salinity associated with many lake playas severely limits establishment of vegetation.

3.4 VALUES OF RIPARIAN HABITAT

From a physical perspective, the function of riparian and stream habitat is to regulate the transport of water and sediments from positions of high topographic relief to positions of lower relief. The structure, composition, and dynamics of riparian habitats both affect and are affected by specific transport mechanisms. The values of riparian and stream habitats are based on interpretations of their structure, composition, and dynamics relative to a particular function or human use. Values commonly attributed to stream and riparian habitat include:

1. flood storage and desynchronization,
2. regulation of sediment transport,
3. enhancement of water quality parameters,
4. fish and wildlife habitat, and
5. socioeconomic benefits.

The value for flood storage and desynchronization is a measure of the influence of riparian and stream habitats upon the temporal and spatial dynamics of water transport along the gradients of watersheds. Flood storage and desynchronization may be influenced by the geomorphic form and distribution of riparian and stream habitats, the permeability and water storage capacity of riparian soils and channel substrates, and the position of habitats relative to hydrologic sources. In the past, riparian vegetation has been destroyed through dredging, channelization, and levee construction in the name of flood control. The inadvisability of these actions and the inherent value of riparian habitats in regulating stream discharge is being recognized (Griggs 1984).

Fluvial mechanisms are primarily responsible for the transport of sediments along the gradient from headwaters to sink, occurring primarily during brief intervals of peak discharge. The competence of streamflow in transporting sediments increases exponentially as a function of velocity (Bloom 1978). The effectiveness of riparian habitat in regulating the flux of sediments is influenced by the rate that sediment is delivered from uplands, the size of sediments, the distribution of sediments relative to streamflow geometry and the erodibility of soil and substrate relative to the magnitude of fluvial forces. Vegetation plays an important role in stabilizing sediments within and contiguous to the floodplain (Chaimson 1984; Kondolf and Curry 1984).

The value of riparian habitat for influencing the chemical qualities of water is thought to be a response to complex interactions between biotic and abiotic processes. Biotic processes include absorption and assimilation by plants and microfauna. Abiotic processes include sedimentation, precipitation, and adsorption. The effectiveness of biotic and abiotic processes are further influenced by the chemical qualities of the influent water and the hydrologic flux through the riparian system. Thorough discussions of the effects of wetlands upon water-quality parameters have been prepared by Burton (1981), Kadlec (1981), Adamus (1983), Sather and Smith (1984), Unsicker et al. (1984), and Herron (1986).

The value of riparian habitats to wildlife may be influenced by the structure and species diversity of vegetation, the spatial distribution of contrasting riparian communities composing the habitat, substrate and soil characteristics, and hydrologic regime and water qualities (Clark 1978).

Dobkin and Wilcox (1985) studied the relative dependence of 65 bird species upon discrete riparian habitats in the Toiyabe Range in central Nevada. Differences in the distribution of the birds were attributed to geomorphic criteria and floristic parameters. The diversity of butterfly species was found to be correlated with the distribution of plants in the same area (Murphy and Wilcox 1985). Oakleaf and Klebenow (1975) attributed a decline in avifauna species utilizing riparian habitat along the Truckee River with habitat degradation resulting from river channelization and grazing pressure.

The socioeconomic value of riparian habitat may be separated into consumptive and nonconsumptive uses (Sather and Smith 1984). Consumptive uses entail the harvest of resources associated with riparian and stream habitats, including timber, crops, fish, wildlife, energy, and water. Nonconsumptive uses include scenic, recreational, educational, aesthetic, archeological, heritage, and historical values. Nonconsumptive uses are experienced by individuals while preserving the essential attributes of the habitat (Sather and Smith 1984). Discussions of socioeconomic values of riparian habitats applicable to the Great Basin region have been prepared by Fox (1977), Nielsen et al. (1977), Nielsen and Godfrey (1977), and Swanson (1977).

CHAPTER 4. AQUATIC HABITAT

Although the study of Great Basin aquatic environments dates to before the turn of the century (Packard 1879), it is still in its infancy. As will be evident from the present overview, the ensuing research during this century is patchy in both a temporal and a spatial sense whether lentic or lotic habitats are considered. Even the most recent reviews of work in this area are more than 20 years old (Edmondson 1963; Pennak 1963). A scattering of studies were conducted during the first half of the 1900's (Daniels 1917; Kemmerer et al. 1923; Clarke 1924; Needham and Christenson 1927; Hutchinson 1937), but most of the aquatic research has occurred since the mid-1950's, especially that related to stream environments.

As might be expected, a considerable amount of research on lentic waters in the Great Basin has focused on the Great Salt Lake, the largest remnant of ancient Lake Bonneville. Great Salt Lake has attracted attention especially as a hydrologic phenomenon and in terms of water chemistry. The early survey of Gilbert (1890) remains the classic description of the basin, the lake, and its shore features, but more recent papers have discussed the hydrology (Eardley 1938; Eardley et al. 1957). The geology of the Lake Bonneville deposits has been described by many; Hunt et al. (1953) gave many of the pertinent references. Biological aspects of the lake have been variously investigated, but generally with only scattered reference to the organisms and little experimental study (e.g., Packard 1879; Daniels 1917; Nelson 1955; Carozzi 1962).

A major early limnological work in the Great Basin was that of Hutchinson (1937) on five lakes in the Lahontan Basin. More recently, Galat et al. (1981) conducted a comprehensive study of the limnology of Pyramid Lake.

Initial interest in flowing waters was stimulated by a concern for the development of a productive fishery (e.g., Needham and Christenson 1927), and many relevant reports are buried in the archives of government management agencies. Most of the work on Great Basin streams dates from Gaufin's (1959) study of macroinvertebrates in the Provo River, conducted during the late 1940's, and McConnell and Sigler's (1959) study of primary productivity in the Logan River. Research on flowing waters in the Great Basin has centered on a few locations close to universities [e.g., Deep Creek, ID-UT (Idaho State Univ.); Logan River and Blacksmiths Fork, UT (Utah State Univ); Provo River and Stewarts Creek, UT (Brigham Young Univ.); and Truckee River, NV (Univ. Nevada, Reno)], but much of the work unfortunately still resides in unpublished theses and reports.

4.1 WATER CHEMISTRY PARAMETERS

Most of the published interpretive analyses of water chemistry in the Great Basin has involved lentic waters (Kemmerer et al. 1923; Clarke 1924; Hutchinson 1937, 1957; Whitehead and Feth 1961; Galat et al. 1981; Lamarra et al. 1986). Apart from analyses of a few tributaries flowing into closed-basin lakes (Clarke 1924; McConnell et al. 1957; Whitehead and Feth 1961), relatively little has been published on the chemical composition of Great Basin streams, and no previous attempt has been made to characterize conditions over the whole area.

The Truckee River drainage system, including Lake Tahoe and Pyramid Lake, probably has been examined more intensively than any other area of the Great Basin (and perhaps the entire United States), although most of the information on the river itself has been relegated to limited-circulation reports. The sources and fates of potential plant nutrients have received particular attention primarily because of economic and social concerns for the ecological integrity of the two lakes resulting from adverse anthropogenic influences within the drainage. Notable exceptions to the dearth of published findings in the open literature are the work of C.R. Goldman and his colleagues on Lake Tahoe and the study on Pyramid Lake by Galat et al. (1981).

4.1.1. General Chemical Characteristics

4.1.1.a Lakes. Principal factors affecting the composition of closed-basin lentic waters are interrelations of temperature, precipitation, and evaporation, including long-term effects of concentration by evaporation in some lakes, such as the Great Salt Lake, and the amount and composition of influent waters from streams and springs. Also involved are the effects of the biota, the basin sediments, and the kinds of rock that compose the drainage basin (Whitehead and Feth 1961).

Several papers on the chemical make-up of closed-basin lakes have been published. Clarke (1924, p. 156-180) included a chapter on them. Rankama and Sahama (1950) and Hutchinson (1957) also considered the chemistry of these complex waters. Hutchinson (1937) studied several lakes in the western Lahontan Basin and discussed theoretical aspects of the chemistry of the water. He also showed the effect of return flow from irrigation upon the chemical composition of the lake waters.

Whitehead and Feth (1961) gave the results of more recent chemical analyses of waters from several closed-basin lakes in the western United States and analyses of some tributary stream and spring waters. The waters were analyzed by methods current in the U.S. Geological Survey, which incorporate many advances in analytical instrumentation and reagents since the collection of Clarke's (1924) data, which were largely collected and analyzed in the late nineteenth century.

(1) Great Salt Lake. The Great Salt Lake is a hypersaline system. Ion concentrations are so high that salt precipitates from solution when water evaporates during dry periods. The precipitated salt at the north end of the lake consists of about 99.9% sodium chloride except during the winter when a jelly-like precipitate of hydrated sodium sulfate ($Na_2SO_4 \cdot 10H_2O$) forms (Stube et al. 1976).

The chemical composition of the Great Salt Lake (Table 7) fluctuates considerably from year to year and season to season. Great Salt Lake water contains primarily sodium chloride which apparently has reached a concentration that will not permit large concentrations of many other constituents in solution.

Waters tributary to the Great Salt Lake also were examined by Whitehead and Feth (1961); most were rich in sodium and chloride. The Bear, Weber, and Jordan Rivers add a variety of mineral constituents. A typical brine sample collected on the Bonneville salt flats is more concentrated than water from the lake but chemically similar.

(2) Bear Lake. Kemmerer et al. (1923) were the first to determine the chemical composition of Bear Lake water (Table 8).

Table 7. Principal chemical constituents of Great Salt Lake, Utah.

	Concentration (mg/L except pH)	
Constituent	Whitehead and Feth 1961	Stube et al. 1976
Sodium	83,600	101,450
Magnesium	7,200	10,400
Potassium	4,070	4,140
Calcium	241	300
Boron	30	
Chloride	140,000	177,600
Sulfate	16,400	21,540
Bicarbonate (HCO_3)	251	
Bromide	86	
Fluoride	4.2	15.9
Silica	6.2	6.5
pH	7.4	7.7

Table 8. Chemical analyses of water from Bear Lake, Utah-Idaho, and from two tributary streams. All values, except pH, in milligrams per liter (from McConnell et al. 1957).

Source and date	Location	Ca	Mg	Na	K	Cl	SO_4	CO_3	HCO_3	Phenolphathalein alkalinity	Methyyl orange alkalinity	pH
Kemmerer et al. 1923	Bear Lake	4.1	152.0	66.3	10.5	78.5	96.8	78.45	566.0	----	586a	----
Hazzard 1935	Bear Lake	---	----	----	----	----	----	----	----	25-37.5	430-479	8.0-8.5
Perry 1943	Bear Lake	---	----	----	----	----	----	----	----	15-25	375-400	8.4-8.7
Project personnel 1952-55	Bear Lake	---	----	----	----	----	----	----	----	27-29	294-313	8.4-8.6
Soils Lab 1952	Bear Lake surface water range of 3 analyses	17	78-87	23-47	6-11	53-57	71-78	13-18	352-381	----	----	----
Soils Lab	Bear Lake sample from 200 ft	17	81	28	6	57	78	18	352	----	----	----
Soils Lab 1952	Inflow from Mud Lake	27	95	54	12	58	75	0	467	----	----	----
Soils Lab 1952	Swan Creek	47	13	4	2	----	----	----	----	----	----	----

Their sample was taken in 1912 before diversion of Bear Lake water into the lake. Additional, more cursory analyses were performed by Hazzard (1935) and Perry (1943). In the early 1950's a fairly complete assessment of Bear Lake water and its tributaries was done by the U.S. Department of Agriculture Soils Laboratory at Utah State University as part of a study of the lake and its fishery (McConnell et al. 1957). More recently a detailed hydrologic budget and estimates of nitrogen and phosphorus loading of Bear Lake have been worked out by Lamarra et al. (1986). The dilution of Bear Lake water by the Bear River (beginning about 1918) can be traced from the changes in alkalinity (Table 8). Methyl orange alkalinities of the inflowing streams in milligrams per liter are: Bear River 192; Swan Creek 181, and St. Charles Creek 195 (McConnell et al. 1957).

(3) Deer Creek Reservoir. Gaufin and McDonald (1965) monitored several aspects of the water chemistry of Deer Creek Reservoir on the Provo River, in conjunction with a study of algal productivity. The reservoir is essentially a hard-water lake, the total alkalinity of which varied from 90 mg/L to over 170 mg/L during the course of the study. The high alkalinity was due largely to inflowing waters of the Provo River, whose total alkalinity generally exceeds 120 mg/L except during periods of high runoff when water from melting snow may reduce it to less than 70 mg/L. Carbonate concentrations varied from 0 mg/L to more than 20 mg/L. Bicarbonate concentrations were often highest (up to 166 mg/L) in deep water areas where an abundance of free carbon dioxide caused the conversion of carbonate into bicarbonate.

The silica concentration of both the surface and subsurface water was markedly influenced by diatom blooms. Increases in diatoms, especially Fragiliaria capucina, caused a subsequent reduction in the concentration. A bloom during the summer of 1959 caused the silica concentrations of the waters to drop from 5.3 mg/L on August 6 to 4.1 mg/L on August 21. Upon decline of the algae, the silica concentration increased to 6.1 mg/L by September 8. An Anabaena flos-aquae bloom in July 1959 caused no appreciable change in the amount of silica present.

Orthophosphate was present in small quantities (~0.02 mg/L) in surface samples from various sections of the reservoir and in somewhat larger quantities (up to 1.15 mg/L) from the deeper waters. The orthophosphate content of surface waters remained relatively constant, but was quite variable at the 30-m level. There appeared to be an increase in these deeper areas during the summer stratification period, probably due to liberation of phosphate from sediments on reduction. Phosphate concentrations declined in these areas following the autumnal overturn.

Ammonia was found in small quantities throughout the reservoir, probably as a result of metabolism and decomposition of aquatic organisms. The concentration of ammonia in the surface waters showed a gradual increase from early July 1959 (0.01 mg/L ammonium nitrogen) until mid-September when the samples contained 0.14 mg/L ammonium nitrogen. With the advent of the autumnal overturn, the ammonia concentration increased rapidly, reaching 0.61 mg/L of ammonium nitrogen near the surface on September 24, 1959. This increase may have been due to disruption of the bottom sediments and release of gas formed by the bacteria in the mud. Continued agitation of the waters by the overturn apparently was responsible for rapid release of the gas into the atmosphere, as the concentration dropped to 0.02 mg/L in surface samples by October 15. During the following months the amount fluctuated, but showed a gradual increase until it reached a concentration of 0.23 mg/L in December, when sampling was discontinued. The ammonia concentration in deeper water was found to be generally higher than that in surface water but more variable, showing little correlation with seasonal changes or plankton blooms. Minute amounts of nitrite nitrogen were found in the majority of samples, but quantities were too small to permit conclusions about the relationship between NO_2 and other limnological factors.

(4) Pyramid Lake. Pyramid, Walker, and Big Soda Lakes lie in areas of volcanic rocks and weakly consolidated or unconsolidated Pleistocene sediments within the area once covered by ancient Lake Lahontan. Waters from all these lakes are similar in chemical composition, showing notable

variation only among the anions (sulfate in particular) (Whitehead and Feth 1961). The similarity of chemical composition is particularly striking since all the lakes receive various amounts of return flow from irrigation. Big Soda Lake is fed entirely by ground water, whereas Pyramid and Walker Lakes are fed by major streams. The chemical composition of water from the Truckee River, flowing from Lake Tahoe into Pyramid Lake, and that of the Walker River, which supplies Walker Lake, are discussed in the following section.

A detailed account of the chemical makeup of Pyramid Lake is given by Galat et al. (1981). Sodium chloride dominates the chemical composition of Pyramid Lake. The order of cation abundance is $Na^+ > K^+ \geq Mg^{2+} > Ca^{2+}$ and among the anions, $Cl^- > HCO_3^- > CO_3^{2-} > SO_4^{2-}$ (Table 9). Walker Lake, pluvial Lake Lahontan's other major remnant, exhibits a similar pattern, except SO_4 concentration exceeds that of HCO_3 (Koch et al. 1977). Both lakes are in Hutchinson's (1957) chlorocarbonate category. Cole (1968) provides a detailed ionic comparison of Lahontan basin lakes and the world's other saline systems. As with several other Great Basin terminal lakes (notably Walker and Mono), 20th century water diversions are rapidly increasing Pyramid's total dissolved solids (TDS) concentrations. Between 1933 and 1979, the lake's TDS rose 29% from about 3,750 mg/L to 5,250 mg/L in October 1977. Small spring and summer trophogenic decreases were observed, undoubtedly due to phytoplankton uptake and storage. At no time were orthophosphate concentrations low enough to restrict algal productivity. Walker Lake (Koch et al. 1977), Big Soda Lake (Axler et al. 1978), and Mono Lake (Mason 1967) also exhibit high phosphorus levels. Hutchinson (1937) concluded that only rarely is there a phosphorus deficiency in the biological economies of desert lakes in general.

Ammonia (NH_4-N) levels ranged from less than 0.01 mg/L during holomixis to 0.07 mg/L (Galat et al. 1981). This maximum concentration was recorded in the deoxygenated profundal zone during late fall stratification. Incomplete nitrification of bacterially mineralized trophogenic

Table 9. Summary of 1976-77 Pyramid Lake water chemistry. Values in milligrams per liter unless otherwise noted (from Galat et al. 1981).

Item	Range	Mean
pH	0.1-9.3	9.2
Specific conductance (μS/cm at 25 °C)	8,200-8,650	8,420
Bicarbonate alkalinity (HCO_3)	1,400-1,440	1,430
Bicarbonate ($CaCO_3$)	780-950	860
Carbonate (CO_3)	260-475	300
Chloride (Cl)	1,930-2,150	2,080
Sulfate (SO_4)	260-300	280
Sodium (Na)	1,580-1,765	1,720
Potassium (K)	102-125	118
Magnesium (Mg)	111-120	114
Calcium (Ca)	8.8- 9.0	9.3
Boron (B)	9.7-13.6	12.0
Total dissolved solids		
(Evp. at 180 °C)	5,020-5,270	5,110
(summation)	5,145-5,605	5,350

particulate organic matter may be responsible for this condition.

Mean epilimnetic nitrate (NO_3-N) concentration was 0.03 mg/L (Galat et al. 1981). Highest values (0.06 mg/L) were concurrent with winter turnover and were succeeded by rapid phytoplankton assimilation and depletion to less than 0.01 mg/L as spring progressed. Nitrogen compounds are a primary limiting nutrient for Pyramid Lake's non-nitrogen-fixing algae (Hutchinson 1937; Galat et al 1981). Low precipitation and scant terrestrial vegetation, which characterize the Lahontan basin, reduce terrestrial nitrogenous input. In addition, the lake's deep basin and 6-month thermal stratification prevent summer-fall recirculation of hypolimnetic ammonia and nitrate. Recently, laboratory algal growth potential evaluations for several Pyramid Lake diatom and green algal taxa confirmed that nitrogen was their primary limiting nutrient (Lider et al. 1980). At present, nitrogen influxes via the Truckee River and by the lake's nitrogen fixing blue-green algae exert a strong influence on the lake's productivity.

Pyramid Lake's diatom populations and blue-green algal productivity are limited by the seasonal and spacial distribution of silica in the lake (Galat et al. 1981) and soluble iron concentrations. Silica levels ranged from 0.1-2.5 mg/L with a mean of 1.2 mg/L, and iron, generally less than 0.03 mg/L. Both levels are quite low.

(5) Lake Tahoe. Holm-Hansen et al. (1976) examined the vertical distribution of oxygen, nutrients, and temperature near the center of Lake Tahoe to a depth of 400 m in spring, middle and late summer 1969, and winter 1970. Most of the oxygen values were close to the solubility of oxygen, which is 8.84 mg/L O_2 at 20 °C and 12.37 at 5 °C with little or no significant decrease of oxygen concentrations between 100 and 400 m. It appears that phytoplankton in Lake Tahoe are most limited by nitrogen, but may be affected by deficiencies of other inorganic nutrients (Goldman 1964, 1972; Paerl et al. 1975). Nitrogen, iron, and phosphorus at times may all be at or near limiting concentrations. In the upper 50 m of the water column, where nitrate and phosphate are often undetectable, phytoplankton growth is most likely nutrient limited, in addition to being inhibited, by high light intensities in the upper layer. Even at 105 m, it appears that the available nitrate concentration (2.8-8.4 µg/L N) might be limiting for many phytoplankton. Cultures containing 5 µg/L of ferric citrate produced a 20% stimulation over normal growth during a 5-day incubation of Tahoe water (Goldman 1964).

The primary productivity and recycling of nutrients in Tahoe are dependent on the extent to which the water in the lake is mixed each year (Goldman 1974). Paerl et al. (1975) have shown that nitrogen exhaustion occurs in the euphotic zone and that Tahoe is holomictic, at least during some years. There can be complete turnover during the winter with dissolved and particulate material uniformly distributed throughout the lake. Data on dissolved nutrients and total particulate material do not reveal any such period of homogeneity at any of the four times the water column was sampled, rather, marked gradients persisted throughout the year.

In February the water column was almost isothermal, 5.4 °C at the surface and 5.0 °C at 135 m. By late summer there was a well-developed mixed layer of surface water (slightly over 20 °C) with a sharp thermocline between 20 and 30 m. The temperature at 135 m on this date was 6.2 °C, as compared with 4.8 °C in April of 1969 (Holm-Hansen et al. 1976).

Nitrate was low (0-5 µg/L NO_3 as N) in the upper 100 m of the water column throughout the year and increased with depth down to 400 m (15-25 µg/L NO_3 as N). There was no evidence of a uniform distribution of dissolved nutrients due to winter turnover. Phosphate was below detectable limits (<0.2 µg/L PO_4 as P) from 0-100 m in February, increasing slowly to 0.7 µg/L P at 400 m. Although data from the other two sampling dates were different, the concentrations found in July and August were still very low (2-3 µg/L P) in comparison with those in most bodies of freshwater. Dissolved organic carbon varied from 400-800 µg/L C in the euphotic zone and averaged about 400 µg/L C in the deep water. Dissolved organic nitrogen varied more widely, from 20-80 µg/L N without any clear trend with depth. The profiles for dissolved organic phosphorus showed that all surface samples were high (about 6 µg/L P) with a rapid decrease to about 1 µg/L P at 25-50 m depth, and then an increase to about 2 µg/L P from 100-400 m.

Reuter et al. (1986) measured rates of $N_2NO_3^-$ and NH_4^+ uptake by the sublittoral epilithic periphyton in Lake Tahoe in order to determine the importance of N_2 fixation to the seasonal N budget of this community, the kinetic parameters of ammonium and nitrate uptake, and the pattern of dissolved inorganic nitrogen (DIN) uptake relative to inorganic carbon assimilation. They also investigated the influence of light and temperature on DIN uptake metabolism.

Levels of inorganic nitrogen and phosphorus were extremely low (<15 µg/L$[NH_4^+ + NO_3^- + NO_2^-]$-N; <1 µg/L PO_4^3 as P) throughout the year with the concentrations of DIN highest in the spring following snowmelt and overturn. Inputs of allochthonous nutrients were minimal during summer and fall due to reduced precipitation. Lake Tahoe is warm and monomictic and the summer thermocline is generally at ~20 m. The circulation of NO_3-enriched aphotic zone water into the euphotic zone (~0-105 m) is an important source of DIN for the spring increase in phytoplankton production; however, the vertical extent of mixing is not consistent from year to year (Paerl et al. 1975). The littoral zone represents 19% of the lake surface area and it has been estimated that more than 60% of the primary production in this region may be contributed to epilithic periphyton (Loeb et al. 1983).

4.1.1.b Streams. Although the U.S. Geological Survey routinely measures a broad array of chemical constituents for a number of Great Basin streams, no interpretive analysis or summary of these data has been published. Representative values are given in Table 10 for selected streams throughout the Great Basin. The dates for which data are reported were chosen to approximate base-flow conditions and are the most recently published results available at the time of this writing. It is likely that virtually all of the locations reported are impacted by agricultural activities and some (e.g., Truckee River, Bear River) receive treated domestic wastes as well.

Most of the streams are intermediate in dissolved solids (about 150-600 mg/L), although a couple of streams (East Walker River, Donner and Blitzen Rivers) were as low as 80 mg/L and the Sevier River reached 1,220 mg/L (Table 10). Most of the dissolved solids are calcium/magnesium carbonate, although in several streams sodium sulfates and chlorides contribute significant fractions. In the Sevier River, both sulfate and chlorides matched carbonates in concentration and sodium markedly exceeded calcium and magnesium. Potassium was always low (0.7-11 mg/L) and the streams were all near neutral (pH 7.8-8.8).

Total phosphorus ranged from 0.01 to 0.18 mg/L and in about half the cases exceeded nitrite plus nitrate nitrogen. Organic nitrogen (0.18-0.77 mg/L) commonly was equal to or greater than the inorganic forms. The relatively high nutrient levels reported for the Great Basin in general probably resulted from the location of the monitoring stations toward the downstream reaches of heavily used streams. The trace metals reported in Table 10 showed similar ranges (1-30 mg/L) except for the high iron value in the Sevier River and the 8 mg/L limit for copper in the Humboldt River.

(1) Deep Creek. The chemical composition of Deep Creek, Idaho-Utah was characterized by Minshall et al. (1973) based on monthly samples over a 2-year period (Table 11). Mean concentrations of total-dissolved solids were two to three times as great at the two downstream stations. Most of the difference appeared to be due to increases in sodium chloride and sodium sulfate levels. Mean values at stations 1 and 2 were similar to those found in better-watered regions of the area. The maximum sulfate values recorded at station 3 and especially at station 4 (both in December 1970) were suspect. Otherwise the tabulated values (Table 11) were in good agreement with those obtained by the U.S. Geological Survey for samples collected in the vicinity of station 4 on June 17, 1949, and October 11, 1967 (Bolke and Price 1969). In addition, Bolke and Price measured sodium (226 and 299 mg/L) and potassium (19 and 13 mg/L) for the two dates, respectively. Mean concentrations

Table 10. PART A: Major dissolved chemical constituents (in milligrams per liter except pH) in selected Great Basin streams (U.S. Geological Survey data).

	Date	Dis-solved solids	Hard-ness (as $CaCO_3$)	Alka-linity (as $CaCO_3$)	pH	Ca	Mg	Na	K	SO_4	Cl
CENTRAL GREAT BASINS SUBREGION											
Steptoe Creek (nr Ely, NV)	8/84	190	180	179	8.4	54	1.1	2.2	0.7	10	0.7
BONNEVILLE BASINS SUBREGION											
Great Salt Lake Basin											
Bear River at Border, WY	9/84	339	240	200	7.8	55	25	27	2.2	72	31
Bear River nr Corinne, UT	9/84	511	290	260	8.1	57	35	78	9.0	54	110
SEVIER LAKE BASIN											
Sevier River nr Lynndyl, UT	12/83	1,220	570	300	8.1	89	85	230	6.2	300	310
LAHONTAN BASINS SUBREGION											
Carson River Basin											
Carson River nr Ft. Churchill, NV	8/84	400	190	159	8.0	56	12	53	5.5	130	16
Humboldt River Basin											
Humboldt River nr Carlin, NV	9/84	320	180	205	8.5	50	13	39	7.7	37	21
Humboldt River nr Rye Patch, NV	9/84	410	170	252	8.5	48	13	74	11	40	43
Quinn River Basin											
Quinn R. nr McDermitt, NV	9/84	610	200	216	8.1	52	18	120	8.3	130	110
Truckee River Basin											
Truckee River nr Nixon, NV	9/83	164	75	79	8.2	19	6.7	24	3.6	22	21
Walker River Basin											
East Walker R. nr Bridgeport, CA	9/84	86	49	57	8.8	15	2.9	8.7	2.5	6.8	1.2
Walker River nr Wabuska, NV	8/84	270	130	136	8.2	39	7.9	42	4.2	57	12
NORTHWEST BASINS SUBREGION											
Malheur and Harney Lakes Basin											
Donner und Blitzen R. nr Frenchglen, OR	9/83	80	38	47	8.3	9	3.7	5.5	1.5	1.8	1.1

(Continued)

Table 10. PART B: Certain nutrients and trace elements (in milligrams per liter) in selected Great Basin streams (U.S. Geological Survey data).

	Date	$NO_2 + NO_3$ as N	Org N	Dis P	Total P	AL	Cu	Fe	Zn	Discharge m^3/s	km^2
CENTRAL GREAT BASINS SUBREGION											
Steptoe Creek nr Ely, NV	8/84	0.19	<0.20	<0.01	0.01					0.28	28.8
BONNEVILLE BASINS SUBREGION											
Great Salt Lake Basin											
Bear River at Border, WY	9/84	<0.01	0.5	0.03	0.12	20	5	30	10	15.5	6,439
Bear River nr Corinne, UT	9/84	0.85	0.7	0.07	0.18	20	2	10	10	114.3	18,205
SEVIER LAKE BASIN											
Sevier River nr Lynndy, UT	3/84	0.59	0.6	0.01	0.07	<10	2	370	9	6.7	16,240
LAHONTAN BASINS SUBREGION											
Carson River Basin											
Carson River nr Ft. Churchill, NV	8/84	<0.10	0.18	0.13	0.17	20	4	__	8	.71	3,116
Humboldt River Basin											
Humboldt River nr Carlin, NV	9/84	<0.10	0.27	0.08	0.11	10	3	6	8	4.5	11,163
Humboldt River nr Ryepatch, NV	9/84	<0.10	0.77	0.11	0.15	20	8	7	12	6.5	41,699
Quinn River Basin											
Quinn R. nr McDermitt, NV	9/84	<0.10	0.26	0.06	0.08	10	2	6	4	0.14	
Truckee River Basin											
Truckee R. nr Nixon, Nv	9/83	0.63	0.58	0.04	0.07	20	4	28	32	12.6	4,732
Walker River Basin											
Walker R. nr Wabuska, NV	8/84	--	0.59	0.10	0.18	20	2	11	9	4.4	6,734
NORTHWEST BASINS SUBREGION											
Malheur and Harney Lakes Basin											
Donner and Blitzen R. nr Frenchglen, OR	9/83	0.18	0.24	0.02	0.04	<4	2	<3	3	2.1	518

Table 11. Comparison of water chemistry conditions (range and mean) during years I (Sept. 1970-Aug. 1971) and II (Sept. 1971-Aug. 1972) in Deep Creek, Idaho-Utah (from Minshall et al. 1973). Except for pH, all values are in milligrams per liter.

	pH		Calicum		Magnesium		Bicarbonate (as $CaCO_3$)		Chloride		Sulfate		Silica		Iron		Ortho-P		NH_2-N		NO_2-H		TDS	
	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II
Station 1																								
Maximum	8.5	8.6	150	130	29	70	216	182	150	160	41	31	39	45	.16	.31	.79	1.81	1.25	3.00	1.34	1.28	562	537
Minimum	7.4	7.7	40	60	7	5	135	50	110	100	11	17	26	12	.02	.00	.06	.30	.00	.35	.05	.00	396	332
Mean	8.0	8.2	83	87	14	26	181	137	130	128	18	20	36	27	.05	.14	.39	.92	.53	1.00	.56	.37	464	443
Station 2																								
Maximum	8.2	8.5	140	120	22	30	274	256	163	150	31	22	17	40	.08	.10	.61	1.00	1.01	1.19	1.10	.23	644	549
Minimum	7.6	7.8	36	30	10	6	165	200	95	100	9	11	14	7	.00	.00	.01	.16	.00	.15	.01	.00	403	416
Mean	7.9	8.2	63	61	16	12	223	219	122	124	16	16	15	15	.03	.04	.14	.51	.28	.45	.34	.10	402	480
Station 3																								
Maximum	8.2	8.3	190	335	28	51	272	260	520	450	364	210	28	45	.73	.10	1.65	1.00	5.30	1.96	2.50	.57	1,286	1,134
Minimum	7.5	8.0	50	60	15	0	180	162	145	180	57	38	15	8	.01	.00	.09	.20	.18	.21	.03	.00	539	683
Mean	7.9	8.2	89	125	20	29	243	223	313	274	147	122	20	21	.10	.05	.39	.42	1.00	.87	.30	.11	851	855
Station 4																								
Maximum	8.6	8.6	195	440	33	60	324	310	575	500	740	255	33	80	.19	.38	.35	1.65	1.62	.193	.80	.32	1,663	1,369
Minimum	7.8	8.1	40	70	16	28	200	175	285	300	101	37	16	9	.01	.00	.04	.08	.17	.35	.06	.00	785	1,023
Mean	8.1	8.4	92	167	22	40	263	252	382	349	269	148	22	25	.09	.12	.22	.36	.82	.81	.30	.09	1,163	1,166

during the 2 years of the Minshall et al. study were similar for most constituents except calcium (stations 1 and 4), iron (station 1), orthophosphate (stations 1, 2, and 4), and ammonia (stations 1 and 2), which showed substantial increases; and bicarbonate (station 1), chloride (stations 3 and 4), iron (station 3), ammonia (station 3), and nitrate (all 4 stations), which decreased from year I to year II.

Bicarbonate and calcium-plus-magnesium hardness values were relatively constant at all stations, but especially noticeable decreases occurred at stations 3 and 4 during the 1971 runoff period and at station 1 in April and June 1972. In all cases except one (Station 2, 1972), hardness exceeded bicarbonate concentrations, indicating that some of the calcium and magnesium was associated with other anions (chiefly sulfate and chloride). Although sodium was not measured during the present study, it is believed to account for most of the remaining cations (see above) and chloride, and the bulk of the remaining anions (Table 11).

An analysis of total carbon, by component fractions, was conducted in August 1972; this also provided an independent check on the alkalinity measurements (Table 12). It was suspected that some of the minor acid radicals (especially silica) might be adding significantly to the alkalinity. However, this does not appear to be the case, as the estimates of inorganic carbon based on alkalinity measurements are lower (by 5-11 mg/L) than those determined directly with a carbon analyzer. The organic part of the dissolved fraction was similar at all stations (25-31 mg/L) and about two to three times the particulate fraction, except at station 4 where the dissolved organic carbon was more than eight times the particulate.

Mean ammonia levels were noticeably high at all stations, although values at station 2 were lower than at the others (Table 11). Mean nitrate values were highest at station 1, but concentrations reached lows at all stations during the summer in both years. The lowest mean phosphate concentrations occurred at stations 2 and 4 in year I and station 4 in year II. Monthly measurements of phosphate were high throughout the study at stations 1, 3, and 4, but showed a low at station 2 near the start of the 1971 growth season. Nitrate appeared to be a possible limiting factor during the growing season, but phosphorus did not. However, nitrate-nitrogen supplies seemed to be adequately supplemented by ammonia sources of nitrogen. There was no clear evidence that a flood in March 1971 had any major effect on the chemical parameters of the water except phosphates (which increased) and iron (which decreased).

4.1.2 Nutrient Dynamics

Studies of the sources, transformations, and fates of particular chemical species have been delineated for only a few aquatic systems in the world, and the Great Basin is no exception. However, the research conducted by Goldman and his associates on Lake Tahoe, California-Nevada, and its surrounding watershed and by Herron on Dingle Marsh, Idaho, are important. Both cases provide valuable insights into the

Table 12. Carbon analyses in milligrams per liter of Deep Creek water collected August 21, 1972, and comparison between the dissolved (filtered) inorganic fraction and that calculated from alkalinity measurements (from Minshall et al. 1973).

	Total carbon (C)			Inorganic carbon	Total carbonate	
Station	unfiltered	filtered	particulate	filtered (C)	($CaCO_3$)	(C)
1	86	65	21	34	178	29
2	106	73	33	42	196	31
3	88	67	21	40	198	32
4	61	58	3	33	176	28

dynamics of nutrients in Great Basin lentic systems and serve as models for additional future work. Further, as both of these aquatic habitats are relatively open lentic systems having inlet and outlet, the approaches and findings are also useful to lotic ecologists.

4.1.2.a **Nitrogen.** The two major nitrogen sources in the Lake Tahoe watershed aquatic system are bulk precipitation and biological nitrogen fixation. Inorganic nitrogen inputs in precipitation are about 1-2 kg/ha (Coats et al. 1976). Total annual nitrogen input by symbiotic nitrogen fixation is on the order of 10-20 kg/ha. Much of this nitrogen fixation is by species of Ceanothus on nonriparian sites. Inorganic nitrogen released to soil water on non-riparian sites probably is taken up efficiently by forest vegetation before entry into the stream system. However, soil and stream water in and immediately below alder stands shows appreciable NO_3-N release in fall and early winter (Coats et al. 1976).

(1) **Nitrate concentrations**. Concentrations of nitrate in Tahoe Basin streams are most readily interpreted in relation to four runoff periods: summer low flow, winter low flow, rainfall, and spring snowmelt (Leonard et al. 1979). Summer concentrations, in the absence of significant rainfall, were uniformly very low and constant at all sites examined on Ward and Blackwood Creeks (adjacent tributaries to Lake Tahoe). Early winter concentrations also were low but tended to increase considerably as winter progressed. Relatively high nitrate concentrations prevailed throughout the winter, with the peak occurring early in the snowmelt period well before peak streamflow.

Ward Creek is the most intensively studied and the fourth largest (2,510 ha; 6% of total annual runoff) of the 63 watersheds of the Tahoe basin. The Ward Creek watershed is divided into two subdrainages in its upper portion (900 ha). The north bowl is undergoing light development and the south bowl is totally undeveloped. Three stream gauging stations are located near the mouths of the south fork (station 2), north fork (station 14), and main stem (station 8). Most of the riparian zones in the south bowl of the Ward Creek drainage are dominated by mountain alder, in contrast to the north bowl. Large areas of the watershed containing nitrogen-fixing species (especially riparian areas) charge the soil and stream channels with nitrate in fall and early winter (Coats et al. 1976), usually exceeding 100 μg/L in alder areas and reaching the mg/L range between October and March (Coats et al. 1976). Some nitrate is contributed directly from the snowmelt in winter, but average concentrations in the pack, added to the streamflow in relatively low-melt volumes, could not explain the winter 1975 concentrations. However, base flow from the alder areas in the bowl can easily sustain the concentrations found if appreciable flushing of the soil does not occur early in the water year. In water years 1973 and 1974, such flushing did occur. As a result, the midwinter concentrations were lower than in 1975 (Leonard et al. 1979).

Insight into the sources of stream nitrate in Ward Creek can be obtained from the discharge-concentration relationship there. Starting with a certain level of nitrate in precipitation, the concentration nitrate in water reaching a stream channel at a given time is primarily a function of the course of water movement either over or through the soil, and the nature of the soil and vegetation on the site adjacent to the channel (Leonard et al. 1979). During spring runoff periods with regular diel discharge patterns, the relationship between salt concentration and discharge changes in a regular hysteretic manner. A typical clockwise curve does not involve biological factors and has a simple physical interpretation: in phase I, as discharge increases rapidly, the concentration of nitrate increases slightly or remains constant due to flushing of salts from the soil and from "old" water in the stream bed; in phase II, concentration drops in the period of peak discharge due to increasing dilution from direct runoff; in phase III, concentration begins to increase again and discharge continues to drop as the base flow component again becomes dominant.

Ward Creek showed a counterclockwise curve representative of relationships between nitrate and discharge at all three stations during each of the three annual snowmelt periods studied (Leonard et al. 1979). Major features of the Ward system that distinguish it from that described above are the presence of appreciable nitrate in snow and a soil-vegetation system that is capable of stripping nitrate from melt water that passes through the soil. Daytime temperatures generally are well above freezing throughout much of the snowmelt period. Plant growth and nutrient uptake in most regions of the watershed are at their maximum in the spring, and uptake of inorganic nitrogen from snowmelt water is apparently efficient. Leonard et al. (1979) provide an explanation of the possible mechanisms responsible for the associated nitrate concentration changes.

(2) Nitrate flux. The net flux patterns were similar to those for concentration because nitrate concentrations in the streams were positively correlated with streamflow (Leonard et al. 1979). The predominance of rainfall and spring runoff were the primary transport vectors for total nitrate. The annual totals were uniform from year to year despite different climatic and runoff conditions. Total flux from Blackwood Canyon in 1975 was 2.6 times the Ward flux, reflecting both higher average streamflow and considerably higher nitrate concentrations in spring.

Major transport of inorganic nitrogen in the streams was limited to periods of heavy runoff (Leonard et al. 1979). The very high concentrations of nitrate attained during rainfall resulted in impressively high total transport in a matter of hours or days. Such events can dominate the water year. For example, over 30 percent of the total nitrate for the 1974 water year at one Ward Creek station was transported in a 10-day period in mid-November. Movement of water through Ward Valley soils is rapid and water enters the stream channels quickly once the relatively low moisture storage capacity of the soils is exceeded. The lowest 2.5-km reach of the stream probably receives much less direct input of water that has moved through the adjacent alluvial soil than the upper reaches because of predominantly downward migration of soil water into the deep glacial till underlying the alluvial area near the lake. Most of the Ward Creek ground water is in that alluvium and moves directly to Lake Tahoe rather than toward the stream channel (Loeb and Goldman 1979). Thus the yield of nitrate to the lake via the stream is derived primarily from the upper watershed.

NO_3-N yields in Ward Creek water were low relative to estimated inputs (Leonard et al. 1979). In the mainstream the yields ranged from 0.21 to 0.27 kg/ha for the three water years studied. Yields from the upper reaches of the watershed were higher: 0.55 to 0.74 in the south fork and 0.30 to 0.33 in the north fork.

The fact that total nitrate flux for each of the three water years did not correlate with volume of streamflow is additional evidence that net release of nitrate into the stream system is controlled both by runoff magnitude and by the quantity of nitrate in the soil at times of water movement (Leonard et al. 1979). Release of nitrate from soil to stream water is the net effect of several processes occurring simultaneously in the ecosystem. The major nitrate transformations involve N_2-fixation, uptake, and metabolism by vascular plants, mineralization, nitrification, and denitrification. Leonard et al. (1979) concluded that nitrate immediately available for stream transport derives directly from precipitation and indirectly from nitrification of mineralized organic nitrogen.

Alder in the riparian zones requires special consideration because of evidence for quantitatively significant and seasonally variable nitrate release in surface waters draining alder stands. Fleschner (1975) described the alder in Ward Valley as a steady-state edaphic climax with respect to nitrogen output and input. His estimate of annual output was 18 kg/ha. Extrapolating to the approximately 30 ha of riparian alder in the watershed gives an estimated maximum annual NO_3-N output (assuming NO_3-N as the main product and ignoring gaseous losses) in stream water from this source in the range of 500 kg (Leonard et al. 1979). This inorganic nitrogen is mainly from decomposition of alder litter fall and nitrification during late autumn when soil temperatures remain high enough to allow microbial activity. This rough estimate of the annual contribution of alder to Ward

Creek water nitrate flux reveals that a majority of the total flux in a given year is due to nitrogen fixation. The proportion undoubtedly varies widely from year to year depending on precipitation patterns and intensity. Years with above-normal precipitation in the form of rain would have a large component of stream water nitrate flux derived from atmospheric nitrogen sources.

Other forms of nitrogen. Concentrations of ammonium nitrogen were usually below the level of detection (5 μg/L) (Leonard et al. 1979). Elevated NH_4-N levels did occur briefly during rainfall runoff, but total flux was insignificant. NO_2-N concentrations also were near the level of detection (2 μg/L) at all times, and total flux in comparison to NO_3-N was insignificant. These results are consistent with low concentrations found in Ward Creek soil water in all seasons (Coats et al. 1976). Apparently the NH_4-N pool in the soil is almost entirely adsorbed or rapidly incorporated in microbial and plant rhizosphere biomass.

4.1.2.b Phosphorus. Daily concentration patterns for dissolved phosphorus in Great Basin streams appear to be distinctly different from those for particulate phosphorus (Leonard et al. 1979). Different sources and modes of transport of the two principal fractions of phosphorus appear to be the factors responsible. The dissolved load passes through the soil and rhizosphere and thus is strongly influenced by the terrestrial ecosystem. The particulate load, primarily mineral in origin, responds to the condition of the stream channel and water discharge levels.

(1) Dissolved phosphorus concentration. During water year 1975, the mouth of Ward Creek nearly always had a higher daily total soluble phosphorus (TSP) concentration ($\bar{x}$=16 μg/L) and always exhibited a higher soluble reactive phosphorus (SRP) concentration ($\bar{x}$=12 μg/L) than the north (7 and 4 μg/L, respectively) and south forks (12 and 9 μg/L, respectively) (Leonard et al. 1979). Midwinter and early spring soluble phosphorus peaks were followed by a continuous concentration decline throughout May as snowmelt progressed. However, a concentration increase did occur near peak discharge in the mainstream and south fork. The TSP and SRP annual concentration maxima occurred at different times, but each peak was approximately synchronous at these two stations. The annual TSP and SRP concentration minima followed similar patterns among stations. SRP ranged from 44%-100% of TSP in the main stem and from 25%-100% in the south fork.

The soluble phosphorus regime of the north fork differed from the other two sites in several respects. Most striking were the consistently lower concentration values at all times of the year. Other significant distinguishing features included oscillating concentrations in the spring compared to the continuous decline already mentioned, soluble phosphorus minima occurring in the winter and not the spring, coincident TSP and SRP annual concentration maxima, and coincident TSP and SRP concentration minima. SRP ranged from 40%-88% of TSP.

The complex factors that influence the dissolved phosphorus levels in Ward Creek involve interactions between phosphorus sources and water moving through the soil system to the stream (Leonard et al. 1979). Sources of dissolved phosphorus include sparingly soluble minerals, desorption of phosphorus from the surface of cationic soil components, decay and mineralization of soil organic matter, leaching of tree litter, excretion, analysis of stream organisms, and precipitation (Keup 1968). Phosphorus removal from through-flow could occur primarily through the absorption of phosphorus in the soil and secondarily by slow microbial uptake in the cold but unfrozen soils. Removal of dissolved phosphorus from stream water may be seasonally significant as a result of microbial uptake and chemical interaction with sediments.

In Ward Creek, the dynamics of the periphyton community affected the forms and concentration of dissolved phosphorus during the active growing season (Perkins 1976). During winter and early spring, Ward Creek lies under ice and snow. Algal standing crop is low, and bacterial metabolic rates involved in the decomposition and mineralization of organic matter probably decrease sharply in fall and remain low through spring.

Fluctuations in the dissolved phosphorus concentrations appeared to be independent of discharge fluctuations. Linear regressions of TSP versus discharge yielded nonsignificant regression coefficients. While stream discharge and dissolved phosphorus showed poor correlation, the volume of water moving through the soil and reflected in discharge had an impact on the transport of dissolved phosphorus into Ward Creek.

During May, in the mainstream and south fork of Ward Creek, snowmelt increased and dissolved phosphorus concentrations declined as discharge increased (Leonard et al. 1979). At least two factors operated during the May TSP decline. Rising temperatures increased biological activity, and as the soils approached saturation, more interstitial space was occupied by water, allowing more contact of dissolved phosphorus and adsorption sites. In contrast, phosphorus concentrations in discharge from the north fork remained relatively constant during the same period, consistent with the general conservation of phosphorus in the north bowl. These conditions prevailed prior to peak water discharge in early June.

Samples from mid-June showed dramatic increases in dissolved phosphorus concentrations at all stations. The volume of water entering the stream between late May and the discharge peak in early June relative to the May 28 flow, increased by 92% in the mainstream, 114% in the south fork, and 68% in the north fork (Leonard et al. 1979). These values represent not only a substantial relative gain, but a large absolute increase in the volume of water moving through the soils. The higher volumes of melt water and increasing temperatures in May led to near saturation conditions with concomitant biological uptake and adsorption of dissolved phosphorus. However, the peak snowmelt of June saturated the entire soil profile, leading to significant lateral flow in the upper soil and rapid discharge into surface channels and the main stream. The combination of saturated soils and biological activity could easily deplete oxygen in the interstices of the soil over large areas. Anaerobic conditions and a drop in redox potential would decrease adsorption of phosphorus in the soil water and could initiate desorption. In addition, biotic uptake of phosphorus would be diminished as the less efficient anaerobiosis is replaced aerobic respiration. Thus the soil system that controlled the levels of dissolved phosphorus flowing through it and entering Ward Creek in other periods temporarily lost its controlling influence under the fully saturated conditions of snowmelt. Increases in dissolved phosphorus, particularly from the north bowl, the most phosphorus-conservative area studied, underscored the impact of soil saturation.

(2) Particulate phosphorus concentration. In contrast to the soluble phosphorus concentration regime, the particulate phosphorus (PP) concentrations in Ward Creek exhibited distinct seasonal trends: levels below 10 μg/L throughout most of the year, a rapid rise through May and early June, and a decline in late June (Leonard et al. 1979). During spring runoff, snowmelt-induced diel discharge variations caused diel patterns in PP concentration.

Sources of particulate phosphorus in Ward Creek included blow-in of leaf litter and other plant debris, sloughing off of periphyton and sediments from bank erosion, rill erosion, and movement across the forest floor (Leonard et al. 1979). Fluvial sediments appeared to be the primary source of PP. Seasonal trends at all stations corresponded to the general seasonal trend of the suspended sediment load. The total amount of phosphorus incorporated in the periphyton in any given season was minimal compared to the total PP discharge from Ward Creek (Perkins 1976). Estimates of allochthonous detrital inputs to the stream were not made, but PP concentrations in the late fall were low, indicating only minor allochthonous sources.

The mouth of Ward Creek had markedly higher PP concentrations than either upstream fork (Leonard et al. 1979). PP concentration differences among stations were related to the greater bank erosion in the lower reaches of the stream channel and the greater energy for transport available with increased discharge. Strong differences in average concentrations were found from day to day. There was poor linear correlation ($r = 0.61$, $P = 0.61$) between particulate phosphorus and sediment load over the entire snowmelt period. However, the correlation improved ($r = 0.88$, $P = 0.01$) for a given 24-hour period, as did the strength of correlation of PP and discharge ($r = 0.87$, $P = 0.01$). The degree of prior flushing of the stream channel affected the relationship of PP load and suspended sediments throughout the snowmelt period. A steady 4-day decline in PP concentration observed after concentration peaks in May and June was particularly striking. The rapid decline indicated removal of readily erodible materials with new sources mobilized only after a major increase in discharge a week later. A concomitant decrease in suspended sediment concentration over the same time period was further evidence for the role of channel scour.

(3) Phosphorus flux. The spring snowmelt period dominated the flux of phosphorus from the Ward Creek watershed (Leonard et al. 1979), reaching at least 97% of the annual total during May, June, and July. Of the total phosphorus flux, the particulate fraction accounted for 84% in the main stream, 70% in the south fork, and 68% in the north fork, while the SRP fraction represented 11%, 17% and 19% of the total, respectively. SRP as a percent of TSP was 67%, 60% and 59%, respectively for the three locations.

All three stations exhibited similar flux patterns for the year 1975, unusual for the lack of rains. Particulate phosphorus flux remained negligible throughout most of this water year except for the vernal snowmelt, while a significant fall PP flux occurred in other years. The particulate flux peaked before dissolved phosphorus, and then fell abruptly back to near zero after early snowmelt discharge removed phosphorus-bearing sediments from the stream channel before the peak water discharge.

That the majority of the terrestrial ecosystem did not strongly conserve phosphorus may be typical of high mountain watersheds characterized by heavy spring snowmelt runoff and periodic intense rainfall. The apparent juxtaposition of a phosphorus-leaky drainage basin and an oligotrophic lake further argues for an overall nitrogen limitation in Lake Tahoe (Leonard et al. 1979).

While in suspension, the PP from Ward Creek represents a potential source of biologically usable phosphorus. However, the considerable delta off Ward Creek indicates the fate of most of the particulate inputs, probably resulting in permanent loss from the water column. Only the SRP flux, 11% of the TP output from Ward Valley, remains biologically available, most of it reaching the lake during the spring algal bloom.

Herron (1985) described the dynamics of phosphorus in Dingle Marsh, Idaho, located at the northern edge of Bear Lake. Dingle Marsh was a net annual sink for total suspended solids (TSS), total phosphorus (TP), and phosphate phosphorus (PO_4-P) in the years studied, but was less efficient at retaining TSS and TP in a drought year than in wet years. The detritus in Dingle Marsh was a daily net sink for PO_4 in all study months (May - Sept.), except May, and a daily net sink for dissolved organic phosphorus (DOP) in all study months except September. The maximum net uptake and release of PO_4 by the detritus in the Dingle Marsh study corresponded to maximum net uptake and release by the periphyton community. Periphyton was observed utilizing the detritus as a substrate and probably controlled PO_4 DOP dynamics. Detritus, on a dry weight basis, contained half as much periphytic chlorophyll a as did periphyton alone; i.e., 2 g of wet detritus contained as much chlorophyll a as did 1 g of periphyton scraped from wooden dowels. Detritus, therefore, was heavily colonized with periphyton and was a major sink for PO_4 and, to a lesser extent, DOP, at least during most months of the growing season.

Periphyton communities grown on wooden dowels in Dingle Marsh occasionally removed some DOP from the water during summer, suggesting that attached algae or bacteria used at least a small portion of the DOP (Herron 1985). The periphyton community removed larger amounts of PO_4 from the water column, with maximum estimated daily uptake occurring in June and August and minimum in July. Since Herron was unable to quantify the amount of periphyton growing naturally within the marsh, the total impact of periphyton on water quality was unknown, but thought to be significant.

Phytoplankton appeared to remove PO_4 from the water at a higher rate than periphyton because of the dispersion of phytoplankton throughout the water column. Plankton were a net sink for PO_4 in Dingle Marsh, Idaho, night and day except for a net release at night in September (Herron 1985), which may have been due to death and autolysis of cells brought on by freezing water conditions, or the temperature drop may have slowed algal uptake to the point where zooplankton excretion exceeded algal uptake. DOP was probably released into the water column by invertebrate excretion and bacterial activity and may not have been very available to phytoplankton. Concentrations of DOP further increased because the plankton removed a small portion during the day and released a large portion at night.

Herron (1985) reported that TP entering Dingle Marsh via the Rainbow Canal consisted primarily of particulate phosphorus (PP) and was highly correlated with TSS ($r = 0.94$). Herron believed that TSS, TP, and PP dynamics were controlled primarily by the hydrology of the system, with sedimentation accounting for most TSS, TP, and PP removal from the water. Herron (1985) observed a net flux of PO_4 into the sediments during daylight in all study months and a net release at night in all study months except August, when a net uptake was noted in Dingle Marsh. Maximum nighttime PO_4 release rates from the sediments were observed in May and July corresponding to maximum daytime PO_4 flux into the sediments. Daily PO_4 flux into the sediments occurred in May, July, and August, and daily net releases were observed in June and September. Sediments had a major impact on DOP concentrations by usually releasing DOP into the water column night and day. DOP release from the sediments may have been due to invertebrate activity. The net flux of PP was into the sediments due to sedimentation of PP bearing TSS, except when ambient concentrations were low and organisms bound in a sediment matrix were released from the bottom sediments.

When Bear Lake water, low in nutrients and TSS, was flushed through the marsh, it tended to export TSS, TP, and PP. Dingle Marsh retained about 10%-62% of the TSS and as much as 54% of the influent PP. Herron (1985) described two other mechanisms by which TSS and PP may have been exported from Dingle Marsh. Plankton production increased in open areas of the marsh in summer, and some apparently was carried from the marsh with effluent water. The marsh became a strong net source for chlorophyll _a_ in May and continued to export chlorophyll _a_ until September when the study ended. Herron also described the formation and release of mats of algae in a sediment matrix from the sediments during summer; these were observed to float out of the marsh with effluent waters. The release of algal mats from the sediments probably took place because oxygen produced by algal cells became trapped in the sediment matrix and floated the entire community. It is also possible that microorganisms other than algae (e.g., bacteria) were responsible for flotation of the mats, with filamentous algae acting only to bind the sediment particles together.

4.2 BIOLOGICAL PARAMETERS

The sparsity of descriptive (systematic) and ecological studies on the aquatic biota of the Great Basin is almost unbelievable, particularly in view of the size and diversity of the area involved. Fewer than a half dozen studies have been published on either the algal, the vascular hydrophyte, or the aquatic invertebrate communities of aquatic environments in the Great Basin. Even though the taxonomy and distribution of fishes in the area are well known, very little quantitative work related to their ecology has been published.

Characteristically the aquatic plant component of the Great Basin consists of an admixture of periphyton and macrophytes. Diatoms are common microalgae in the periphyton and phytoplankton whereas both macroalgae and vascular plants compose the macrophytes. Visually, macrophytes are a predominant feature of Great Basin marshes and low gradient streams and contribute significantly to their trophic base as well.

4.2.1 Microphytes (Algae)

Several authors in more extensive studies have noted the presence of the common algae in specific streams in the Great Basin. Gaufin (1959) recorded _Chaetophora_, _Cladophora_, _Hydrurus foetidus_, _Oedogonium_, _Oscillatoria_, _Prasiola_, _Spirogyra_, _Synedra_, _Tabellaria_, _Ulothrix_, _Vaucheria_, _Zygnema_, and diatoms for various locations in the

Provo River. During their study, McConnell and Sigler (1959) found Cladophora, Hydrurus, Nostoc, Phormidium, Prasiola, Shizothrix, Vaucheria, and diatoms attached to rocks in the Logan River.

An intensive ecological investigation of sestonic algae in the Logan River by Clark (1958) indicated that diatoms were dominant in both density and diversity in the water column, and that they originated from the benthos. There was little evidence of diurnal fluctuations in density. Behmer and Hawkins (1986) noted that Hydrurus foetidus was abundant during their studies in the adjacent Blacksmith Fork River. Cladophora and Oscillatoria were abundant in the Truckee River during the study conducted by Thomas and O'Connell (1966).

One of the most detailed studies of the attached algae (periphyton) in streams in the Great Basin was conducted by Lawson and Rushforth (1975). They examined the diatom flora of the Provo River at monthly intervals over a full year. Thirty-eight genera containing 156 species, 45 varieties, and 4 forms were identified, described, and illustrated. The most common diatoms occurring in the Provo River during this study were Achnanthes, A. linearis, A. minutissima, Cocconeis placentula var. lineata, Cylotella meneghiniana, Cymbella sinuata, C. turgida, C. ventricosa, Diatoma vulgare, Fragillaria leptostauran, F. vaucheriae, Gomphonema angustatum, G. olivaceum, Melosira varians, Navicula cryptocephala var. veneta, N. tripunctata, Nitzschia palea, Surirella angustata, S. ovata, and Synedra ulna.

These diatoms were distributed in the river in two broad zones with a transition zone between. The first floristic zone extended from the headwaters to near the village of Woodland on the Upper Provo River. This section of the river is cold and fast flowing with a low nutrient concentration. The average number of species collected at each site in this first zone was 90. The second floristic zone was on the lower Provo River from the outlet of Deer Creek Reservoir to Utah Lake. This section of the river has undergone extensive alteration (diking, channelization, irrigation diversion) and receives runoff and effluents from farm, ranch, and urban sources. Fourteen species and three varieties of diatoms were confined to this zone. On the average, 62 species were collected per site in this floristic zone.

A transition zone between the first and second zones extended from Woodland to Deer Creek Reservoir. This transitional region is equivalent to the lower half of the upper Provo River and is about 40 km long. Species common to the upper zone, but not confined to it, usually diminished in frequency through this zone. On the other hand, species common in the lower zone, but not confined to it, also occurred infrequently in the transitional zone. Eleven species and two varieties were confined to the transition zone, and there was an average of 76 species per site.

Forty-seven species and 10 varieties occurred essentially throughout the entire river system. There were 44 species and 13 varieties identified either from one specimen or very few specimens.

Squires et al. (1973) and Benson and Rushforth (1975) studied the algal flora of Huntington Creek, Emery County, Utah. Although Huntington Creek is a tributary of the Colorado River via the San Rafael and Green Rivers, the findings are directly applicable to the Great Basin. Huntington Creek is a cold, clear, fast-flowing, calcareous stream that supports a diverse algal flora adapted to these conditions. Diatoms are the most abundant algae present, occurring throughout the year on the substrate and in the plankton. The dominant genera are Navicula, Cymbella, Gomphonema, Nitzschia, Synedra, Achnanthes, and Diatoma. Diatoms show maximum production on the substrate in late spring and early summer and in late fall and early winter.

Benthic diatoms are the main contributors to the nannoplankton, and the composition and seasonal fluctuations of the nannoplankton are largely determined by similar fluctuations of the substrate. Water level and water temperature changes, and mechanical disturbances also appear to be factors influencing nannoplankton levels. Nannoplankton increase as the water moves downstream, but the increase is not entirely cumulative since destruction of cells occurs in the turbulent water. Periphyton colonization was found to be higher in the right fork of Huntington Creek than lower in the canyon.

True planktonic algae, including Asterionella formosa, Fragiliara crotonensis, Dinobryon cylindricum, Pandorina morum, and Ceratium hirundinella, occur in the plankton of Huntington Creek. These algae are thought to originate in reservoirs on the upper drainage of the left fork of Huntington Creek, and their occurrence in the creek basically correlates with algal cycles in these reservoirs (Squires et al. 1973).

Upper Huntington Creek flows through a steep, narrow, rocky canyon. The stream here supports a flora preferring montane, colder, fast-flowing, low-nutrient waters. The diatom community reached maximum development during the late spring-early summer season. It was dominated by species of Asterionella, Amphora, Cymbella, Navicula, Neidium, Stauroneis, and Tabellaria. The diatom flora became prevalent again during fall and winter months, with predominant species being Diatoma, Fragilaria, and Gomphonema. Filamentous algae in this section of the creek were dominated by Oscillatoriaceae during the spring and summer, and by Ulothricaceae and Hydrurus foetidus through winter and early spring (Benson and Rushforth 1975). Hydrurus foetidus grows profusely from late winter to early summer, especially in the upper reaches of the canyon, forming thick mucilaginous growths on the rocky streambed. Blue-green algae are present on the creek substrate throughout the year, but show highest production during summer and fall when encrusted communities form on the stony substrate. Other filamentous algae present in the canyon include Ulothrix tenuissima, U. zonata, and Stigeoclonium stagnatile, which occur mostly in the spring, and Mougeotia spp., Spirogyra spp., Zygnema spp., and Vaucheria germinata, which grow in backwaters, pools, and ponds along the creek through the summer and fall (Squires et al. 1973).

Fragments from these filamentous algae are an important source of seston. Hydrurus foetidus fragments are prevalent in the seston in spring, and filaments of blue-green algae occur in large quantities during October and November. Most filamentous green algae occur during the summer months, and they are most prevalent in the right fork where protected areas along the stream channel allow for their development. Most of these filamentous algae are quickly destroyed as they are carried downstream by the current.

Cladophora glomerata and Oedogonium sp. also appear in significant numbers in Huntington Creek. C. glomerata is most abundant in the lower reaches of the right fork during the fall, and Oedogonium sp., abundant in the upper right fork during the same period. These genera are also prevalent in the lower Huntington Creek as it flows through Castle Valley, where they form long streamers from the stones during late spring and early summer.

Lower Huntington Creek, from the mouth of the canyon to the junction of the right and left forks, provided a rather different environment. Campgrounds, picnic areas, and coal-mining effluents influenced these generally slower-flowing valley waters and provided unique colonization possibilities. Diatoms dominated the algal flora. Species of Achnanthes, Cylotella, Cymbella, Fragilaria, Hannaea, and Navicula were common during the spring-summer seasons. Species of Diatoma, Fragilaria, Gomphonema, Nitzschia, and Synedra were often found during fall and winter. This section of Huntington Creek supported a filamentous community dominated in the spring and summer months by Cladophora glomerata, Mougeotia spp., Oscillatoriaceae, Spirogyra spp., Ulothricaceae, and Zygnema spp. Species of Oedogonium, Ceratium, Dinobryon, Pandorina, and Stigeoclonium were common from early summer through fall (Benson and Rushforth 1975).

Lower Huntington Creek exhibited increased alkalinity, dissolved salts, hardness, sulfates, turbidity, and organic enrichment due to agricultural and municipal uses. The spring and summer diatom population here contained species of Achnanthes, Amphora, Cocconeis, Cymatopleura, Cymbella, Diploneis, Epithemia, Eunotia, Fragilaria, Gyrosigma, Pleurosigma, and Navicula. Species of Diatoma, Gomphonema, Navicula, Nitzschia, Surirella, and Synedra became prevalent during the fall season. Cladophora glomerata, Desmidaceaea, Hydrurus foetidus, Oscillatoriaceae, and Zygnemataceae dominated the filamentous algal flora during the spring-summer season. *Chara vulgaris* occurred in lower Huntington Creek from July to December, forming large mats and sometimes filling large sections of the stream channel.

The permanent ponds of the Huntington Canyon drainage provided distinctly different habitats for algal floras. The seasonal populations were similar to those of the creek in Castle Valley, although greater species richness was noted. Species of *Achnanthes*, *Cocconeis*, *Cymbella*, *Epithemia*, *Gomphonema*, *Navicula*, *Nitzschia*, and *Synedra* together with species of *Aphanochaete*, *Carteria*, *Chlamydomonas*, *Characium*, *Coleochaete*, Euglenophyta, Scenedesmaceae, Ulothricaceae, and Zygnemataceae were abundant during spring and summer months. With their decline and the subsequent enrichment of the waters, late summer and fall populations were dominated by species of *Amphipleura*, *Diatoma*, *Epithemia*, *Fragilaria*, *Nitzschia*, Oscillatoriaceae, *Mougeotia*, and *Spirogyra* (Benson and Rushforth 1975).

The most common algae throughout the Huntington Creek drainage were *Achnanthes lanceolata*, *A. minutissima*, *Cocconeis placentula* var. *euglypta*, *C. parva*, *Cymbella ventricosa*, *Diatoma anceps* var. *linearis*, *D. hiemale*, *D. vulgare*, *Gomphonema solivaceum*, *Lyngbya aerugineo-caerulea*, *L. major*, *Navicula cryptocephatla*, *N*. *elginensis*, *N. lanceolata*, *N. tripunctata* var. *schizonemoides*, *Nitzschia amphibia*, *N. dissipata*, *N. linearis*, *N. palea*, *Oscillatoria limosa*, *O. tenuis*, *Synedra rumpens*, *S. ulna*, *Stauroneis smithii*, and *Ulothrix zonata*. Diatoms also were the most abundant taxa in the periphyton of Convict Creek, California (Leland et al 1986), except in late spring and summer when several seasonal blue-green algae (*Chamaesiphon incrustans*, *Lyngbya* spp., and *Oscillatoria* spp.) reach maximum densities.

The most abundant phytoplankton genera in the Bear Lake study of McConnell et al. (1957) were *Ankistrodesmus*, *Oocystis*, *Lyngbya*, *Lagerheimia*, *Dinobryon*, and *Dictyosphaerium*. Diatoms never exceeded 5% by number of the total cells. All of the cells were small (from 2 to about 50 µm in their largest dimension); only an occasional diatom was larger than 50 µm. Evidence indicated some changes in the species composition of the larger forms during the development of the lake as a reservoir with the subsequent changes in chemical composition of the water. However, since earlier investigators did not sample the nannoplankton forms, no comparisons can be made.

The cold water diatoms *Cyclotella* sp. (probably *kutzingiana*) and *Stephanodiscus* spp. dominated the phytoplankton community of Pyramid Lake during winter (Galat et al. 1981). (Species of these two genera have been reported from other saline lakes.) Spring conditions of clear, cold water and high nitrate concentration often resulted in a pulse of *Chrococcus*. Pyramid Lake's most abundant planktonic chlorophyte, *Crucigenia*, attained maximum cell numbers in May (1977), when it made up 20% of total phytoplankton abundance. By July, summer stratification in the lake is well developed. Epilimnetic water temperatures remain over 20 °C, while nitrate and silica concentrations may become limiting to green algae and diatoms. Such conditions favor the annual bloom of *Nodularia spumigena*, the lake's most abundant algal species, beginning as early as July and persisting into October, although yearly duration and intensity varies considerably. During August 1977, *N*. *spumigena* cell concentrations peaked at over 3,200 cells/mL.

Diatoms dominated the periphytic community growing on introduced glass slides in Pyramid Lake, and accounted for 99.5% of the total number of algae collected and 28 of 33 genera identified (Galat et al. 1981). Their numbers exhibited a bimodal annual pattern, peaking in spring and again in fall. *Cyclotella* spp., *Nitzschia* spp., and *Diatoma* sp. (cf. *elongatum*) were the principal March diatoms colonizing glass slides. Although *Cyclotella* spp. decreased considerably by May, *Nitzschia* spp. and *Diatoma* sp. numbers remained high until June. The early fall periphytic diatom growth consisted mainly of *Diatoma* sp., *Amphora coffeaaormis*, *Fragilaria* spp., and *Nitzchia* spp. In September luxuriant growths of *Enteromorpha* also were observed.

In Pyramid Lake, tufa and rock supported a thick *Cladophora glomerata* community in early April, and during May and June it outcompeted other forms. By mid-June 1977, growths attained lengths up to 1 m and maximum gross photosynthesis (7.94 g $O_2/m^2/d$) was measured. As summer progressed, water temperatures increased, light penetration decreased due to the N. spumigena bloom, and C. glomerata growth subsequently declined. Epilithiphyton productivity correspondingly decreased.

More than 120 species were found in the phytoplankton of Lake Tahoe, 108 of which were diatoms, 99 pennate (Holm-Hansen et al. 1976). Although many of those species were present at each sampling time, three dominant species, Fragilaria crotonensis, Melosira crenulata, and Cyclotella bodanica, represented between 79% of the biomass in the entire water column in February and 90% in July. Fragilaria crotonensis was consistently dominant both in number of cells and total biomass: in the upper 100 m, it accounted for a minimum of 33% in August to a maximum of 67% of the biomass in April, and for the entire column from 38% in February to 66% in April. The only other species to make a significant contribution to the total biomass was the chrysophycean, Dinobryon sociale, which accounted for 16% of the total biomass in the upper 100 m in July and 6% in April. Total biomass is greatest in April, due almost entirely to F. crotonensis, and in August due to several species, mainly M. crenulata, C. bodanica, and Cyclotella ocellata, as well as F. crotonensis.

Only about 30% of the phytoplankton in Tahoe exist within the euphotic zone (Holm-Hansen et al. 1976). Whereas the phytoplankton biomass is maximum between 50 and 100 m, the productivity maxima are between 10 and 40 m. The shape of the productivity profiles may reflect the combined effects on photosynthesis of light intensity (which is saturating from the surface to about 30-40 m and rate-limiting from there to the compensation depth below 100 m), temperature, and nutrient availability. Algal cells from all depths appear alive and healthy under the microscope, and this conclusion is supported by ATP data.

Deer Creek Reservoir on the Provo River exhibited a clearly defined cycle of plankton succession which was basically similar from year to year (Gaufin and McDonald 1965). This cycle was related primarily to the effects of seasonal changes and other factors, such as the addition of nutrients by overturns and high runoff, variations in water temperatures, and effects of stagnation and ice cover.

During spring months there was an increase in both numbers and kinds of Chlorophyta. In all probability these blooms of green algae were caused by increases in available nitrogen and phosphorus due to the spring overturns and increased runoff from incoming streams. Runoff to the Provo River during periods of high water often carries large amounts of manure and other organic matter into the reservoir. The primary factor correlated with diatom populations during the summer months is high water temperatures. Asterionella formosa, Stephanodiscus, and other diatoms declined rapidly as water temperatures approached 21 °C, first appearing in surface waters and later in deeper areas as the temperatures of these waters also increased. With advent of the autumnal overturn and decreasing water temperatures, the diatom population again increased. A decrease in plankton concentration in the upper 3 m of water in Deer Creek Reservoir often was observed to accompany extended periods of clear skies and bright sunlight during summer. This was especially evident for Daphnia and other zooplankters.

Many temperate lakes tend to show a bimodal curve of plankton production with maxima in the spring and fall, coinciding with periods of overturn. However, this condition was not evident in the phytoplankton of Deer Creek Reservoir. A slight increase in total plankton in the spring, followed by a decrease during most of the summer, was observed during 1959, but a fall maximum was absent.

During January and February 1959, Fragilaria capucina was the dominant plankter in the reservoir, reaching concentrations of over 3,000 organisms per milliliter. High plankton counts in the spring of 1959 were produced chiefly by the diatom Cyclotella, which was especially abundant in deeper waters. Possibly this multiplication was related in part to the release of nutrients caused by the spring overturn, although it was first observed in high concentrations from surface samples. This form disappeared rapidly following the March and April peaks of 30,000 organisms per milliliter. Fragilaria capucina was also abundant in surface waters during this period. In the spring runoff, the Provo River introduced many diatoms into the reservoir that were normal inhabitants of the river, along with plant matter and other polluting materials. These additional nutrients may have contributed to the growth of a number of green algae such as Pandorina morum, Ankistrodesmus falcatus, and Sphaerocystis, which appeared in the reservoir along with blooms of Fragilaria capucina and Asterionella formosa.

As summer stratification progressed and surface temperatures rose to 21 °C, plankton counts of Asterionella formosa and other diatoms decreased, although a diverse assemblage of green algae appeared in surface waters. Anabaena flos-aquae appeared in the reservoir during mid-July but the bloom was not allowed to develop because the reservoir was treated with copper sulphate to reduce the algae present. Nephrocytium and Coelastrum were among the first algae to increase in numbers in the treated areas, followed by Fragilaria capucina and Tabellaria. With the advent of the autumnal overturn, Stephanodiscus, which had previously been confined to bottom samples, was common throughout surface waters of the reservoir. This form lives all year in the bottom muds and was brought to the surface by the vertical currents of the overturn where it was capable of living and reproducing in the cooler waters. The overturn also produced conditions favorable for growth of Asterionella formosa, which reappeared in surface waters. It persisted to the close of the study, but did not reach the maximum attained in the spring. Fragilaria pulchella counts increased gradually during fall and remained relatively high throughout spring.

Studies conducted in 1958 showed a similar pattern of seasonal succession. Fragilaria capucina was the dominant plankter, reaching its greatest concentrations of over 10,000 organisms per milliliter in July and September. Various species of green algae occurred throughout the reservoir, reaching maxima in late June when Tetraspora and Palmella were predominant. Another maximum occurred in August when a more diverse flora, including Sphaerocystis, Tetraspora, Chlamydomonas, Pediastrum duplex, and Sphaerozosma filiforme were abundant. A high concentration of carbonates present during August and early September may have been due in part to this bloom. Several species of diatoms appeared to be adversely affected by the high summer water temperatures. Asterionella formosa began to decline in July and did not reappear until November. This decline apparently was influenced by factors other than temperature, as it disappeared not only from surface waters but also from deeper areas with appreciably lower temperatures. The autumnal overturn resulted in the appearance of Stephanodiscus, which persisted in the surface waters throughout the winter.

4.2.2 Macrophytes (Algae and Vascular Hydrophytes)

Studies of aquatic macrophytes commonly include macroscopic growths of algae (particularly Chara, Cladophora, and Spirogyra), as well as vascular plants. In lowland streams and marshes of the Great Basin the macrophyte assemblage commonly constitutes the major standing crop of primary producers.

The most detailed ecological study of macrophytes in the region was conducted on Deep Creek, Idaho-Utah (Minshall et al. 1973). The dominant species, which contributed most of the total macrophyte biomass included Chara vulgaris, Eleocharis macrostachya, and Potamogeton pectinatus. Occasionally Cladophora, watercress (Rorippa nasturtium-aquaticum), and Potamogeton filiformis contributed significant amounts at one or more of the four locations examined intensively. Chara vulgaris was by far the dominant form of vegetation in the stream. During the autumn of 1970, its biomass exceeded 200 g ash-free dry weight (AFDW)/m^2, but production was reduced significantly during the summer of 1971, probably due to the excessive scouring action to which it was exposed during high runoff in the spring of 1971. During the growing season of 1972, this taxon was a significant contributor to total macrophyte biomass only at the sampling site (station 3) below Curlew Reservoir.

Eleocharis macrostachya was restricted almost entirely to the stream margins at the most upstream location where biomass of this species exceeded 75 g AFDW/m^2 during the early fall of 1970, and the plant showed impressive growth during the period June to July 1971. However, at the next sampling (August), the biomass had declined from more than 170 to less than 25 g AFDW/m^2, attributed to grazing by cattle. Eleocharis macrostachya was also an important contributor to the total biomass in the stream margin portions at the two intermediate locations (stations 2 and 3), with levels exceeding 50 g AFDW/m^2 measured at both of these locations and reaching a maximum of 144 g AFDW/m^2 at station 3 on September 1, 1972. Eleocharis macrostachya was not common at the lower most location (station 4) because of channel dredging. The resulting near-vertical bank of the stream is not typical of the habitat in which this species occurs. However, the more gradually sloping banks at all other sampling stations carried substantial populations of this plant. When available, it appears to be a favorite of cattle.

Potamogeton pectinatus led all macrophyte species in abundance at any of the sampling stations. Typified by stations 3 and 4 downstream from Curlew Reservoir, large amounts of this species were found. Total biomass in the combined samples regularly exceeded 100 g AFDW/m^2 and approached 230 g AFDW/m^2 at station 3 by June 1972. This species was not found in any of the samples at station 1 and was present only infrequently at station 2. Potamogeton pectinatus is common in alkaline, moderately fast streams throughout the Intermountain West and is regarded as a pest in irrigation channels.

Rorippa nasturtium-aquaticum was of consequence only at station 2. Total biomass of this species never exceeded 50 g AFDW/m^2, although a 1970 gross examination sometimes revealed extensive beds growing along the stream margin. At stations 1 and 2, Rorippa almost totally disappeared from the samples collected after the heavy runoff of 1971, and did not reappear in any of the samples collected at these two stations. However, visual observation of the reaches of the stream in which these stations were located did reveal an occasional regrowth.

Potamogeton filiformis was found only at station 2. This species was regularly collected but never exceeded 25 g AFDW/m^2. Influenced by both current and stable water temperatures, its presence was restricted to riffle areas at station 2.

During 1970, macrophytes attained the highest level at station 1, exceeding 300 g AFDW/m^2 late in the growing season. Only in June 1972 did combined macrophyte biomass again approach 300 g AFDW/m^2 and then only at station 3. The high values declined with the onset of cooler weather and shorter photoperiod. At station 1 during the winter and spring of 1971, extreme icing or very high flow prevented some sampling, but in the sampling that was done, macrophytes were almost completely absent. Macrophyte growth was finally initiated in 1971 by May 1, and in the first sample interval did not increase significantly (total macrophyte biomass at station 1 along the stream edge was less than 10 g AFDW/m^2). In August, cattle were observed in the area, in association with a dramatic reduction of macrophyte biomass along the stream margin. Total biomass in the combined samples at this time declined to less than 35 g AFDW/m^2. A similar situation occurred in August 1972. In contrast to data collected in 1971, macrophyte production at station 1 in 1972 was insignificant until July in both the channel and stream margins. At that time, macrophyte standing crop approached 100 g AFDW/m^2 along the stream margin and 5 g AFDW/m^2 in the stream channel.

In year I (September 1970-August 1971), an appreciable difference between total macrophyte biomass in the stream channel and along the stream margin at station 2 was evident. The overriding influence of stable water temperatures was reflected by the 1970-71 winter standing crop values at station 2. With the onset of the 1972 growing season, macrophyte production did not markedly increase. On May 31, 1972, total macrophyte production in the combined samples at this station was less than 30 g AFDW/m^2. On July 26, there was a decline in macrophytes due to severe reduction of stream flow for irrigation, but by September 1, 1972, normal water levels were reestablished with the termination of irrigation, and rapid recovery was noted.

Total macrophyte biomass was similar at stations 3 and 4 during year I. No samples were collected at these stations from November 1970 through May 1971, because of plant senescence in autumn, followed by ice cover during winter months and exceedingly high water, which persisted through May 1971. Macrophyte standing crop at both stations rarely exceeded 100 g AFDW/m^2 either along the stream margin or in the channel. Although less complete than the 1971 observations, measurements of macrophyte standing crops in 1972 at station 3 come closest to predicted measurements given the climatic regime in which the station is located. Macrophyte growth showed pronounced seasonal variation and was well initiated by March. On May 31, the highest level (300 g AFDW/m^2 in the combined samples) of total macrophyte biomass was noted. Only a slight decline in macrophyte biomass was noted on July 26, when the total approached 250 g/m^2 and remained relatively unchanged on September 1, 1972.

Bradley (1972) described the desert shrub, phreatophyte, and salt marsh vegetation types bordering Saratoga Springs, California. The salt marsh vegetation showed some overlap of species with the other two more xeric communities, but showed an increase in diversity with five to seven species having 5% or higher frequency, and average total cover increasing to 60% or 80%. Within the hydric area of the spring, Ceratophylum demersum and Ruppia maritima were present.

An analysis of the salt grass complex and bulrush communities in Saratoga Springs is given in Table 13. Twelve species were sampled on the transects within the marsh, and six of these were present in adjacent phreatophyte communities. Although there is considerable overlap of the dominant species within these two communities, they are easily delimited as distinct communities.

The salt grass complex, represented by several important species occurs around the periphery of the marsh, occupying all sites with the exception of a few stands of reed grass. It occurs on dry soils at the edge and extends at the northern end into areas of submersed soils which are covered at times by water up to 30 cm deep. Salt grass is not only widespread, but also makes up approximately 60% of the plant

Table 13. The percent frequency of occurrence and percent cover of perennial species occurring in the salt grass complex and bulrush communities (Bradley 1972).

	Salt grass complex 325-m^2 plots		Bulrush 250-m^2 plots	
Species	Frequency (%)	Avg. Cover (%)	Frequency (%)	Avg. Cover (%)
Distichlis spicata	81.2	49.3	21.1	4.6
Juncus cooperi	39.4	13.3	5.5	0.8
Nitrophila occidentalis	30.3	11.7	--	--
Scirpus olneyi	7.2	1.3	66.6	48.8
Phragmites communis	5.6	0.1	7.7	0.6
Cressa truxillensis	5.3	0.9	--	--
Anemopsis californica	5.3	0.6	--	--
Sporobolus airoides	4.6	3.4	--	--
Scirpus robustus	1.9	0.2	7.1	3.0
Suaeda fruticosa	1.6	<0.1	--	--
Triglochin concinna	1.2	0.1	--	--
Allenrolfea occidentalis	0.7	0.1	--	--
Total cover		78.1		57.8

cover. Two other widespread and important species are rush (Juncus cooperi) and Nitrophila occidentalis, which make up an additional 30% of the plant cover.

Bulrushes are found along the channels that extend from the main spring to the southern third of the marsh, and also adjacent to some areas of open water in the northern half of the marsh. One widespread species, Scirpus olneyi, occupies areas of deeper water along the channels and much of the area adjacent to open water, making up 85% of the total plant cover. Other important species include salt grass (Distichlis spicata), which is widely distributed, especially around the edges of bulrush stands, and Scirpus robustus which occurs as small stands in shallower water. Most of these stands are found at the northern end of the marsh.

Sizeable areas of reed grass (Phragmites communis) are scattered around the outer edge of the marsh. Most of these stands grow on dry to damp soils, but some Phragmites may grow in several centimeters of water. These stands have an estimated canopy cover of about 70%, except at the edges of the stand. There is little understory development, although a sparse growth of salt grass, rush, and Anemopsis californica is present around the outer edges.

The standing crop for each community was estimated by multiplying the average height of each species in the community by its average percent cover. The products for all species in the community were then totaled and presented as an index of standing crop. The standing crop of the more mesic phreatophytes, especially the marsh communities, was far greater than the crops occurring on the surrounding desert or salt flat. The lowest indices (0.88 and 0.89) are for the salt flat and are in close agreement with each other, as are their average cover values. By contrast, the indices for the salt grass complex and bulrush communities are 29.75 and 95.20, respectively, indicating that the highest standing crop is more than 100 times larger than the lowest.

A few other scattered references to aquatic macrophytes in the Great Basin were found. Zannichellia palustris and Ruppia maritima were the aquatic macrophytes most frequently observed in Pyramid Lake (Galat et al. 1981). Both species are also successful in the lower Truckee River between Nixon, Nevada (15 km upstream), and the river's terminus. Gaufin (1959) reported Ceratophyllum, Lemna, Myriophyllum, Nasturtium (Rorripa?) officinale, Ranunculus, and Potamogeton filiformis from one or two locations on the Provo River. McConnell et al. (1957) recorded Ceratophyllum demersum, Potamogeton, Ranunculus, Scirpus, and Typha in Bear Lake plus Myriophyllum, Polygonium, and Utricularia in adjacent Mud Lake.

4.2.3 Invertebrates

The aquatic invertebrates of the Great Basin are conveniently subdivided into those found suspended in the water (i.e., zooplankton) and those associated with some form of substratum, commonly rocks or vascular plants (benthic invertebrates). Zooplankton are primarily microscopic in size and, in the Great Basin, have been described only from lakes and ponds. Benthic invertebrates may be either microscopic or macroscopic in size. Work on Great Basin habitats has dealt mainly with macroscopic forms from streams.

a. Zooplankton. Kemmerer et al. (1923) reported two copepods, Epischura and Canthocamptus, and the rotifer, Polyarthra, in Bear Lake. Hazzard (1935) found Epischura, the five rotifer species Conochilus, (the most abundant); Polyarthra, (second); Anurae, Triathra, and Nothalaca, (occasional); and one cladoceran, Daphnia. Conochilus also was an important plankter in practically every other collection reported from Bear Lake (Hazzard 1935; Perry 1943; McConnell et al. 1957).

The production of plankton in Bear Lake is low when compared to Henry's Lake and Island Park Reservoir in Idaho, and Strawberry Reservoir, Fish Lake, and Panguitch Lake in Utah (McConnell et al. 1957). Production of phytoplankton in these waters is often of sufficient volume to color the water green. Where the zooplankton volume from a 15-m haul in Bear Lake would be measured in tenths of a cubic centimeter, an equivalent haul in one of these other waters might yield 10 to 100 times this volume.

The zooplankton community in Pyramid Lake is composed of five cladocerans (Alona costata, Ceriodaphnia quadrangula, Diaphanosoma leuchten bergianum, Daphnia schodleri, and Moina hutchinsoni), one cyclopoid copepod (Cyclops vernalis), one calanoid copepod (Diaptomus sicilis), one harpactacoid copepod (Cletocamptus albuquerquensis), and four rotifers (Hexarthra jenkinae, Brachionus plicatilis, B. quadridentatus, and B. caudatus) (Galat et al. 1981).

Seasonal abundance of zooplankton appears related to the lake's heat budget. Diaptomus sicilis was a perennial species, dominating the zooplankton (66 percent of net zooplankton) throughout most of the study. Maximum reproduction occurred when surface water temperatures approached 6-7 °C (February and March), and adult numbers peaked in April and May.

Early summer conditions of rising water temperatures and a slight decline in phytoplankton production are concurrent with declining numbers of D. sicilis and increasing populations of the raptorial copepod Cyclops vernalis and the cladoceran Ceriodaphnia quadrangula. The latter two species appear to be limited in their salinity tolerance, but in Pyramid Lake they constituted 5% and 21% of the net zooplankton, respectively.

During the summer months (July-August), a sharp decline of all zooplankton species was associated with maximum water temperatures, Nodularia spumigena production, presence of large numbers of larval fish, and increased activity of tui chubs. Total zooplankton numbers increased during late August and September, due primarily to two polythermal species, Diaphanosoma leuchtenbergianum and Moina hutchinsoni (Galat et al. 1982). The cladoceran D. leuchtenbergianum is widely distributed in saline Saskatchewan lakes (Rawson and Moore 1944). Moina is also common in saline lake systems. M. hutchinsoni has been recorded in Nevada in Big Soda Lake (conductivity 42,000 µs/cm), Walker Lake (TDS, 10,300 mg/L), and during the desiccation of Winnemucca Lake (TDS, 30,000 mg/L) (Galat et al. 1981). In Mono Lake, California (TDS 90,000 mg/L), the brine shrimp Artemia is the major zooplankter, although several protozoans and occasionally two rotifers also occur there (Mason 1967, Melack 1983).

Copepods were the major zooplankton in Off Spring of the Locomotive Springs complex, Utah (Holman 1972). They were abundant in the summer of 1970, with a peak in August; during 1971 numbers were very low, with a small peak in September. The same held true for rotifers. Cladocera seemed to repeat their pattern both years with peaks during the fall. In the channel, all three organisms displayed peaks in 1971 in September and October.

b. Benthos. The distribution of leeches and mollusks over a substantial portion (Utah, Nevada) of the Great Basin was recently described by Hovingh (1986). Eight species of leeches were reported from Utah and five from Nevada. Erpobdella punctata, Helobdella stagnalis, and Nephelopsis obscura appear to be the most common. Approximately 100 species of mollusks occur in the Great Basin, but aquatic mollusk species have diminished greatly in both prehistoric and historic times (Hovingh 1986). This decline is demonstrated at Utah Lake where 30 species once lived, 8 genera survived into historic times, and possibly only one remains at present. Johnson (1986) has compiled a preliminary inventory of the crayfish in the Bonneville subdivision of the Great Basin. The native Pacifastacus gambelli is widespread. Pacifastacus leniusculus, of unknown origin, was restricted to two ponds near Utah Lake. Orconectes virilis, an introduced species, was found in Deer Creek Reservoir in the Provo River drainage and Willared Reservoir in the Weber River basin.

In chemically extreme Great Basin lakes, such as Great Salt Lake, Utah, and Mono Lake, California, the brine fly Ephydra is the sole macroinvertebrate inhabitant of the benthos (Melack 1983). Galat et al. (1981) collected 35 genera of macroinvertebrates from Pyramid Lake. Insects predominated, making up 28 of the 35 genera. Chironomids were the lake's most abundant macroinvertebrates, comprising 5 genera and 63% of the total organisms collected using a Petersen dredge. Chironomus spp. were the principal taxa, averaging 582/m^2. Maximum larval and pupal numbers occurred above the 25-m depth during March and April just before emergence, and a second smaller peak appeared in the fall. This bimodal annual distribution of *Chironomus* may indicate either a bivoltine life history or the presence of two separate species. Species of *Pseudochironomus* were found most often from April through September and represented 20 percent of the total Petersen dredge invertebrates, averaging 303/m^2. Like *Chironomus*, this midge exhibited a bimodal annual distribution although peak larval and pupal numbers were reached in May and August. *Cryptochironomus* spp., *Procladius* spp., and *Pelopia* spp. were of minor importance in Pyramid Lake.

Oligochaetes were the second most prevalent macroinvertebrate group in Pyramid Lake, constituting 33% of total numbers and averaging 480/m^2. In the profundal zone ($\geq$60 m) their numbers increased to 88% of bottom fauna. Highest numbers in Pyramid Lake were counted in January and February, dropping off sharply for the remainder of the year. In Pyramid Lake the two euryhaline amphipods *Gammarus lacustris* and *Hyallela azteca* were always associated with tufa and rocks; *H. azteca* far outnumbered *G. lacustris*. Tufa, rocks, and aquatic macrophytes also supported the largest numbers of mites and the following insects: *Argia emma*, *Enallagma clausum*, and *Macromia magnifica* (Odonata); *Callibaetis* spp. (*Ephemeroptera*); *Ambrysus mormon* (Hemiptera); *Hydropsyche* spp. (Trichoptera); and the lepidopteran, *Paragyractis confusalis*. Extensive windrows of exposed snail shells (*Physa humerosa*, *Gyraulus* sp., *Helisoma* sp., and *Parapholyx effusa*) bear witness to their once enormous populations in Pyramid Lake. *Physa* and *Parapholyx*, previously believed extinct in the lake, were collected at depths greater than 1 m by Galat et al. (1981).

The classic work on lotic benthic invertebrates in the Great Basin was conducted by Gaufin (1959) on the Provo River during 1946-49. Nine major sampling stations were selected from a point 1.6 km below the principal source of the river at Trial Lake to a point 8 km above its outlet into Utah Lake (Table 14). The stations selected were most typical of the different altitudinal zones along the river and were expected to give the best possible picture of the stream as a whole. Dissolved oxygen concentration at all of the stations was always essentially 100%, and little or no free carbon dioxide was found in the stream at any time. However, substantial differences in alkalinity were found, increasing from a mean of 8 mg/L near the headwaters to 164 mg/L near the mouth (Table 14).

The great majority (95.2%) of the bottom fauna in the Provo River belonged to five insect orders: Trichoptera, Ephemeroptera, Diptera, Plecoptera, and Coleoptera (Gaufin 1959). The same five orders also made up 94.2% of the total volume. The most abundant and widely distributed organism was caddisfly, *Brachycentrus occidentalis*.

Table 14. Physical-chemical characteristics of the Provo River, Utah (from Gaufin 1959).

Station	Elevation (m)	Mean slope (m/km)	Mean width (m)	Mean depth (m)	Velocity (m/s)		Discharge (m^3/s)		Mean temperature (°C)	Mean alkalinity as $CaCO_3$ (mg/L)
					min.	max.	min.	max.		
Upper Bridge	2,898	25	7.3	0.20	0.46	2.3	0.32	4.39	11	8
Soapstone RS	2,364	21	9.8	0.43	0.27	2.9	0.72	16.87	13	17
Stewart's Ranch	2,166	18	10.7	0.36	0.44	2.3	0.91	16.57	8	25
Lemon's Grove	1,952	15	12.8	0.38	0.67	2.2	2.40	14.13	11	97
Jordanelle	1,800	6	17.4	0.38	0.10	2.8	0.05	30.08	11	96
Heber-Midway	1,678	6	26.8	0.52	0.20	2.5	0.57	63.68	12	125
Deer Cr. Park	1,617	12	26.8	0.73	0.63	1.8	6.60	24.29	9	159
Vivian Park	1,586	8	22.9	0.48	0.46	1.7	1.91	64.81	11	156
Highway 89	1,369	12	25.3	0.28	0.34	1.9	0.72	32.46	13	164

This species constituted 12.3% of all the organisms collected. A stonefly, *Pteronarcys californica*, composed 22.4% of the total volume; the most abundant species other than these two were three mayflies, *Baetis tricaudatus*, *Ephemerella inermis*, and *E. grandis*; a stonefly, *Pteronarcella badia*; and a beetle, *Heterlimnius quardimaculatus*.

The standards of Hazzard (1935) were used in grading the productivity of the Provo River. According to these standards a grade 1 (exceptionally rich) stream has in excess of 540 bottom organisms/m^2, with a volume of more than 22 cm^3; a grade 2 (average) stream has in excess of 540 bottom organisms/m^2, but these have a volume of only 10-22 cm^3; a grade 3 (poor) stream has less than 540 organisms/m^2, with a volume less than 10 cm^3. By these criteria the Provo River qualified as an exceptionally rich stream both from the standpoint of numbers and volume (Table 15); however, there was considerable variation both with season and at different altitudes.

Of the 119 samples taken from the upper main fork of the stream, only 3 rated exceptionally rich, 17 samples could be classed as average, and the rest, poor in bottom fauna. By contrast, of 100 samples taken from the lower river below Deer Creek Reservoir, 73 rated as exceptionally rich, 12 as average, and only 14 as poor. This remarkable increase in productivity was correlated with an increase in size, volume, and carbonate content of the river, and a decrease in water velocity. Associated with the increase in productivity, there was also a definite change in the species of organisms. Eighty percent of the specimens collected at Upper Bridge were Ephemeroptera, Plecoptera, and Diptera (Table 16). The most common species represented were the mayfly *Baetis bicaudatus*; stoneflies *Alloperla* spp. and *Acroneuria pacifica*; Diptera, *Chironomus* spp.; caddisfly *Arctopsyche grandis*; and beetle *Optioservus quadrimaculatus*.

The average number of invertebrates taken at Upper Bridge was only 775/m^2, with an average volume of 9.5 cm^3. The river in this area and in the following 26 km was markedly less productive than the rest of the stream. At Soapstone, the productivity also was poor, with the average number of organisms taken per square meter only 733. Stoneflies were less common and caddisflies were slightly more common. Of the 1,976 specimens collected, 68% were Ephemeroptera, Trichoptera, and Diptera. The principal species were a mayfly, *Baetis*

Table 15. Bottom fauna per square meter sample at various stations on the Provo River, Utah, 1946-49 (modified from Gaufin 1959).

Station	No. of samples	No. of collection dates	Average organisms/m^2		Rating			Avg. rating
			No.	Vol. (cm^3)	Rich	- Avg.	- Poor	
Upper Bridge	29	16	776	9.5	1	5	10	Poor
Soapstone	29	17	733	9.3	--	6	11	Poor
Stewart's Ranch								
Main Fork	44	25	840	6.4	2	4	19	Poor
Lemon's Grove	34	25	4,538	34.4	13	5	7	Rich
Jordanelle	34	25	1,833	16.5	9	7	9	Avg.
Heber-Midway								
before dredging	24	20	2,727	28.0	8	7	5	Rich
after dredging	12	4	194	2.8	0	0	4	Poor
Deer Creek Park	27	24	5,088	68.2	20	3	1	Rich
Vivian Park	30	24	3,676	76.4	17	3	4	Rich
Highway 89	31	24	3,094	45.1	13	3	8	Rich

Table 16. Major taxonomic composition of bottom fauna by stations, Provo River, Utah, 1946-49 (modified from Gaufin 1959).

Stations	Total no. of organisms	Percentage of each order						
		Ephemeroptera	Plecoptera	Diptera	Trichoptera	Coleoptera	Hydracarina	Others
Upper Bridge	2,095	30.7	27.1	22.4	7.9	2.5	--	9.4
Soapstone	1,976	34.4	12.6	15.6	18.2	2.5	13.3	0.4
Stewart's Main Fork	3,439	24.7	7.0	25.6	20.5	12.2	8.5	1.5
Lemon's Grove	14,315	7.6	5.2	13.9	62.5	7.6	1.3	1.9
Jordanelle	5,779	12.3	26.6	19.0	30.3	9.3	1.2	1.3
Heber-Midway Bridge	6,294	12.9	28.7	23.5	26.7	5.2	--	3.0
Deer Creek Park	10,945	39.1	2.2	22.6	24.4	--	--	11.7
Vivian Park	10,232	23.2	9.3	14.3	39.1	3.7	1.1	9.3
Highway 89	8,892	26.9	3.5	38.4	18.1	7.4	1.1	4.6

bicaudatus; caddisflies, Arctopsyche grandis, and Brachycentrus spp.; midges, Chironomus spp.; stoneflies, Alloperla spp., and a beetle, Zaitzevia parvula.

The main fork of the Provo River at Stewart's Ranch was similar in fauna and productivity to the two upper stations. However, the entrance of the South Fork produced a noticeable physical, chemical, and biological effect by the time the stream reached Lemon's Grove. The latter section of stream could be rated as exceptionally productive; the average number of organisms being around $4,500/m^2$, with one species, Brachycentrus occidentalis, accounting for 42% of the total. In addition to this species, diptera (Chironomus spp., and Atherix sp.); stoneflies (Pteronarcella badia and Alloperla spp.); mayflies (Ephemerella grandis and inermis, Baetis bicaudatus); and a riffle beetle (Optioservus quadrimaculatus) were the most common forms.

The river at Jordanelle undergoes great fluctuation in volume every year due to the diversion of part of its flow for the Heber Power Plant. The sampling station was located immediately below the diversion dam. This section displayed a decided drop in productivity in comparison to Lemon's Grove (Table 16). Trichoptera, Plecoptera, and Diptera constituted 76% of the fauna collected. The most common species represented were Brachycentrus occidentalis, Hydropsyche sp., Pteronarcella badia, Brachyptera pacifica, Chironomus sp., Baetis bicaudatus, and Optioservus quadrimaculatus. The large increase in numbers of Plecoptera consisted of one species, Brachyptera pacifica.

Of the 6,294 organisms taken at Heber-Midway Bridge during the 16 months before the stream bottom was disturbed, 28.7% were Plecoptera, 26.7% Trichoptera, and 23.5% Diptera (Table 16). The most common species collected were Pteronarcella badia, Brachyptera pacifica, Hydropsyche spp., Baetis spp., Ephemerella grandis, Chironomus spp., and Optioservus quadrimaculatus. After dredging, no species was very common and the standing crop was reduced to $193/m^2$.

Deer Creek Park is typical of the conditions produced in the river as a result of impoundment in Deer Creek Reservoir. The sampling station was located 0.8 km below the reservoir spillway and outlet pipes. The stream bed here was the most stable of any of the stations and exceptionally productive at all times. Of the total number of 10,945 organisms collected, Ephemeroptera constituted 39.1%, Trichoptera 24.4%, Diptera 22.6%, and Plecoptera only 2.2%. The principal species both here and at Vivian Park were Ephemerella inermis, Ephemerella grandis, Brachycentrus occidentalis, Glossosoma spp., Chironomus spp., Simulium spp., Arcynopteryx americana, Tubifex spp., and Glossiphonia sp. Despite wide fluctuations in water level due to irrigation diversion, this station was exceptionally productive of benthic invertebrates (Table 15). The most common species were also common at Deer Creek Park and Vivian Park, but midge and blackfly larvae and pupae were far more abundant here than at any other station.

Of all of the factors considered by Gaufin (1959), greater uniformity in flow, higher and more uniform temperatures, lower pH (≥7.7), and a higher carbonate content were believed to be most responsible for the increase in productivity in the lower sections of the Provo River.

Over the years, more than 275 species and 165 genera of invertebrates, most of them insects, have been reported from the Provo River (Winger et al. 1972). The most abundant orders include Coleoptera (67 sp.), Trichoptera (54 sp.), Plecoptera (46 sp.), and Ephemeroptera (37 sp.). However, the Diptera at 37 species probably is underestimated due to difficulties with their taxonomy.

Winget (1981) studied the aquatic macroinvertebrates at five sites in Ophir Creek in May, August, and October, 1981. Ophir Creek is a small stream (0.2 m^3/s discharge in May 1981) heavily impacted by diversion practices, which flows off the west side of the Oquirrh Mountains, Tooele County, Utah. The information presented here will focus on the three locations sampled by Winget that were not subject to dewatering by artificial diversions: Upper Right Fork (UPRF), Upper Left Fork (UPLF), and Ophir Creek 0.2 km below the confluence of the two forks (OC-0.2). Analyses of water chemistry for June, August, and October, 1981, revealed moderately high total dissolved solids (184-224 mg/L) of a calcium (50 mg/L) - magnesium (15 mg/L) carbonate type (hardness 186-214, alkalinity 166-194; both as mg/L $CaCO_3$). Sulfate ranged from 9 to 13. Nitrate nitrogen (0.77 to 1.07 mg/L as N) and total phosphates (0.004 to 0.007 mg/L as P) were consistently high enough to support a good periphyton growth. Nitrates showed little seasonal change, while phosphate concentration dropped throughout the 5-month sampling season. UPRF, UPLF, and OC-1.8 in May 1981, showed discharges of 0.08, 0.2, and 0.3 m^3/s; mean widths of 2.4, 2.1, and 2.4 m; mean depths of 0.15, 0.15, and 0.18; and stream gradients of 7%, 6%, and 4%, respectively (OC-0.2 was not evaluated at this time, but probably was comparable to OC-1.8). Substrates were predominantly gravel(30%-60%), rubble (25%), and sand (5%-15%). Riparian vegetation was predominantly trees (70% cover) at UPRF and trees, grass, and brush at UPLF and OC-1.8.

Macroinvertebrate species richness was relatively high at all five sites (Table 17). Densities were much higher at UPRF than at any other station; however, biomass at UPRF was only slightly higher than at OC-0.2 and OC-1.8, indicating a higher proportion of smaller individuals (e.g., Baetis, mayflies, Hydracarina, and Chironomidae). Community composition at OC-0.2 differed from that at UPRF or UPLF in certain species, especially Plecoptera and Trichoptera (Table 18).

Winget (1982) also examined the benthic invertebrate community at three locations in Pine Grove Creek during summer and autumn of 1980 and 1981. Pine Grove Creek is a small stream (≥ 0.03 m^3/s at base flow) originating as a series of springs surfacing in the bottom of an old volcanic crater in the Wah Wah Mountains, Beaver County, Utah. The predominant terrestrial plants in the watershed are pinyon pine, juniper, rabbit brush, and sagebrush. Water-quality measurements made in January 1980 indicate moderately high total dissolved solids (290 mg/L) consisting primarily of calcium bicarbonate (hardness 224, bicarbonate alkalinity 239; both as mg/L $CaCO_3$). Sulfate also was relatively high (55 mg/L as SO_4). The wetted channel is less than 1 m wide at base flow. Channel gradient ranges from 5% to 9%. Shale accounts for 22% to 35% of the total substrate and has formed a claylike matrix surrounding sand (about 40% of the substrates) and small gravel (between 10% and 15%). This matrix prevents water circulation in the interstitial spaces between underlying rubble and large gravel

Table 17. Mean and range of aquatic macroinvertebrate community descriptors for June, August, and October, 1981, from Ophir Creek, Tooele County, Utah (Winget 1981). UPRF = Upper right fork; UPLF = Upper left fork; OC = Ophir Creek and the distance downstream from the joining of two forks.

Station		Number/m^2	Dry wt. (gm/m^2)	Number of taxa	Diversity (H')
UPRF	Mean	67,604	8.25	28.0	2.932
	Range	58,438-72,797	3.8-16.9	26-30	2.86-3.02
UPLF	Mean	28,500	5.30	31.7	3.530
	Range	25,036-30,566	2.2-8.0	29-36	3.24-3.68
OC-0.2	Mean	18,273	7.48	27.3	3.199
	Range	12,412-29,297	2.7-10.6	25-31	3.01-3.31
OC-1.8	Mean	27,840	7.74	26.0	2.722
	Range	27,616-28,011	2.9-13.8	26-26	2.02-3.41
OC-5.7	Mean	8,189	4.05	22.0	2.752
	Range	6,569-10,050	1.7-6.86	19-24	2.06-3.11

Table 18. Macroinvertebrate community composition for Ophir Creek. Mean of samples collected May 27, August 13, and October 8, 1981 (from Winget 1981).

Taxa	Mean number/m^2		
	UPRF	UPLF	OC-0.2
Nematoda	43	58	29
Planorbidae	--	7	--
Pelecypoda	22	7	--
Oligochaeta	373	351	509
Turbellaria	1,220	4,480	2,987
Hydracarina	5,186	1,621	344
Copepoda	660	179	93
Ostracoda	5,570	976	305
Ephemeroptera			
Baetis	17,843	5,750	4,416
Cinygmula	2,919	1,073	1,248
Epeorus	1,073	316	100
Tricorythodes minutus	--	14	--
Ephemerellidae	813	1,557	301
Ephemerella	585	29	--
Ephemerella coloradensis	733	1,270	954
Ephemerella inermis	7	581	43
Plecoptera	7		
Nemouridae	--	36	--
Zapada	3,982	574	416

(Continued)

Table 18. (Concluded).

Taxa	Mean number/m^2 UPRF	UPLF	OC-0.2
Zapada cinctipes	1,334	14	147
Capniidae	--	4	29
Leuctridae	40	21	72
Megarcys signata	37	52	17
Isogenoides zionensis	--	--	7
Isoperla	68	86	21
Chloroperlidae	487	1,087	179
Hesperoperla pacifica	1,140	7	--
Trichoptera		50	7
Rhyacophila	488	402	113
Rhyacophila acropedes	--	208	7
Rhyacophila hyalinata vocala	47	14	21
Rhyacophila tucula kincaide	25	--	--
Hydropsyche	--	7	15
Parapsyche	442	80	234
Hesperophylax	--	--	15
Oligophlebodes	441	2,279	1,223
Neothremma	2,733	22	--
Lepidostoma	--	14	--
Oligoplectrum	--	495	--
Coleoptera			
Dytiscidae	7	--	7
Elmidae	7	15	--
Diptera			
Antocha monticola	4	--	1
Dicranota	14	--	4
Holorusia grandis	65	101	58
Eriocera	35	10	17
Ormosia	7	7	4
Pericoma	--	--	7
Dixa	165	287	22
Simuliidae	--	4	--
Chironomide	111	83	452
Ceratopogoidae	21,907	3,770	3,590
Stratiomyiae	18	22	--
Euparyphus	--	54	187
Hemerodromia	--	--	7
Syrphidae	301	323	79

substrates. Streambanks range from flat marsh to steep rocky hillsides. Sampling station 1 was just below the headwater springs in a steep-sided clay channel showing extensive erosion. The riparian zone was 0.06 to 7.6 m wide with 60% cover by brush and grass. Station 2 was in a meadow area (60 m wide) dominated by grass with some wild rose and willow. Watercress was common in the stream at this site. Station 3 was in a broad (60-183 m wide) valley adjoined by sloping hills (38% gradient). The riparian zone was 2 to 9 m wide with 50% cover by grass and brush.

Pine Grove Creek supported a limited number of invertebrate taxa (Table 19). The "big three" aquatic orders in the

Table 19. Macroinvertebrate community composition as number per square meter at three stations on Pine Grove Creek, Beaver County, Utah. Mean of samples taken May 20 and September 17, 1980, and May 1 and October 10, 1981 (modified from Winget 1982).

Taxa	Station		
	PGC-1	PGC-2	PGC-3
Nematoda (round worms)	325	549	120
Gastropoda (snails)	52	1,259	121
Pelecypoda (clams)	8	347	75
Hirudinea (leeches)	--	80	38
Oligochaeta (worms)	739	1,506	1,063
Turbellaria (flat worms)	137	11	--
Hydracarina (mites)	91	51	43
Amphipoda (scuds)	3	269	--
Copepoda	122	--	11
Ostracoda	161	129	250
Ephemeroptera (mayflies)			
Baetis	2,150	3,809	2,644
Callibaetis	--	75	--
Cinygmula	--	11	--
Ephemerella inermis	6	11	6
Pseudocloeon	--	16	--
Zygoptera (damselflies)			
Argia	176	75	
Plecoptera (stoneflies)			
Prostoia besametsa	--	3	--
Zapada cinctipes	7	--	108
Isoperla quinquepunctata	--	45	342
Trichoptera (caddisflies)			
Hydropsyche	250	2,531	1,079
Hydroptila	2	--	--
Limnephilidae	--	14	--
Hesperophylax consimilus	71	66	98
Lepidostona	--	48	34
Oligophlebodes	8	--	--
Coleoptera (beetles)			
Elmidae	--	30	--
Diptera (true flies)			
Antocha monticola	6	--	--
Dicranota	12	--	--
Pericoma	--	--	2
Simulium	20	326	195
Chironomidae	1,077	1,281	3,093
Ceratopogonidae	2	29	40
Hemerodromia	24	54	37
Tabanus	6	--	--
Stratiomyidae	9	1	11

Western United States--mayflies, stoneflies, and caddisflies--were represented by only seven species. The Ephemeroptera genus *Baetis* was common while *Ephemerella* and *Cinygmula* were rare. Both Plecoptera species, *Zapada cinctipes* and *Isoperla quinquepunctata*, were fairly common; these hardy species are widely distributed throughout the intermountain West. The Trichoptera *Hesperophylax* and *Hydropsyche* also are hardy species with wide distributions (Winget 1982). The dragonfly *Cordulagaster* in Pine Grove Creek represents a southern faunal element that has extended at least this far north. However, most of the insects present belong to a basically northern montane faunal element. Winget (1982) concluded that in the past Pine Grove Creek probably had a somewhat richer invertebrate fauna, but because of changing conditions from domestic livestock grazing, road construction, and mining, the community has been reduced to the few existing hardy species. The past community, though more diverse, probably was still simple compared to other streams due to the peculiar clay-sand matrix and high sulfur content of the sediments associated with the ancient volcano origin of the environment. In Pine Grove Creek there were fewer invertebrate taxa, which were considerably less productive (Table 20) than in Ophir Creek or the Provo River.

One hundred and twenty taxa of invertebrates have been recorded from Convict Creek, California, including 26 kinds of Chironomidae (Leland et al. 1986). Many of these taxa appear to be widespread in the Great Basin. Mean population densities of 28 common benthic insects ranged from 0.002 to 0.150 g dry weight (DW)/m^2. Common taxa most abundant in late spring (May-June) included the Ephemeroptera *Epeorus longimanus*, *Drunella flavilivea*, and *Caudatella heterocaudata* and the Plecoptera *Calineura californica*, *Doroneuria baumanni*, and *Pteronarcys princeps*. Those abundant in the summer included the plecopteran *Malenka*, the trichoptera *Arctopsyche grandis*, *Hydropsyche oslari*, and *Rhyacophila acropedes*, at least two species of the ephemeropteran genus *Baetis*, and the dipterans *Simulium* and Chironomidae. Peak densities of many common taxa in Convict Creek occurred in autumn including Ephemeroptera (*Epeorus dulciana*, *Ephemerella infrequens*, *Ironodes lepidus*, *Paradeptophelebia pallipes*), *Trichoptera* (*Brachycentrus americanus*, *Glossosoma califica*, *Hydropsyche oslari*, *Lepidostoma*, *Micrasema*, *Neophylax*, *Rhyacophila vaccua*), and Diptera (*Antocha monticola*, Chironomidae, and *Pericoma*). Taxa abundant throughout the year included the mayfly *Baetis* (principally *B. devinctus* and *B. tricaudatus*) and the elmid beetle *Optioseruvus divergenus*.

Behmer and Hawkins (1986) compared macroinvertebrate abundance and production between an open and shaded site on Blacksmith Fork River in the Wasatch Mountains, Utah. Average density, average biomass, and epilithic production of important taxa were estimated for the time period when sufficient numbers of these organisms were present in samples (Table 21). Mean biomass was significantly higher at the open site for midges (Chironomidae); *Baetis bicaudatus*; *Baetis tricaudatus*; *Drunella coloradensis*; and *Cinygmula* sp. than at the shaded site. Abundance of most other macroinvertebrates also was greater

Table 20. Mean and range of aquatic macroinvertebrate community descriptors at three stations on Pine Grove Creek, Beaver County, Utah, during 1980 and 1981 (from Winget 1982).

	Number of samples	Number of taxa		Avg. no./m^2		Avg. dry wt. gm/m^2	
		Mean	Range	Mean	Range	Mean	Range
PGC-01	4	15.0	10-17	5.3	1.7- 7.7	3.8	0.4- 8.1
PGC-02	4	20.5	12-26	12.8	5.8-18.1	8.1	5.2-11.2
PGC-03	4	18.3	11-23	9.7	6.1-13.6	4.2	1.6- 6.1

at the open site, but differences were not statistically significant. Black fly biomass at the shaded site was about 1.5 times that at the open site.

It was not possible to estimate growth rates of all taxa, but when estimated, growth rates (mm/day) did not differ significantly between sites and generally did not contribute greatly to differences in production estimates between canopy types (Table 21). However, all growth rates were calculated from only three estimates of mean length. Confidence limits for these estimates are too wide to be useful with only one degree of freedom, but standard errors of the estimates are included in Table 21.

Seasonal production, estimated by the size-frequency and instantaneous growth rate methods, was greater at the open site than the shaded site for most taxa (except black flies) and reflected differences in standing crops between the sites rather than differences in rate of growth. Excluding black flies, production at the open site was twice as high as at the shaded site. The greater abundance and production of most invertebrate taxa at the open site probably is associated with either higher quality food (algae and algal detritus), or a phototactic attraction to sunlit areas.

Taxa listed in Table 21 accounted for over 95% of the estimated epilithic standing crop of all invertebrates at the study sites. The remaining biomass was made up of taxa that were rare or in an early stage of development and contributed little to the total biomass because of their low density or small size.

The mean epilithic biomass of the taxa listed in Table 21 for the study period was approximately 3.4 g DW/m^2 planar rock area at the open site and 2.6 g DW/m^2 at the shaded site. Corresponding estimates for the entire stream bottom are 2.8 gDW m^2 at the open site and 2.0 g DW/m^2 at the shaded site. Minimum estimates of epilithic production for these taxa are 14.6 g DW/m^2 planar rock area at the open site and 13.2 g DW/m^2 at the shaded site. These estimates are very close but black flies accounted for more than 50 percent of the epilithic production at the shaded site. Epilithic production of taxa excluding black flies was 10.1 g DW/m^2 at the open site and 5.3 g DW/m^2 at the shaded site.

The taxa were grouped into four feeding guilds for more specific comparisons of production between sites. Glossosoma sp. was considered an obligate scraper/grazer. All black fly production and half the production of A. grandis was assigned to the filter-feeding guild. Predator production included Rhyacophilidae, all stoneflies except Nemouridae, half the production of D. coloradensis, and half that of A. grandis. All other taxa were lumped into the collector-gatherer/facultative grazer guild. Production of these guilds for the open site was (g DW/m^2): obligate scrapers/grazers, 0.7; filter-feeders, 5.4; predators, 1.6; and collector-gatherers/facultative grazers, 7.0. The ratio of production at the open site to that at the shaded site for these feeding guilds was 1.7, 0.6, 1.1, and 2.8, respectively. Predators accounted for 28.8% and 26.5% of the total epilithic biomass and 10.9% and 11.1% of the total epilithic production at the open and shaded sites respectively.

Total annual production (dry weight) of herbivorous and detritivorous benthic insects from a riffle in Convict Creek was estimated to be 3.9 g/m^2 (Leland et al. 1986), not including oligochaetes and mollusks, which constituted 10%-20% of the mean annual standing stock. Total annual production of benthic insect predators was approximately 1.7 g/m^2.

Hyalella azteca was by far the major benthic invertebrate in Off Spring of the Locomotive Springs Complex, Utah (Holman 1972). During July 1970, numbers in the pool were high (180/L), with a drop to 14/L occurring during the winter months. However, there was no recovery during 1971 when numbers remained very low (<3/L) with a small peak (15/L) in August. During 1971, the numbers were higher in the channel than in the pool, peaking at 533/L in August. Other common invertebrates in both the pool and the channel were tubifex worms (2,000-80,000/m^2), Chironomidae (800-39,000/m^2); Ischnura (11,000-139,000/m^2); Callibaetis (2,000-106,000/m^2), Nematoda, and Physa.

Table 21. Mean density (N), biomass (B), and annual production of principal macroinvertebrate taxa for open and shaded study sites on Blacksmith Fork River, Utah. Production estimates for abundant taxa are by size-frequency and instantaneous growth rate (IGR) methods; those for less abundant (common) taxa are from daily P/B ratios times 94-day B values. Estimates of daily growth rates in length are given with ±2 standard errors. Confidence limits (95%) for mean densities and biomass are based on transformed data, but means are of original data (based on Behmer and Hawkins 1986).

Taxon	Time period (days)	Canopy cover	Density N (no./m^2)	Biomass B (mg DW/m^2)	Growth rate (mm/day) or CPI	Annual Production mg DW/m^2 Size-freq.	Annual Production mg DW/m^2 IGR
Abundant taxa							
Epeorus longimanus	7/6-8/19 (44)	Open	502* 1.31	435* 1.43	0.0434±0.0161	361	357
		Shade	386* 1.43	290* 1.43	0.0360± 0.0284	212	226
Cinygmula sp.	7/6-8/19 (44)	Open	419* 1.28	320* 1.28	0.0454±0.0360	369	316
		Shade	257* 1.28	199* 1.31	0.0646±0.0342	322	245
Serratella tibialis	7/6-8/19 (44)	Open	236* 1.44	55* 1.31	0.0610±0.0136	117	133
		Shade	133* 1.44	48* 1.31	0.0635±0.0064	93	108
Glossosoma sp.	8/19-10/8 (50)	Open	1,846* 1.39	697* 1.23	0.0227±0.0037	689	558
		Shade	1,431* 1.39	452* 1.23	0.0196±0.00045	408	323
Arctopsyche grandis	8/19-10/8 (50)	Open	512* 1.44	730* 1.43	0.126 ±0.0745	1,596	1,790
		Shade	546* 1.44	815* 1.43	0.0132±0.0620	1,886	1,979
Baetis bicaudatus	7/6-10/8 (94)	Open	2,214* 1.33	284* 1.22	CPI = 80 days	1,676	---
		Shade	630* 1.33	50* 1.22	CPI = 80 days	335	---
Baetis tricaudatus	7/6-10/8 (94)	Open	3,565* 1.25	377* 1.20	CPI = 80 days	2,333	---
		Shade	1,731* 1.25	166* 1.20	CPI = 80 days	1,035	---
Chironomidae	7/6-10/8 (94)	Open	2,431* 1.40	144* 1.23	CPI = 40 days	2,035	---
		Shade	471* 1.40	31* 1.23	CPI = 40 days	423	---
Simuliidae	7/6-10/8 (94)	Open	3,104* 1.82	473* 1.78	CPI = 40 days	4,581	---
		Shade	4,983* 1.82	820* 1.78	CPI = 40 days	7,873	---

(Continued)

Table 21. (Concluded).

Taxon	Time period (days)	Canopy cover	Density N (no./m²)	Biomass B (mg DW/m²)	Growth rate (mm/day) or CPI	Annual Production mg DW/m² Size-freq.	Annual Production mg DW/m² IGR
Common taxa							
Hesperoperla pacifica	7/6-10/8	Open	103* 1.28	637* 1.60			378
	(94)	Shade	79* 1.28	417* 1.60			276
Rhyacophilidae	7/6-10/8	Open	67* 1.20	114* 1.31			158
	(94)	Shade	30* 1.20	21* 1.31			52
Chloroperlidae, Nemouridae, Perlodidae, and Perlidae	7/6-10/8	Open	251* 1.32	40* 1.18			262
	(94)	Shade	232* 1.132	32* 1.18			231
Drunella coloradensis	7/6-10/8	Open	34* 1.22	87* 1.33			92
	(94)	Shade	5* 1.25	7* 1.37			11

4.2.4 Fish

The Great Basin presents a study in extremes. Its mountainous peaks exceed 4,000 m in elevation, and its lowest valleys extend to below sea level. The Great Basin is a vast arena where there has long been an active interplay between processes of faunal establishment and extinction, habitat disruption, and the isolation and differentiation of the remnant fish populations (e.g., Minckley et al. 1985). Lakes Bonneville and Lahontan once covered most of this basin. As the climate became more arid, the streams that remained in their desiccated basins increased in length. Most of these basins and the beds of their contained lakes are bounded on one or both sides by great fault scarps, along which typically issue valley-bottom or valley-edge springs in which a remnant of the fish life of the basin has somehow persisted. In contrast, the canyon and mountainside springs of the basins, though seemingly permanent and hospitable, seldom contain native fish, presumably because flash floods resulting from rare torrential rains sweep everything before them.

Great Basin fishes are often unique because they developed in what, for many centuries, was an inland drainage with no access to the sea--the largest area of closed basins in North America. In recent geologic time, lakes in the basin rose and fell, some drying up; thus, salinity fluctuations are large. Several species and subspecies that persisted over the millennia since the late Pleistocene disappeared during recent times through deterioration of their environment; still others are on the verge of extinction.

The following presentation covers the Bonneville basins, the Lahontan basins, the central basins, and the southern basins subregions (Figure 7). Much of the information presented here was taken from Sigler and Sigler (1987), which is one of the more comprehensive sources available on Great Basin fishes. Additional information is available in the review chapter prepared by Minckley et al. (1985). This section covers the past historical evolution of the Great Basin fishes and fisheries, their present condition, and their future. Scientific names of fishes are listed in Table 22.

a. Historical overview. Members of the genus Salmo, both anadromous and resident, were in the Great Basin by the Pliocene (5

Table 22. Fishes presently established in the Great Basin (from Sigler and Sigler 1987). Symbols are as follows * = native, c = endangered, t = threatened, and sc = special concern.

Common name		Scientific name
		Order Salmoniformes
Trouts		Salmonidae
Sockeye salmon (Kokanee)		Oncorhynchus nerka (Walbaum)
Bear Lake whitefish	*	Prosopium abyssicola (Snyder)
Bonneville cisco	*	P. gemmiferum (Snyder)
Bonneville whitefish	*	P. spilonotus (Snyder)
Mountain whitefish	*	P. williamsoni (Girard)
Golden trout		Salmo aquabonita Jordan
Cutthroat trout	*	S. clarki Richardson
Lahontan cutthroat trout	*,t	S. clarki henshawi Gill and Jordan
Paiute cutthroat trout	*,t	S. clarki seleniris Snyder
Bonneville cutthroat trout	*,t	S. clarki Utah Suckley
Rainbow trout	*	S. gairdneri Richardson
Brown trout		S. trutta Linnaeus

(Continued)

Table 22. (Continued).

Common name		Scientific name
Brook trout		*Salvelinus fontinalis* (Mitchill)
Lake trout		*S. namaycush* (Walbaum)
Arctic grayling		*Thymallus arcticus* (Pallas)
Pikes		Esocidae
Northern Pike		*Esox lucius* Linnaeus
		Order Cypriniformes
Carps and Minnows		Cyprinidae
Chiselmouth	*	*Acrocheilus alutaceus* Agassiz and Pickering
Goldfish		*Carassius auratus* (Linnaeus)
Grass carp		*Ctenopharyngodon idella* (Valenciennes)
Common carp		*Cyprinus carpio* Linnaeus
Desert dace	*,t	*Eremichthys acros* Hubbs and Miller
Alvord chub	*,sc	*Gila alvordensis* Hubbs and Miller
Utah chub	*	*G. atraria* (Girard)
Tui chub	*	*G. bicolor* (Girard)
Borax Lake chub	*,e	*G. boraxobius* Williams and Bond
Leatherside chub	*	*G. copei* (Jordan and Gilbert)
Arroyo chub		*G. orcutti* (Eigenmann and Eigenmann)
Pahranagat roundtail chub	*,e	*G. robusta* jordani Tanner
California roach		*Hesperoleucus symmetricus* (Baird and Girard)
Least chub	*,t	*Iotichthys phlegethontis* (Cope)
White River spinedace	*,e	*Lepidomeda albivallis* Miller and Hubbs
Big Spring spinedace	*,e	*L. mollispinis* pratensis Miller & Hubbs
Golden shiner		*Notemigonus crysoleucas* (Mitchill)
Spottail shiner		*Notropis hudsonius* (Clinton)
Sacramento blackfish		*Orthodon microlepidotus* (Ayres)
Fathead minnow		*Pimephales promelas* Rafinesque
Northern squawfish		*Ptychocheilus oregonensis* (Richardson)
Relict dace	*,sc	*Relictus solitarius* Hubbs and Miller
Longnose dace	*	*Rhinichthys cataractae* (Valenciennes)
Speckled dace	*	*R. osculus* (Girard)
Redside shiner	*	*Richardsonius balteatus* (Richardson)
Lahontan redside	*	*R. egregius* (Girard)
Suckers		Catostomidae
Utah sucker	*	*C. ardens* Jordan and Gilbert
Desert sucker	*	*C. clarki* Baird and Girard
Bridgelip sucker	*	*C. columbianus* (Eigenmann & Eigenmann)
Bluehead sucker	*	*C. discobolus* Cope
Owens sucker	*	*C. fumeiventris* Miller
Largescale sucker	*	*C. macrocheilus* Girard
Mountain sucker	*	*C. platyrhynchus* (Cope)
Tahoe sucker	*	*C. tahoensis* Gill and Jordan
Warner sucker	*,t	*C. warnerensis* Snyder
Cui-ui	*,e	*Chasmistes cujus* Cope
June sucker	*,sc	*C. liorus* Jordan

(Continued)

Table 22. (Continued).

Common name		Scientific name
		Order Siluriformes
Bullhead catfishes		Ictaluridae
White catfish		*Ictalurus catus* (Linnaeus)
black bullhead		*I. melas* (Rafinesque)
Yellow bullhead		*I. natalis* (Lesueur)
Brown bullhead		*I. nebulosus* (Lesueur)
Channel catfish		*I. punctatus* (Rafinesque)
		Order Atheriniformes
Killifishes		Cyprinodontidae
White River springfish	*,e	*Renichthys baileyi* (Gilbert)
Railroad Valley springfish	*	*R. nevadae* Hubbs
Devils Hole pupfish	*,e	*Cyprinodon diabolis* Wales
Amargosa pupfish	*	*C. nevadensis* Eigenmann and Eigenmann
Owens pupfish	*,e	*C. radiosus* Miller
Salt Creek pupfish	*	*C. salinus* Miller
Pahrump killifish	*,e	*Empetrichthys latos* Miller
Plains killifish		*Fundulus zebrinus* Jordan and Gilbert
Rainwater killifish		*Lucania parva* (Baird)
Livebearers		Poeciliidae
Mosquitofish		*Gambusia affinis* (Baird and Girard)
Sailfin molly		*Poecilia latipinna* (Lesueur)
Shortfin molly		*P. mexicana* Steindachner
Guppy		*P. reticulata* Peters
Green swordtail		*Xiphophorus helleri* Heckel
		Order Gasterosteiformes
Sticklebacks		Gasterosteidae
Threespine stickleback		*Gasterosteus aculeatus* Linnaeus
		Order Perciformes
Temperate basses		Percichthyidae
White bass		*Morone chrysops* (Rafinesque)
Sunfishes		Centrarchidae
Sacramento perch		*Archoplites interruptus* (Girard)
Green sunfish		*Lepomis cyanellus* Rafinesque
Pumpkinseed		*L. gibbosus* (Linnaeus)
Bluegill		*T. macrochirus* Rafinesque
Smallmouth bass		*Micropterus dolomieui* Lacepede
Spotted bass		*M. punctulatus* (Rafineque)
Largemouth bass		*M. salmoides* (Lacepede)
White crappie		*Pomoxis annularis* Rafinesque
Black crappie		*P. nigromaculatus* (Lesueur)

(Continued)

Table 22. (Concluded).

Common name		Scientific name
Perches		Percidae
Yellow perch		Perca flavescens (Mitchill)
Walleye		Stizostedion vitreum vitreum (Mitchill)
Chiclids		Chichlidae
Convict cichlid		Cichlasoma nigrofasciatum (Gunther)
Redbelly tilapia		Tilapia zilli (Gervais)
Sculpins		Cottidae
Mottled sculpin	*	Cottus bairdi Girard
Paiute sculpin	*	C. beldingi Eigenmann and Eigenmann
Bear Lake sculpin	*	C. extensus Bailey and Bond

to 1.8 million years ago), and by then had probably covered the currently occupied area (Sigler and Sigler 1987). By Pleistocene times, most fishes had taken on their present forms. The upper Bear River, which at one time flowed into Lake Bonneville, supplied five species of fish (mountain white fish, cutthroat trout, Utah sucker, longnose dace, and mottled sculpin) to the Great Basin. The fish fauna in Bear Lake are unusual with several relict species from ancient Lake Bonneville; four species of whitefishes of the genus Prosopium and a sculpin, Cottus extensus, are endemic. Relationships among certain species of fish occupying both the Lahontan and Bonneville Basins indicate that these two large ancient lakes probably were connected during the Pliocene or early Pleistocene. In several separate basins of the Great Basin in Oregon, north of the Lahontan basin and west of the Alvord basin, redband trout evidently completely replaced the cutthroat trout. The evolutionary specialization into large, lacustrine predators made the Lahontan cutthroat trout, the Bonneville cutthroat trout, and two yet undescribed subspecies native to the Alvord basin ill-adapted to life in small streams and made non-native trout introductions quite easy (Behnke 1976).

The earliest fishermen to use Great Basin fisheries were wandering bands of Asians who crossed the Bering Strait. These people were present on the shores of ancient Lakes Bonneville and Lahontan, 8,000 to 10,000 years ago. When European settlers arrived a century ago, Lahontan cutthroat trout could still be found throughout the Truckee, Carson, Walker, and Humboldt River drainages where there was an estimated 5,632 km of suitable stream habitat. The trout also lived in Lakes Tahoe, Cascade, Fallen Leaf, Donner, Independence, and Twin in California and Pyramid, Winnemucca, Walker, and Summit in Nevada. Altogether these fish occupied about 125,575 ha of lake habitat and the total trout population probably numbered in the millions. Europeans first utilized the fisheries in the late 1700's, but it was not until the California Gold Rush that they began to exploit them. By 1868, a railroad had been completed close to Pyramid Lake and the cutthroat trout-spawning run up the Truckee River allowed fish to be captured in large numbers and shipped with minimal spoilage to western Nevada and surrounding states. During the late 1800's, the trout became a familiar delicacy from Ogden, Utah, to San Francisco, California, and as far east as Chicago. During this period about 518,000 kg of trout from Pyramid Lake and the Truckee River were sold commercially.

1. Bonneville basins. Humans first occupied the shores of Lake Bonneville as it was receding, some 10,000 to 11,000 years ago. Little evidence is available to determine if they were using fish from the lake at this time. At some point in history far preceding the coming of Europeans, the Great Salt Lake had become too saline to sustain a fishery. Utah Lake, however, was a large supplier of fish to the Indians and later to the early settlers. In 1847,

the first Mormon pioneers reached the Bonneville basin, and within 10 years they had settled 161 km from Salt Lake City and had begun to utilize the fishery. Commercial fishing on Utah Lake and tributaries started immediately after these first settlers arrived. Three species of fish were harvested commercially: the Utah cutthroat, the Utah sucker, and the Utah chub. A single net haul could yield 1,591 kg of trout from Utah Lake in 1864, but no more than 227 kg by 1872, and only 45 kg by 1889. The last native cutthroat trout was taken from Utah Lake in 1933.

An expanding human population created a growing market for Utah Lake fish, and by 1872, decreases in catch were obvious. From 1876 to 1896, the trout population in Utah Lake rapidly declined because of too effective fishery methods, lack of regulation and enforcement, irrigation effects, loss of water quality, and introduction of exotic species (Carter 1969).

As lake levels receded and salinity dramatically increased following the Pleistocene, many fishes were driven to incoming streams, where they were isolated from contact with each other for about 8,000 years. The ancient Pleistocene Lake Bonneville in the Great Basin once supported large numbers of a rare cutthroat trout, the only native trout species in the Bonneville basin, which abounded in surrounding streams upon the lake's decline (Hickman and Duff 1978). Sizeable migrations of trout entered the tributaries of Utah Lake and also the Bear, Sevier, and Duchesne Rivers (Cope 1955). This cutthroat, often called the Utah cutthroat (<u>Salmo</u> <u>clarki</u> <u>utah</u>), is still present in the pure state in such streams as Pine, Goshute, Hampton, and Henry's Creeks in Nevada and in Trout Creek in Utah. Hybridized populations are found in Muncy and Mill Creeks in Nevada, and Birch and Johnson Creeks in Utah (Behnke 1976).

Cutthroat populations from some high gradient streams in the basin were eliminated because natural recolonization could not be effective after desiccation of pluvial lakes. Following droughts and violent thunderstorms, a large number of barren streams were found in the Great Basin before rainbow trout were introduced.

Introduction of exotic fish into Bonneville basin waters began in the late 1880's. By 1890, carp were appearing in the seine hauls of commercial fishermen. Largemouth bass were introduced in 1890 and by 1894 were being taken in the Utah Lake fishery. Around the turn of the century, brook trout were planted throughout the Bonneville basin in suitable waters (Sigler and Sigler 1987). Efforts to forestall the large decrease in fisheries resulted in hatchery rearing of native species and massive stocking of exotic species. White bass, introduced in the 1950's, are now the dominant fish in Utah Lake. Carp are present at lower elevations in all the major drainages in the Bonneville basin (Sigler and Miller 1963).

Other fish species stocked during this period included Sacramento perch, McCloud River chinook salmon, Schuylkill River catfish, Lake Michigan whitefish, American shad, chinook salmon, sebago salmon, rainbow trout, brown trout, Montana grayling, American eel, channel catfish, black bullhead, yellow perch, largemouth bass, rock bass, black crappie, green sunfish, and bluegill.

The Bear River flowed north into the Portneuf River in Idaho and then into the Snake River 34,000 years ago and now is presently connected to Bear Lake by an artificial canal. The fish of Bear Lake belong to the Bonneville fauna and show considerable local differentiation, particularly among several species of the family Corregonidae including the Bonneville cisco, the Bonneville whitefish, and the Bear Lake whitefish.

McConnell et al. (1957) reported that during the first quarter of the century, a commercial fishery operating on Bear Lake harvested large numbers of cutthroat trout and suckers. Since the early 1920's, sport fishing has been the only harvest allowed, but lake trout, introduced in 1911, and the winter fishery for cisco, have also provided valuable fisheries. Presently, no known populations of the Bonneville cisco exist outside of Bear Lake, but some lakes, such as Lake Tahoe (Nevada), have been stocked. Despite annual introductions of rainbow trout in Bear Lake, this species has never become established, and a rainbow trout fishery in Bear Lake is maintained only by stocking catchable fish. The cutthroat trout of Bear Lake represent, with only a minute hybridization, a genotype of the original lacustrine stock of the Bonneville cutthroat from ancient Lake Bonneville.

2. Lahontan basins. The marked isolation of Nevada's major drainage systems from each other and from the larger numbers of small spring-fed pools and streams that do not flow beyond the confines of their own separate valleys established a situation in which small, disconnected populations of fishes evolved away from their parent stock to the point where the differences between the isolated stock and the ancestral stock grew to genetic importance.

The Lahontan cutthroat trout at one time lived in abundance throughout the Lahontan basin of California and Nevada, having entered during the Pleistocene epoch when the lake may have been connected to the Klamath, Sacramento, or Snake Rivers. Major lacustrine populations inhabited Pyramid Lake, Walker Lake, Independence Lake, Lake Tahoe, and Summit Lake, but the Lahontan cutthroat trout was forced to adapt to stream environments through desiccation of Lake Lahontan. Fluvial populations occurred in the Carson, Walker, and Truckee River systems of California and Nevada, and in the Humboldt drainage of Nevada (Behnke and Zarn 1976). Currently the only lakes that harbor pure stocks of Lahontan cutthroat trout are Summit Lake and Independence Lake, California.

Pyramid Lake, the largest remaining artifact of ancient Lake Lahontan, is the deepest, most voluminous saline lake in the Western Hemisphere. A favorable water chemistry (highly ionic) and an abundant supply of forage fish (tui chub) produced a cutthroat trout fishery with some 27.2 kg fish. It estimated that the annual production of cutthroat trout was 0.5 million kg/y, but in just 70 years the fish was extinct in this lake.

Pyramid Lake historically supported the prime fishery in the Lahontan Basin. Indians survived on the Pyramid Lake cui-ui, the Tahoe sucker, and the Pyramid Lake cutthroat many centuries before the coming of the white man. The spawning of the cui-ui was of great importance to the local Indians as well as tribes to the south who traveled many miles to fish for this abundant food source. When the "Fremont Party" arrived in 1844, large harvests of Pyramid cutthroat were coming from the Truckee River where it entered the lake.

Between 1860 and 1900, from 27,000 to 91,000 kg (Sigler and Sigler 1987) of trout were harvested and shipped annually from the Pyramid Lake Basin (Townley 1980). Behnke (1974) estimated that about 0.5 million kilograms of cutthroat trout could have been harvested annually between 1860 and 1920, by sport, Indian, and commercial fishers and that the cui-ui population was probably as large or larger than the trout population.

As early as the 1860's, logging activities, roads, and diversion dams for sawmills prevented access of Pyramid Lake fish to their historic spawning grounds on the Truckee River system as far as Lake Tahoe and its tributaries. By 1884, 11 dams blocked the Truckee River and only 2 of them had functioning fish ladders. During this period, the first significant pollution entered the Truckee from sawmills and paper plants. Fortunately, by 1900, cleanup efforts almost eliminated this type of pollution. However, industrial pollution, habitat modification and degradation, and overfishing promoted the decline of the Lahontan cutthroat trout after 1890, and by 1900, the trout and some other native fish had been extirpated from 80% of the Truckee Basin (Townley 1980).

Heavy sport fishing did not start until the late 1800's (Sigler and Sigler 1987). Sport fishermen soon started to look for ways to reestablish the Pyramid Lake basin fishery, but pollution from the cities of Sparks and Reno into the Truckee River and Pyramid Lake, along with water diversions and uncontrolled harvest had significantly damaged the fishery.

Water diversions caused the lake level to fall 23 m between 1905 and 1979. Dams for irrigation and industrial water blocked fish passage to Truckee River spawning grounds. The construction of Derby Dam in 1905 effected a transbasin diversion of much of the lower Truckee River, and drastically reduced flows into Pyramid

Lake, causing a vast delta to build at its mouth. Derby Dam, 64 km above Pyramid Lake, diverted most of the Truckee flow into the Carson River basin except during floods. The level of Pyramid Lake dropped 113 m between 1906 and 1968, exposing a large mud flat at the mouth of the river that obstructed trout migrating from the lake. The fish ladder over Derby Dam seldom worked, and stream flows below the dam were inadequate for trout reproduction. Shallower Winnemucca Lake, which shared the natural flow of the Truckee River with Pyramid Lake, dried up in 1938. The Pyramid Lake fishery began its decline in 1906 slowly at first and rapidly during the 1920's (Sumner 1939). The last good spawning took place in 1928, and no spawning runs occurred after 1930. By 1934, angling on the lake was poor; only large fish were being caught. A series of drought years in the early 1930's, together with all the water diversions, spelled the final demise of the Pyramid Lake fishery, and after 1938 cutthroat trout was extirpated from Pyramid Lake. Pollution from the cities of Sparks and Reno, which contaminated the Truckee River for over 80 years beginning around the turn of the century, also contributed to the decline of the fishery. Some pollution is still entering the river.

Juday (1907) reported catches of the Lahontan cutthroat trout in Lake Tahoe. At the turn of the century, a commercial fishery shipped thousands of kilograms of this trout each year, but presently this native trout is extinct because of overfishing, destruction of its habitat, introductions of exotic species, and limitations of access to its tributary spawning areas. The other subspecies of Great Basin cutthroat trout included the Paiute trout, native to only one tributary of the East Fork of the Carson River of the Lahontan basin (Behnke 1976). (The bull trout and the Columbia River squawfish did not become established in the Great Basin.) Lake, rainbow, and brown trout introduced before 1900 were well established in Lake Tahoe by the 1930's and probably helped seal the fate of the cutthroat population. In an unsuccessful effort to restore the fishery, the California Department of Fish and Game planted nearly one million fingerling and yearling cutthroat trout in Lake Tahoe between 1956 and 1962. The failure of this effort suggests that the niche formerly filled by cutthroat trout was already occupied by non-native trout.

Walker Lake also contained giant Lahontan cutthroat trout and supported a commercial fishery. Each spring, great schools of trout moved upriver to spawn in Bridgeport and Antelope Valleys. This fishery began to decline in 1911 and the last good runs occurred in the 1920's and 1930's. Bridgeport Dam, Topaz Diversion, and Weber Dam blocked spawning migrations and introduced rainbow, brown, and brook trout displaced the resident cutthroat in most tributaries of the Walker River.

Stream populations of Lahontan cutthroat trout were not able to coexist with other species of trout. In the Carson River system, non-native trout introduced in the 1880's displaced the native cutthroat trout within a few decades.

Subjective evaluation by Coffin (1982) estimates that of the 3,975 km of the Humboldt River basin, 90% were once occupied by Lahontan cutthroat trout. Today, Lahontan cutthroat trout still live in headwater tributaries of the Humboldt River, but in only 12% of its historic range (Coffin 1982). The Walker River system contains one tiny tributary with a native cutthroat population. Within the Carson River drainage, Lahontan cutthroat trout populations, resulting from early day trout stocking, live in several tributaries above impassable falls. In the Truckee system, only Independence Lake supports a small native cutthroat trout population. As a result of human activity, Lahontan cutthroat trout have been eliminated from 95% of their native habitat (Coffin 1982). The trout was listed as an endangered species in 1970 under the Endangered Species Act, but was reclassified as a threatened species in 1975 so that it could be taken in the popular sports fishery at Pyramid Lake.

b. Present conditions. Numerous species of fish now live in the Great Basin (Table 22) because of continuous indiscriminant fish stocking. Some, such as rainbow and lake trout, were probably beneficial for the recreational fishery, but many other species, such as carp, were detrimental. Present day fisheries have little resemblance to those of the past, nor do the fish used by the Indians for food resemble those which existed during the Pleistocene.

Some species, such as the Lahontan cutthroat trout, have evolved to meet the Great Basin conditions and have survived in spite of natural and artificial constraints. Many species of fishes are endemic to the Great Basin, the Bonneville basin has 67% endemics and the Lahontan, 78%.

Early changes in the ichthyofauna of the Great Basin by Europeans were strictly for food purposes (i.e., carp), but these changes do not fit well with today's emphasis on recreational quality fish. Table 23 lists fish species that were stocked in the Great Basin but did not survive. The Lahontan cutthroat trout of natural Walker Lake held on until 1948 when irrigation divisions no longer provided flows sufficient for reproduction. Today a significant part of Great Basin fish population is supplemented by hatcheries, because of degraded habitats. For example, the present day Pyramid Lake cutthroat fishery is maintained almost entirely through hatchery stocking. The population of Walker Lake is also maintained by hatchery propagation.

Great Basin streams have fertile waters capable of supporting high fish numbers perunit area. These waters have much more potential than stream waters in surrounding areas, such as the batholith parts of the Northern Rocky Mountains to the north and the Sierra Mountains to the west.

Table 23. A list of fishes by common name introduced into the Great Basin but no longer surviving (from Sigler and Sigler 1987).

American eel
American shad
Lake whitefish
Chum salmon
Coho salmon
Chinook salmon
Delta smelt
Sebago salmon
Steelhead trout
Hornyhead chub
Golden shiner
Emerald shiner
Common shiner
Sand shiner
Bluntnose minnow
Bullhead minnow
Blacknose dace
Creek chub
Tench
White sucker
Logperch
Brook stickleback
Rock bass
Trout-perch

The native Lahontan cutthroat trout of the Humboldt River drainage fared better than trout in the Truckee-Walker River drainages because it was more specialized for stream life and adapted to the harsh flood/drought cycle of the arid region (Behnke and Zarn 1976). Platts and Nelson (1983) found dramatic fluctuations in weights, lengths, numbers, and conditions of a native population of Lahontan cutthroat trout in Gance Creek within the Humboldt River Drainage. They state that such fluctuations and the ability to survive under a highly changeable environment present ecological evidence that the Lahontan Basin native cutthroat trout should be divided into two subspecific taxa: the Lahontan and the Humboldt cutthroat trout. Pure populations of the Lahontan cutthroat trout exist in about 20 streams in the Humboldt River Drainage. The wide ranges of fish density and biomass demonstrate the highly variable conditions in this drainage (Table 24). The Salmon Falls Creek drainage also shows the same pattern.

1. Bonneville basin. Great Salt Lake, as mentioned before, is a remnant of historic Lake Bonneville and has become too saline to sustain fish life. Other remnants of Lake Bonneville, including Utah and Bear Lakes as well as streams draining the basin, do contain fish populations. Many species of fish from Lake Bonneville still live in the basin and in the Lahontan basin, indicating a possible connection between the two ancient lakes. Richardsonius (a minnow) and Chasmistes (a sucker) are present in both basins, as are high-elevation fishes the mountain whitefish, cutthroat trout, speckled dace, and Paiute sculpin. The tui chub in the Lahontan basin and the Utah chub in the Bonneville basin are of the same genus (Gila). The presence of similar genera and species suggests that some species were common at the formation of the Great Basin. Table 25 lists the salmonid fish density and biomass from selected streams in the Bonneville Basin.

2. Lahontan basin. Pyramid Lake is presently mesoligotrophic but still supports a highly productive fishery. The

Table 24. Density and biomass of trout in the streams in the Great Basin parts of Nevada.

Drainage/site	Density (fish/m^2)		Biomass (g/m^2)		Species
	range	mean	range	mean	
Humboldt River					
Chimney Creek	(0.06 to 0.6)	0.34	(1.9 to 3.2)	2.2	Humboldt cutthroat
Conners Creek	(0.11 to 0.26)	0.18	---	-	Lahontan cutthroat
Cutt Creek	(0.07 to 10.8)	3.6	---	-	Lahontan cutthroat
Draw Creek	(0.25 to 1.7)	0.76	---	-	
Gance Creek	(0.02 to 0.10)	0.06	(4.2 to 13.6)	8.9	Humboldt cutthroat
Marys River	(0.001 to 0.02)	0.007	---	-	Lahontan cutthroat
Tabor Creek	(0.05 to 0.63)	0.23	(1.3 to 15.5)	6.0	Rainbow
Wildcat Creek	---	0.95	---	-	Lahontan cutthroat
Camp Creek	(0.01 to 0.18)	0.09	---	-	Rainbow
Salmon Falls					
Cottonwood Creek	(0.01 to 0.25)	0.08	---	-	Rainbow
N.F. Cottonwood Creek					
Deer Creek	(0.008 to 0.21)	0.09	---	-	Brook
Salmon Falls Creek	(0.002 to 0.04)	0.02	---	-	Rainbow
Sun Creek	(0 to 0.62)	0.18	---	-	Rainbow

Table 25. Salmonid fish species, density, and biomass for selected streams in the Bonneville Basin (from U.S. Forest Service Intermountain Station Research files and Utah Department of Natural Resources 1980).

Stream	Species	Density (fish/m^2)		Biomass (g/m^2)	
		range	mean	range	mean
Beaver Creek, UT	Rainbow	(0.08 to 0.09)	0.085	(10.6 to 11.7)	11.1
Big Creek, UT	Brown/Rainbow/ Cutthroat	(0.01 to 0.03)	0.018	(0.2 to 1.3)	0.8
Birch Creek, UT	Brook/Cutthroat		0.17		6.5
Bitter Creek, UT	Brook		0.16		10.5
Dunn Creek, UT	Rainbow		0.12		4.1
Fisher Creek, UT	Rainbow		0.39		8.0
Lost Creek, UT	Brown		0.02	(2.4 to 8.4)	7.8
Otter Creek, UT	Brown/Rainbow/ Cutthroat	(0.018 to 1.1)	0.17	(5.3 to 6.4)	5.0
Pine Creek, UT	Rainbow	(0.05 to 0.08)	0.65		5.8

two most important management problems at Pyramid Lake are prevention of desiccation of the lake and provision of a constant source of trout for stocking (La Rivers 1962). Originally, native Lahontan cutthroat trout, cui-ui, and tui chub were the only food fishes found in the lake, but with the extinction of the native trout in the 1930's, rainbow and cutthroat trout were introduced. Lack of sufficient inflowing water in Walker Lake virtually eliminates natural spawning trout (La Rivers 1962), producing high alkalinity and/or salinity so that only a cutthroat trout fishery can be maintained. Lahontan Reservoir has a well-established population of warm-water fish.

The Lahontan cutthroat trout is the most valued native fish in the basin. It achieved its great differentiation from all other subspecies of <u>Salmo</u> <u>clarki</u> during its long physical isolation in the Lahontan Basin, with the resulting evolutionary selection for lacustrine specialization in pluvial Lake Lahontan (Behnke and Zarn 1976). The original population of Lahontan cutthroat trout is now extinct in Pyramid Lake, which produced the largest specimens on record. It has been greatly decreased in Lake Tahoe and may no longer exist in Walker Lake. The last holdout is Summit Lake, Nevada, where it is the only salmonid present and persists in large numbers because of the difficult access.

The redband trout, also an endemic <u>Salmo</u> species, is found in many places within the basin. Table 26 lists the salmonid fish density and biomass the selected streams in the Lahontan Basin.

Sixty percent of the endangered fishes in the United States are endemic to the arid states of Nevada, Utah, Arizona, and New Mexico. The endangered cui-ui also is of great social importance to the Paiute Indians living around Pyramid Lake who continue to foster its comeback. Isolated and endangered species of pupfish (<u>Cyprinodon</u>) represent remnants of large Lahontan Lake populations. Lesser known varieties of native suckers and minnows are also threatened and endangered by water diversions, habitat destruction, and introduction of exotic species.

3. <u>Humboldt River drainage.</u> Approximately 327 streams in the Humboldt River

Table 26. Salmonid fish species, density, and biomass for selected streams in the Lahontan Basin (from U.S. Forest Service Intermountain Station Research files and from Nevada Department of Natural Resources files).

Stream	Species	Density (fish/m^2)	Biomass (g/m^2)
N. Fork Humboldt River	Ct/Bk	0.06	2.2
Pratt Creek, NV	Bk	0.02	0.7
N.Fork Pratt Creek, NV	Bk	0.03	0.5
Deep Creek, NV	Rb	0.19	2.2
Boyd Creek, NV	Rb	0.49	1.0
Jack Creek, NV	Rb/Bk	0.38	5.4
Murphy Creek, NV	Bk	0.09	1.2
Cave Creek, NV	Bk	0.11	0.1
Waterpipe Canyon, NV	Rb	0.21	1.1
Kelley Creek, NV	Rb/Bk	0.35	4.8
Toe Jam Creek, NV	Ct	0.19	7.6
Thomas Creek, NV	Bk	0.02	0.3
Rattlesnake Creek, NV	Bk/Ct	0.12	3.3
Brown Creek, NV	Bk	0.11	2.9
Mitchell Creek, NV	Ct	0.21	12.7

drainage, having 3,975 km of stream channel, have been identified. A total of 176 of these streams, encompassing 1,604 stream kilometers, have been identified as containing fishable resident salmonid populations. Sixty Lahontan cutthroat streams, with 365 km of occupied habitat in eight of the subbasins of the Humboldt River and some interior basins, have been identified.

The west face of the Ruby Mountains and East Humboldt Range in Elko County show the most significant impact of past trout stocking practices. Displacement of native cutthroat trout by other salmonids, principally the eastern brook trout, is a major concern in this area. Of 48 fishable streams along the west face of the Ruby Mountain range, 22 are 100% brooktrout waters; 15 have mostly brook and a few cutthroat; and 6 have a mixture of brook, brown, rainbow, and cutthroat. Within the Rock Creek, Maggie Creek, Marys River, and North Fork Humboldt River subbasins, most of the streams have well-established populations of cutthroat trout with only minor evidence of hybridization or displacement. (Most of the discussion on the Humboldt River Drainage is taken from Coffin [1982]).

4. Death Valley basin. Death Valley and the surrounding area are known for the evolution of uniquely specialized species of fish. The Owens pupfish, the Devils Hole pupfish, and the Amargosa pupfish differentiated at certain restricted locations. Saratoga Springs and Devils Hole in Ash Meadows contain isolated populations of the Devils Hole pupfish, an endangered species. The highly saline, often warm, and alkaline waters of Death Valley are particularly suited to the killifish family, to which these unique fish belong. In the water-filled Devils Hole fissure, which has less than 10 m^2 of water surface area, they number about 800 in the summer and 200 in the winter.

4.2.5 Trophic Relationships

The diets of aquatic animals provide valuable clues to an important set of interactions occurring within aquatic ecosystems. Assessment of both the kinds and amounts of foods eaten is necessary for an adequate understanding of the roles of individual species in the biotic community as well as the impact of these species on other members of the community. In addition, such information is of critical importance for proper evaluation of the flow of energy in a given ecosystem. In many aquatic habitats, the bottom-dwelling invertebrates play an important role in the food conversion processes resulting in products of interest to humans, or which are necessary for the functioning of the ecosystem. This is especially true in streams where the operation of such ecosystems is dependent on benthic invertebrates.

Koslucher and Minshall (1973) determined the food relationships of several numerically important invertebrates inhabiting Deep Creek, Idaho-Utah, a northern Great Basin (Bonneville hydrographic basin) desert stream. An assortment of diatoms (Bacillariophyceae) and the filamentous alga Cladophora glomerata (Chlorophyta) were the only important living constituents in the diets of the herbivores. No aquatic vascular plant material was found in the diet, even when it was abundant in the stream. Plant detritus was the other important food for the herbivores. Of eight invertebrate species studied in detail, five were herbivores: Hyalella azteca (Amphipoda), Baetis tricaudatus and Tricorythodes minutus (Ephemeroptera), Hydropsyche occidentalis (Trichoptera), and Simulium argus (Diptera). Three others, Argia vivida, Enallagma anna, and Ophiogomphus severus (Odonata) consistently were carnivorous. Other groups studied less extensively included the herbivores Gammarus lacustris (Amphipoda), Sigara sp. (Hemiptera), Optioservus divergens (Coleoptera), Limnephilus frijole (Trichoptera), Chironomidae (Diptera), and the omnivore Pacifastacus gambelli (Decapoda). There were no evident differences between size of the animals and the kinds of foods eaten nor between time of the year and diet. In general, the invertebrate animals in Deep Creek were opportunistic and fed in proportion to the foods present.

All of the Hydropsyche occidentalis larvae examined from Deep Creek contained only plant material. However, specimens from Deep Creek held in captivity are known to be cannibalistic, and several other investigators have observed considerable amounts of animal matter in other species of Hydropsyche. Therefore, it is likely that H. occidentalis takes animal prey under certain circumstances, but that this generally is not the case under the conditions of abundant plant matter found in Deep Creek. In general, H. occidentalis was found to ingest more diatoms than detritus; only once was a greater amount of detritus found.

Baetis tricaudatus frequently ate about as much detritus as it did diatoms, but on several occasions the amount of detritus ingested greatly exceeded that of the diatoms. Tricorythodes minutus, another mayfly from Deep Creek, consistently ate more detritus than anything else. Simulium argus larvae in Deep Creek ate both detritus and diatoms more or less indiscriminately; only in about half the samples was more detritus found than diatoms.

Hyalella azteca in lentic waters feeds on the epiphytic growth on rooted aquatic plants, on dead animal and plant matter, and often on live plant material such as filamentous green algae (Cooper 1965). In Deep Creek, H. azteca normally was a detritivore, but it also consumed substantial amounts of diatoms. On three occasions (twice in the autumn and once in the summer) bits of filamentous algae were found.

Animal remains were always present in Argia vivida, Enallagma anna, and Ophiogomphus severus; some detritus and diatoms were always present also, but these could have been ingested during feeding or could have been in the prey. Hyalella azteca, Hydropsyche occidentalis, and Simulium argus were the predominant prey, but the remains of several other taxa were found in the three Odonate carnivores. Somewhat surprisingly, no Chironomidae were found in the gut samples of the carnivores. It is also noteworthy that only Enallagma anna was found to eat Baetis. Both Argia vivida and Ophiogomphus severus consumed E. anna.

Diatoms and detritus were found to provide the main food base at the primary producer level. In Deep Creek, unlike many other streams that have been studied (Minshall 1967), detritus appears to be derived largely from autochthonous sources. The contribution from the surrounding watershed (other than from livestock manure) is relatively insignificant. An important terminal role is indicated for the three Odonata (Argia vivida, Enallagma anna, and Ophiogomphus severus), the crayfish (Pacifastacus gambelli), and the dace (Rhinichthys osculus). The absence of a tertiary consumer level is noteworthy and may be common to small streams (Minshall 1967). Apparently no previous studies of streams have been done in whch Odonata were among the principal predators.

Gray and Ward (1979) conducted a comparable study of the food habits of 17 species of macroinvertebrates in Piceance Creek, northwestern Colorado. Although Piceance Creek is in the Colorado River Basin, the findings are directly applicable to the Great Basin because of a similarity in watershed type (sagebrush/pinyon-juniper steppe) and invertebrate fauna. The macroinvertebrates found in Piceance Creek are common to many Rocky Mountain streams that flow into the Great Basin.

Baetis tricaudatus, Ephemerella inermis, Capnia, Glossosoma ventrale, Limnophora, all taxa of chironomids examined, and tubificid worms were found to be small-particle herbivore-detritivores. The majority of particles ingested were less than 250 μm (usually less than 100 μm) in longest dimension and were composed mainly of detritus and diatoms. Occasionally, filamentous algae were a significant component of the gut contents of the chironomid Pseudodiamesa and of Capnia. Food ingested by herbivore-detritivores averaged 75% detritus, 22% diatoms, and 5% filamentous algae. Tipula commiscibilis and Hesperophylax consimilis ingested primarily detrital particles greater than 1 mm in longest dimension and thus were considered "shredders" or large-particle feeders. Although both species regularly consumed filamentous algae, this food item made up less than 20% of the total diet. Isoperla patricia was the most common invertebrate predator. Hydropsyche oslari was cosmopolitan in food habits, but it was primarily a large-particle herbivore-detritivore with carnivory exhibited only in late instars.

Only Isoperla and Hydropsyche showed significant size class differences in the composition of food ingested. No aquatic vascular plant materials were found in the species examined. Filamentous algae, although abundant at one location, were extensively utilized only as new growths or as decomposing fragments. However, epiphytic diatoms, which extensively colonized algal filaments and vascular plant surfaces, were an important food item.

The food habits of the mayfly Callibaetis in Rattlesnake Springs, Washington, were analyzed by Cushing and Rader (1982). The number of organic detritus particles per nymph ranged from 3,270 to 17,600 and varied in size from 111 μm to 230 μm. The particles composed 95% to 100% of the material present by number. Diatoms made up 1% to 5%, and insect parts probably ingested by chance made up less than 1%. The calculated volume of the particles ranged from 7.6 to 22.3 mm^3.

As reported by Minshall et al. (1973), R. Dunn analyzed the gut contents of the speckled dace (Rhinichthys osculus) from Deep Creek station 2 in October 1972. Hyalella azteca made up the greatest percentage of the diet of R. osculus by weight and numbers in both size classes. By weight, Hyalella azteca made up 70% of the diet of the 0- to 40-mm size class (≈0- to 2-yr age class) and 33% in the 41- to 60-mm size class (≈2 to 3-yr age class). Numerically, chironomids were next in both size classes but formed a low percentage of the diet by weight. By weight, Simulium was second in both groups, forming 11% of the diet in the 0- to 40-mm size class and 15% in the 41- to 60-mm group. Hyalella azteca, Simulium argus, and Chironomidae made up nearly 91% of the diet (by weight) of the 0- to 40-mm size class while composing only 34% of the bottom fauna. In the 41- to 60-mm size class, Hyalella azteca, Simulium argus, Tricorythodes minutus, and Baetis tricaudatus made up 75% of the diet. Altogether, 13 aquatic and one terrestrial taxa were utilized. Six common aquatic taxa were not utilized.

Fleener (1951) examined the foods eaten by cutthroat trout in the Logan River, Utah, over a 2-year period that covered 11 different months. Logan River cutthroat trout ate almost entirely insects, the bulk of which were Ephemeroptera and Trichoptera. Fish were the only vertebrate species taken, and the two occurrences noted were cutthroat trout. The amount of plant material was negligible. Almost no fish eggs entered the diet.

Zarbock (1951) studied the food habits of the Utah sculpin from the same river in eight different months. The diet consisted primarily of insects, with plant material, fish, stones, and occasionally wood. Most of the aquatic insects were Diptera. All of the fish eaten were young sculpins. A total of three trout eggs and two sculpin eggs was found but constituted only a very small percentage of the total food consumed. Species of Diptera occurred more often in January-March than in June-August or September-October. The lower percentage of volume compared to numbers is due in part to the small size of Chironomus and Simulium. Many of the stomachs analyzed during this period contained Chironomus larvae only, with total individual counts sometimes as high as 40. Tanytarsus was taken occasionally, with the percentage being highest during September and October. Simulium were eaten by few fish but numbered up to 50 or more when present in the stomach contents.

Moyle and Vondracek (1985) conducted a cursory examination of the feeding habits of resident fishes in Martis Creek (Placer and Nevada Counties, CA) a tributary of the Truckee River. They found little feeding during winter (December 1982); 70% of the 56 fish examined had empty stomachs and the remainder had only small quantities of algae and insect larvae. In summer (August 1982, 1983) all species except the Tahoe sucker fed exclusively or mainly on aquatic insects. Tahoe sucker adults ate principally algae and detritus (83%) and the juveniles ate Cladocera (64%). Paiute sculpin showed a preference for Ephemeroptera (57%) and Lahontan redside favored Diptera. Speckled dace, rainbow trout, and brown trout all tended to eat the full range of insects present.

CHAPTER 5. PRODUCTION AND CARBON FLUX IN GREAT BASIN AQUATIC ECOSYSTEMS

5.1 LITTER INPUT AND PROCESSING

Values of terrestrial litterfall into aquatic habitats for the entire western United States, exclusive of the west Pacific Northwest, are lacking. Only one published estimate of litterfall of the Great Basin was found (Minshall 1978). Deep Creek, a small stream in the northern cool desert of the Great Basin, receives allochthonous inputs of 2-60 kcal/m^2/yr mainly from sagebrush and grass. Snively Creek, another cool-desert stream, but located outside the Great Basin hydrographic region in south-central Washington, receives 206-231 g DW/m^2/yr (925-1040 kcal/m^2/yr) litterfall in the perennial sections of the stream, which has a dense riparian community of willow (Salix) and wild rose (Rosa) (Cushing 1987). In intermittent sections of the stream, where the riparian community was sparse and consisted mainly of grasses, normal litterfall was 27-72 g DW/m^2/yr (121-324 kcal/m^2/yr). An additional 50% to 70% allochthonous organic matter input to Snively Creek, in the perennial and intermittent sections respectively, was derived from wind-blown materials.

The decomposition of allochthonous detritus in stream ecosystems has been shown to be a function of both physical effects (i.e., temperature and current) and biological effects (i.e., microbial and macroinvertebrate feeding) (Anderson and Sedell 1979). Macroinvertebrate shredders that feed directly on leaf litter in streams have been estimated to account for 20% of total leaf decomposition (Cummins and Klug 1979). In the process of shredding leaves, they not only provide themselves with nutrients, but convert coarse particulate organic matter (CPOM) to fine particulate organic matter (FPOM) and thus provide an energy source for fine particulate detritivores or collectors (Cummins and Klug 1979). On the other hand, they may have an effect on species which use leaf packs as habitat or which graze periphyton from leaf surfaces. Barnes et al. (1986) documented the importance of large shredders in the decomposition of leaves in a Great Basin mountain stream in Utah (Stewart's Creek) and a cold desert (sagebrush-steppe) stream in Washington (Rattlesnake Springs). Significantly higher processing rates were found in the leaf packs exposed to shredder processing than in those from which shredders were excluded by a 1-mm mesh screen. Furthermore, the processing rates in both control and exclusion packs in the cold desert stream were higher than their counterparts in the mountain stream. This was attributed partly to the type of shredders present in the desert stream (Gammarus vs. Zapada cinctipes), but mainly to the higher mean water temperature (20-22 °C versus 6-9 °C) during the experimental period which probably increased microbial processing.

Oberndorfer et al. (1984) studied the effect of the predators Megarcys signata (Plecoptera: Perlodidae) and Rhyacophila sp. (Trichoptera: Rhyacophilidae) on the abundance of macroinvertebrates and the rates of leaf processing in leaf packs, using manipulative field experiments. Predators were confined within artificially constructed leaf packs in Stewart's Creek, Utah, an alpine third-order tributary to the North Fork of the Provo River. Both predators significantly reduced the rate of breakdown of leaves in the fall, but had no effect in late winter when the most important shredder, Zapada cinctipes (Plecoptera: Nemouridae), emerges. Predation on shredders caused a reduction in breakdown rates and an increase in the residence time of the leaf litter in the stream. In experimental treatments where predators significantly reduced the numbers of shredders and decreased the rate of leaf processing, leaf pack half-life increased an average of 10.3 days. These experiments demonstrate that invertebrate shredders can contribute substantially to the rate of leaf processing in streams.

5.2 PRIMARY PRODUCTIVITY

The rate of production of organic matter by aquatic plants has been measured in a variety of habitats in the Great Basin, ranging from mountain streams to large lakes. However, measurements for a particular type of habitat, especially in numbers permitting reliable estimates for an entire year, are quite sparse.

McConnell and Sigler (1959) estimated primary productivity in the canyon section of the Logan River, Utah, by correlating the chlorophyll content of periphyton standing crops during the year with oxygen changes measured in closed glass containers. Because of a lack of current and water replacement, the measured oxygen values (x = 0.95; range 0.07-2.7 mg O_2/h/mg chlorophyll a) were suspect; therefore a value of 1.5 mg O_2/h/mg chlorophyll a was arbitrarily applied to derive a value of 406,125 kg O_2 for the 31.7-ha canyon section of river bottom or 1.3 kg $O_2/m^2/yr$ (3.6 g/m/d). This converts to 356 g C at a photosynthetic quotient (PQ) of 1.25 or 3,560 kcal/m^2/d and 9.8 kcal/m^2/d. Thomas and O'Connell obtained gross primary productivity values ranging from 4.7 to 16.5 g $O_2/m^2/d$ (12.9-45 kcal/m^2/d) at various locations over an 8-km stretch of the Truckee River near Reno, Nevada, during August 1963. The mean for the 8-km stretch was 9.5. Mean community respiration for the entire study reach was 11.4, with a range of 4.8 to 17.7 g $O_2/m^2/d$ for the individual sites. Mean community respiration corrected for waste effluent oxidation yielded a P/R ratio of 1.3 with values for areas of least and peak activity amounting to 1.2 and 2.1 respectively. In Deep Creek, Idaho, mean annual gross primary productivity values ranged from 8.6 to 33 kcal/m^2/d over stations 1 through 3 (Minshall 1978). Community respiration and P/R ratio at station 3 was 33 kcal/m^2/d and 1.18, respectively (Cummins et al. 1983).

Cushing and Wolf (1984) measured primary productivity and respiration in Rattlesnake Springs, Washington. Rattlesnake Springs is a small spring-fed stream on the U.S. Department of Energy's Hanford Reservation in the northerly extension of the cold--desert physiographic province. Base flow is 0.01 m^3/s and the stream gradient is 2%. Mean annual precipitation in this shrub-steppe desert region is about 14 cm. Mean annual total alkalinity of $CaCO_3$, NO_3-N, and PO_4-P is 127, 0.3, and 0.18 mg/L, respectively. Peach leaf willow (Salix amygdaloides) dominates the riparian vegetation. Autotrophic constituents are primarily periphyton, (mostly diatoms of which Achnanthes lanceolata, Gomphonema intricatum, and Melosira varians are the most abundant) and watercress (Rorippa nasturtium-aquatica). Isolated patches of Scirpus sp., Eleocharis sp., and Typha latifolia occupied less than 5% of the stream area.

Net periphyton primary productivity (P_n) in Rattlesnake Springs averaged 98 kcal/m^2/d during the study period and was highest in spring (range = 2-24 kcal/m^2/d) (original values converted to kilocalories using conversion of 10.9 kcal/g C). Daily periphyton gross productivity (P_g) averaged about 95 kcal/m^2/d. Net watercress primary productivity was estimated for the area covered by watercress and the total stream area. For the growing season, net primary productivity rates averaged 3 kcal/m^2/d for both the watercress-covered area and total stream area. Using the very rough estimate that 50% of gross production is expended as respiration, the gross production of the watercress would be essentially double the net production. Gross productivity averaged 7 kcal/m^2/d for both the watercress-covered area and total stream area. Periphyton net photosynthetic efficiency averaged about 0.22% for the study period and was highest in early spring, before extensive watercress growth and in fall. Watercress net photosynthetic efficiency averaged about 0.07% expressed either as watercress-covered area or as total stream area. High spring, early summers, and fall efficiencies were found, with a marked midsummer depression.

A peak in community gross productivity occurred in spring and corresponded to the maximum periphyton standing crop. The highest level of activity, 174.4 kcal/m^2/d, was measured in late summer, which corresponded to the exponential increase in the standing crop of watercress. Annual total gross primary productivity amounted to 29,000 kcal/m^2/yr of which about 94% was attributed to periphyton and 6% to watercress. Daily community gross productivity averaged about 101 kcal/m^2/d. Community respiration rates (R) closely paralleled the gross primary productivity rates. The late summer increase in respiration rates coincided with both the increase in watercress standing crop and an increase in invertebrate biomass. Average daily respiration rates ranged from 63% of gross primary productivity in November to 100% of gross primary productivity in September. The average was about 86% for the study period. Lowest percentages occurred during months when periphytic activity was highest, and watercress and invertebrate biomass were low. Annual community respiration amounted to 24,600 kcal/m^2/yr, of which about 96% was attributable to periphyton and 4% to watercress.

Net primary productivity was positive at all times of the year, except during September when it was essentially zero, which indicates that Rattlesnake Springs is an autotrophic system producing more organic matter than it consumes, at least in this study for this time period. The P:R ratio (P_g: 24-h R) for the system on an annual basis was 1.20 (originally published as 1.38 in Cushing and Wolf 1982). Net productivity rates peaked in spring and fall. Annual net primary productivity amounted to about 4,800 kcal/m^2/yr of which 20% was from water cress and 80% from periphyton. Annual daily P_n averaged about 13 kcal/m^2/d.

Naiman (1976) determined the productivity of Tecopa Bore in Death Valley, California, a small (2.3 to 6.7 m^3/min) thermal spring adjacent to the Great Basin. May was the most productive month, averaging 45 kcal/m^2/d, and December the least productive with 11 (original values converted to kcal using conversion of 9.33 kcal g C). Data from all other months formed a tight clump midway between these two extremes. In productive months, station-to-station productivity varied considerably. Mean annual productivity was similar from station to station (about 33 kcal/m^2/d) except that the 45 °C water and constant supply of essential nutrients near the source and cooler (23 to 35 °C) water and shading by saltgrass near the terminus resulted in the highest ($x = 45$ kcal/m^2/d) and lowest ($x = 19$ kcal/m^2/d) values respectively.

Algal mats at Tecopa Bore fixed an average of 11,065 kcal/m^2/yr. The stream receives 1,629,000 kcal/m^2/yr of solar energy with a gross photosynthetic efficiency of 0.68%. When total annual solar radiation is corrected for photosynthetic spectrum and reflection (757,488 kcal/m^2/yr input), the photosynthetic efficiency becomes 1.46%. The high primary productivity of Tecopa Bore was comparable to that of other thermal systems. Most reported rates fell between 3.7 and 27.4 kcal/m^2/d. The slightly higher rates at Tecopa Bore probably resulted from the absence of shading along the stream, a high percentage of clear sunny days, and an ample supply of inorganic nutrients (Naiman 1976).

Results from the above studies give added credence to Minshall's (1978) contention that western streams, including desert streams, have a higher propensity for autotrophic production and depend less on allochthonous carbon sources than eastern woodland streams. The general lack of a canopy and lower input of allochthonous organic matter in desert streams may result in positive net daily metabolism (P_g: 24-h R; see Bott et al. 1978 for a fuller definition) measurements (or P:R ratios exceeding unity) in first- to fourth-order reaches rather than farther downstream, as predicted by the River Continuum Concept (Vannote et al. 1980).

Pyramid Lake's mean annual epilithiphyton gross photosynthesis was 3.0 g O_2/m^2/d and nonplanktonic community respiration within Plexiglas chambers averaged 23% of gross photosynthesis (Galat et al. 1981). Subtracting respiration and converting to carbon gave 721 mg/m^2/d as the estimate of mean 1977 epilithiphyton apparent net photosynthesis. Phytoplankton productivity in late winter and early spring in 1977, as measured monthly at eight limnetic sites by oxygen changes in light and dark bottles, was minimal: 0.73-2.10 g $O_2/m^2/d$ as gross photosynthesis and 1.4-3.9 $kcal/m^2/d$ as apparent net photosynthesis (PQ = 1.2; 10.9 kcal/g C). This period of low primary productivity corresponds to annual lows in surface-water temperatures (6-7 °C), ambient light (200-300 $kcal/m^2/d$), and overall phytoplankton abundance (<100 cells/mL).

Pyramid Lake's mean 1977 gross photosynthesis was 2.42 g $O_2/m^2/d$ ± 7.8% (99% confidence interval). Annual mean light-dark bottle community respiration accounted for 33% of gross photosynthesis, which, when subtracted from gross photosynthesis and the result converted to carbon, equaled 5.5 $kcal/m^2/d$ mean apparent net photosynthesis. Pyramid Lake phytoplankton also exhibited low, mean annual, apparent net photosynthesis per unit volume: 0.5 $kcal/m^2/d$.

Holm-Hansen et al. (1976) measured phytoplankton productivity (mg $C/m^2/d$) in Lake Tahoe in April (240), July (186), and August 1969 (95), and February 1970 (134). Productivity was low in surface waters (<0.1 µg C/L/h) at all four sampling times and maximal at depths ranging from 15-40 m. Primary productivity expressed per unit chlorophyll per day ranged from 0.3-17.5 in the upper 100 m. Surface values were low at all four times; maximal values were around 15-25 m. There was considerable photosynthetic reduction of CO_2 at depths below the euphotic zone, conventionally defined as that depth to which 1% of the surface light energy penetrates (72-86 m). In April, for instance, the rate of photosynthesis between 0 and 6 m varied from 0.01 to 0.05 µg C/L/h, while at 105 m, where the measured incident light was only 0.2% that of surface illumination, the rate was 0.07 µg C/L/h.

Axler et al. (1978) measured the productivity of Big Soda Lake on a day in April 1977. The lake was stratified with a thermocline at 5 m and a chemocline at 37.5 m. The zone below 17.5 m was oxygen deficient (<1 mg O_2/L) and, presumably, could support photosynthetic growth only by anaerobic bacteria or <u>Oscillatoria</u>. The areal productivity for this zone was calculated to be 317 mg $C/m^2/d$ (3.5 kcal). Similar calculations for the aerobic zone yielded a value of 717 mg $C/m^2/d$ (7.8 kcal) (phytoplankton photosynthesis). At all depths, inorganic carbon uptake in dark bottles represented a large percentage of that in light bottles, indicating significant chemosynthetic activity. In the mixolimnion, this is probably due to both nitrifying bacteria and sulfur oxidizing bacteria.

5.3 TRANSPORTED ORGANIC MATTER (SESTON)

Suspended living or dead organic matter (seston) in streams may account for a significant fraction of the energy entering or leaving a stream segment. A large part of consumer production in streams may be based on the presence of organic particles carried in suspension, which is especially evident in the relative abundance of filter-feeders that are uniquely adapted for feeding upon seston particles (Maciolek and Tunzi 1968; McCullough et al. 1979b). Seston contributes secondarily to stream trophic economy when it settles or adheres to the substrate and is utilized there by grazing fauna.

Brock (1980) detailed the annual transport of particulate and dissolved organic matter in Rock Creek, the main headwaters (40 L/s at base flow) of Deep Creek, Idaho-Utah. Annual transport was dominated by 70% fine particulate organic matter (FPOM; 0.45-263 mm) while coarse particulate organic matter (CPOM; >263 mm) was responsible for only 1%. The predominance of FPOM transport in Rock Creek can be attributed to the poor retention of this size particle in the channel. In addition, there was a large supply of fine particles available on the flood plain, as well as in runoff from the sparsely vegetated watershed.

Particulate organic transport paralleled the spring runoff flow pattern. Maximum observed FPOM concentration (59.4 mg/L) coincided with the May discharge peak. FPOM gradually decreased during late spring and summer and reached a minimum in August (0.5 mg/L). Correlation between discharge and FPOM transport was highly significant. When the year was portioned into ascending hydrograph and descending limb periods

(January-June and July-December, respectively), the correlation remained strong for January-June (r^2 = 0.68), but it was not significant during July-December (r^2 = 0.08).

CPOM seston concentrations in Rock Creek (x = 0.2 mg/L) were generally 20-100 times lower than FPOM (x = 7 mg/L). This fraction was predominantly sloughed algae and amorphous detritus. Minimum CPOM transport occurred in mid-October. Maximum values coincided with the initial spring ice breakup, which usually occurs 6-8 weeks before peak runoff. Over the entire year, discharge correlated significantly with CPOM transport at the two sites. As with fine transport, the CPOM versus discharge relationship was significant during January-June, but not significant for July-December. That portion of the CPOM fraction larger than 1 mm ranged from 16%-75%. This large variation followed no obvious seasonal or flow-related pattern. Dissolved organic matter (DOM) concentrations were comparatively constant throughout the 12 months for which reliable data were available (x = 4 mg/L). From a December minimum (1.3 mg/L), a slight but consistent DOM increase was found each month until July. Maximum concentrations were measured in late August. Dissolved organics correlated poorly with discharge when all data from each site were used. Particulate consistently exceeded dissolved organic concentrations during the rising hydrograph period. DOM predominated in late summer and autumn. The mean monthly dissolved: particulate ratios were significantly related to total monthly discharge by a negative exponential function (r^2 = 0.77).

Discharge in Rock Creek follows a predictable pattern, since it is controlled primarily by seasonal and diel melt cycles (Brock 1980). On the ascending limb of the annual hydrograph, particulate transport in Rock Creek is highly correlated with discharge. As flows increase in spring, benthic organic material deposited during low-flow periods is entrained. Scouring by inorganic transport contributes to the particulate organic load carried by the stream. Increased discharge also widens the stream channel, thereby incidentally incorporating organics from the flood plain.

The relationship between discharge (Q) and CPOM concentration during the rising hydrograph period was not as strong as for Q versus FPOM. This may be a result of the more highly variable distribution of both benthic and transported CPOM in streams. During spring 1975, CPOM concentrations peaked and began to decline while FPOM and discharge were still increasing. The lower specific gravity of large organic particles causes them to be entrained at velocities below those present at peak flow. The low coarse: fine ratios obtained in this study (0.019-0.120) indicate that the coarse fraction is minor in terms of the total particulate organic load, but CPOM transport during spring may be significant as a redistribution mechanism of food resources for large-particle consumers. The autumn peak in CPOM transport recorded in deciduous forest streams was not evident in Rock Creek. Occasional clumps of sloughed algae were collected during late summer and autumn. Transport of CPOM in the form of sloughed algae during August-October was reflected in the net loss of CPOM from the system during that period. An upstream monthly coarse-to-fine ratio increase during September-December and a concurrent decrease in the downstream ratio suggests that there was a net reduction in size of particles through the 540-m study reach during September-December.

Unlike POM, DOM concentration fluctuations in Rock Creek during the year were relatively minor. DOM concentrations in Rock Creek were lower and less variable than for streams with more frequent storm events. DOM was responsible for 29% of the total hydrologic export.

The ratio of DOM to POM in Rock Creek was always less than one during the rising hydrograph period due to particulate concentrations rising more rapidly than DOM, although there was a clear pattern of increased DOM concentrations during December-July. Only during autumn were DOM:POM values of 3-5 found. Low DOM:POM ratios were associated with periods of high discharge.

As in Deep Creek, the microscopic component of the seston, or microseston, in many streams constituted most of the suspended organic matter. Maciolek (1966) described the annual pattern of microseston (particles < 0.4 mm) at a single station in Convict Creek (Owens River Drainage), California, 4 km below Convict Lake. Organic detritus was almost always dominant, averaging 60% for the year. Two other groups averaged about 20% each: miscellaneous micro-organisms, which were rather constant, and dominant lake diatoms, which fluctuated from 0% to 50% of the total. It was estimated that only 20% of the microseston was produced directly within the stream. Thirty to forty percent of the allochthonous portion (80%) originated in the lake, and 40%-50% was derived from streamside or more distant terrestrial sources. Detritus was supplied continuously. Without lacustrine contributions, microseston was more than three fourths detritus. Nearer the lake or farther from it, one would expect to encounter a greater or lesser proportion of cellular material respectively. Microseston averaged 0.67 mg/L dry weight (3.24 gcal/L) for the year. Minima on the order of 0.3 mg/L (1.5 gcal/L) occurred in autumn at low water. A maximum of 2.1 mg/L (10.1 gcal/L) was measured in late spring just prior to the runoff peak. Generally, quantitative fluctuations reflected the annual flow pattern, the microseston increasing with initial increases in flow volume. This direct relationship resulted in a large seasonal difference in microseston discharge or the amount passing the sampling site per unit time. Between low flow in November and high runoff in June, microseston concentrations increased less than fivefold, but discharges increased thirtyfold. Filter-feeding invertebrates of Convict Creek have a continuous supply of microseston. The total population of these consumers may be limited by minimum seasonal concentrations of about 0.5 mg/L. High levels exceeding about 1 mg/L, may not be exploited because of the difficulty the organisms encounter maintaining position and feeding in the high-velocity water.

Maciolek and Tunzi (1968) examined the longitudinal distribution and dynamics of microseston during July, August, and October in Laurel Creek (Owens River Valley), California. Headwater and seepage sources in the 6.5-km system contained minimal quantities (< 2 cal/L or 0.5 mg/L dry wt) as detritus. Maximum concentration (> 12 cal/L or nearly 3 mg/L dry wt) appeared in the stream as effluent phytoplankton from the single lake located near the headwaters. A progressive decrease in cellular microseston below the lake was accompanied by an increase in detritus. The cell loss was due mostly to trophic uptake by filter-feeding simuliid larvae, which were capable of removing 60% of the suspended algae within a 0.4-km section of stream. Downstream gain of organic detritus resulted from external contributions (e.g., streamside vegetation), abetted by decompositional processes within the stream, including digestion by aquatic invertebrates. Autochthonous material was considerably less important quantitatively as seston than allochthonous matter (lacustrine and terrestrial). Sedimentation and physiochemical loss were secondary to trophic uptake in seston removal. Destruction of cellular material by turbulent flow was directly proportional to stream gradient and was clearly evident only where there was a prolonged gradient in excess of 5%.

Algal export from Tecopa Bore, CA (Q = 2.3 to 6.7 m^3/min), showed a single prolonged peak from late spring through summer, dropped off sharply in autumn, and remained at a low level until the following spring (Naiman 1976). Algal export varied from 4.2 g AFDW/d on September 30, 1972 to 123.0 on May 30, 1973. The estimated total exported each year from the study area was 14,400 g AFDW. Drift loss, approximated from a caloric equivalent of 4.4 kcal/g AFDW, ranged from 18.3-542.0 kcal/d with a total of 633,600 kcal lost annually. Hence, only 4.8% of the energy fixed within the system was removed in the form of particulate drift. This drift was produced by an area of about 1,400 m^2 and corresponds to an output of 453 kcal/m^2/yr or 4.1% of the average annual net production of that area.

Dissolved organic carbon (DOC) had two peak periods of export at Tecopa Bore, the summer peak from May to August and an autumn and winter peak from September to April (Naiman 1976). The summer peak (3 months) was shorter but of greater magnitude than the winter (7 months). Summer values approached 2,000 g DOC/day, whereas winter rates were nearer 1,000. An estimated total of 279,000 g DOC was exported from the system each year. The

DOC concentration was usually below 3-4 mg/L, but because of the considerable water discharge (about 1.87 x 10^9 L/yr) it became a sizeable energy export. A conversion value of 5 kcal/g DOC gave 1,395,000 kcal/yr lost from the system in this form, which corresponded to 10.6% of the total annual net production and is 2.2 times the loss by particulate drift. This DOC was produced by an area about 1,400 m^2, resulting in a net export of 996 kcal/m^2/yr, or 9.0% of the annual average net production.

Because the Truckee River is the principal water source to Pyramid Lake, its allochthonous contribution of organic matter is of considerable interest. Truckee River total organic carbon (TOC) and nutrient concentrations respond only to very distinct discharge fluctuations (Galat et al. 1981). During years of normal snowpack, April through June is the season of snowmelt in the Sierra Nevada watershed and, therefore, maximum period of Truckee River discharge. As expected, organic matter and nutrient loadings to Pyramid Lake also peak during this season. Pulses of TOC and nutrients were recorded several times during the summer and fall of 1976, in response to precipitation from strong tropical storm systems.

Total organic carbon imported to Pyramid Lake from the Truckee River for the period March-December 1976, totaled 2,551 mg C. Mean 1976 river water TOC concentration at Nixon, Nevada, was 10.9 g C/m^3 and ranged from a low of 2.7 g C/m^3 in November to a high of 19.2 g C/m^3 during April. Truckee River watershed snow depths for 1977 were 70% below normal and resulted in only 167 mg C imported to Pyramid Lake for the entire 12 months. Mean 1977 river-water TOC declined to 4.5 g C/m^3 and fluctuations narrowed to between 2.7 g C/m^3 in September and 8.0 g C/m^3 in October (Galat et al. 1981).

Analysis of the various TOC fractions demonstrated that coarse particulate organic carbon (CPOC, > 1 mm) always constituted less than 1% of the whole. This observation is typical of a large, high-order stream as conceptualized by Vannote et al. (1980). However, low flows definitely accentuated the condition in Pyramid Lake. The fine particulate organic carbon (FPOC) fraction (< 1 mm; retained on Whatman GFF filter) varied greatly with discharge. Only 10%-15% of TOC at discharges of less than 2 m^3/s was FPOC, but FPOC increased to 32% of TOC at a discharge of 36 m^3/s. This maximum concentration was collected from the falling limb of spring discharge and evidence indicated that rising limb FPOC concentrations were higher. Dissolved organic carbon invariably contributed over 65% of TOC loadings to Pyramid Lake.

Anemotrophy is the wind-transported influx of organic matter and nutrients to desertic lakes (Hutchinson 1937). The role anemotrophy may play in Pyramid Lake's energetics persuaded Galat et al. (1981) to investigate the potential carbon input via wind-blown dust and vegetation. Severe wind storms are common in the Great Basin desert and transport tremendous quantities of dust. The amount of carbon entering Pyramid Lake from this source was estimated biweekly at four lake locations between January and April 1977. The year's most frequent and severe dust storms commonly occurred during this season. However, projecting an annual contribution of airborne carbon to Pyramid Lake from this period only may have biased the results. Although large quantities of dust were collected, only 0.3% by weight were carbon. The mean daily influx for the entire lake surface was very small, 36 mg C, prompting the conclusion that the contribution of wind-blown dust to Pyramid Lake's total carbon budget was negligible.

Tumbleweeds (Russian thistle, Salsola kali) are the most numerous Great Basin terrestrial plants transported by wind action. Mature S. kali plants are detached from their roots at ground level by strong winds and tumble across large distances. Salsola kali is Pyramid Lake's most salt-tolerant terrestrial plant and, therefore, occupies recently exposed lake bed. Lakeward from the Salsola community, the terrain grades directly into the open beach.

The largest expanse of recently desiccated Pyramid Lake bed is a remote area (Fox Valley) located north and northwest of the lake. A tumbleweed ground survey conducted over a large portion of Fox Valley in fall 1976 determined that the

Salsola community covered approximately 3,100 ha. After counting all plants on six 0.01-ha plots, the mean density of plants was estimated to be about 17,000 plants/ha, which produced a standing crop of 4,270 mg C. In lieu of a quantitative measure of Fox Valley tumbleweed transport to Pyramid Lake, Galat et al. (1981) conservatively estimated that 51% (2,135 mg C/yr) of Fox Valley's tumbleweed standing crop would eventually enter the lake.

5.4 ORGANIC MATTER BUDGETS

An ecosystem's gross organic matter budget is an accounting of all inputs and losses of organic energy over a specific period, usually one year.

5.4.1 Streams

Brock (1980) determined the annual organic-matter budget for Rock Creek, Idaho-Utah, during a low-runoff year. Since all substantive transfers of organic materials to and from Rock Creek were quantified, a gross budget for the 750 m^2, 540-m long segment ecosystem was formulated (Table 27).

a. Precipitation. Since Rock Creek lacks a tree canopy, organic matter inputs from precipitation to the stream ecosystem

Table 27. Annual gross organic matter (as ash-free dry weight) budget for Rock Creek, Idaho, from June 1974 to May 1975 (from Brock 1980). Values were converted to kilocalories using the conversion 1 g AFDW = 5 kcal.

Input/Output Mechanism	kg/m^2/yr	kcal/m^2/yr	%
Falling			
Total	0.0064	32	0.02
Precipitation	0.0035	17.5	0.01
Litter	0.0029	14.5	0.01
Transport			
Total	35.237	176.2 x 10^3	99.67
DOM	10.16	50.8 x 10^3	28.74
FPOM	24.69	123.5 x 10^3	69.84
CPOM	0.387	1.9 x 10^3	1.09
Biologic			
Total	0.111	555	0.13
+NEP	0.003	15	0.01
Macrophytes	0.108	540	0.30
Total	35.35	176.8 x 10^3	
Transport			
Total	- 35.373	-176.9 x 10^3	99.72
DOM	- 9.83	- 49.2 x 10^3	27.71
FPOM	- 25.13	-125.7 x 103^3	70.84
CPOM	- 0.413	- 2.1 x 10^3	1.16
Biologic			
-NEP	- 0.099	-495 x 10^3	0.28
Total	- 35.47	-177.4 x 10^3	

are equivalent to bulk precipitation received at the site. A formal sampling program for bulk precipitation was not conducted, but the organic content of precipitation samples, determined on three occasions, provided an approximation of annual precipitation concentration. Samples of accumulated water in a precipitation gauge in March 1974 and May 1975 had a total organic matter (OM) content of 6.66 and 9.28 mg/L, respectively. Rainwater collected during a thunderstorm on July 10, 1974, contained 16.88 mg/L DOM. If the mean of the measured values for Rock Creek (10.9 mg/L) was considered representative of bulk precipitation inputs, then annual input from the 30.7 cm of precipitation which fell during the year yielded 3.35 g OM/m^2.

b. Litter. The annual total mean litterfall was 2.93 g OM/m^2 or 2.21 kg OM/system. This estimate is conservative, since it does not include soil that dropped off the degrading banks during spring runoff or inputs from riparian vegetation that blew into the channel below the 1-meter-high litter baskets. Inclusion of this additional organic material probably would only double or triple the estimated input, which is still two orders of magnitude below the characteristic range of forested streams (500-1825 g/m^2/d; Petersen and Cummins 1974).

c. Transported organic matter. As noted earlier, Rock Creek particulate organic transport concentrations generally followed the runoff-dominated discharge pattern. Both coarse and fine particulate concentrations were highly correlated with instantaneous discharge for each site, but the DOM versus discharge relationships were not significant. FPOM was the dominant fraction of total organic transport in this semiarid drainage. CPOM concentrations were 20-100 times lower than FPOM. DOM concentration variance was appreciably lower than particulate variance over the year. From an annual minimum of 1.3 mg/L in December, DOM increased consistently each month until August, when minimum summer flows occurred. Dissolved, fine, and coarse particulate material respectively accounted for 28%, 27%, and 1% of total organic outflow from the stream segment.

Since dissolved and particulate forms of the organic load may be interconvertible by such processes as leaching and particle formation, it is necessary to consider the total organic load (dissolved plus particulate) when applying mass balance approaches to stream segments. Net flux, the difference between upstream and downstream transport for each fraction, showed a distinct loss of total organic matter from the Rock Creek stream segment during spring runoff (April-June). Import exceeded export during all months except July and October, when net change approximated zero. Losses from the segment during runoff were predominantly particulate, whereas dissolved organics were responsible for midsummer system gains. Fine particle inputs consistently exceeded outputs during winter (November-March). The Rock Creek stream segment had a total net loss of 110 kg OM/yr, which is 0.4% of the total organic throughput.

d. Ecosystem metabolism. Benthic respiration, measured on 12 occasions, yielded an oxygen uptake range for Rock Creek of 0.56-1.70 g $O_2/m^2/d$ and a mean of 0.94 g $O_2/m^2/d$ (SE = 0.12) (Brock 1980). A significant relationship existed between respiration and temperature ($r^2 = 0.72$). Net ecosystem productivity was negative during all months except June, implying that the stream segment relied on imported organic material during other periods. The peak in June corresponded to maximum incident solar radiation.

e. Macrophyte production. An estimated 108 g OM/m^2/yr was contributed annually by macrophytes (Brock 1980), which amounted to less than 1% of total inputs to the segment. However, macrophytes contributed 17 times as much material as the combined inputs of litter and precipitation.

f. Annual organic matter budgets. Transport fluxes dominated the gross budget in Rock Creek, contributing more than 99% to both input and output portions (Brock 1980). The usefulness of a stream segment's gross budget is limited by this transported organic component because hydrologic fluxes (kg/ha) must be expressed on an areal basis if they are to be compared with other budget components (Cummins et al. 1983). The magnitude of the transported organic flux varies directly with the segment length chosen. Longer segments with a fixed mass of organic material apportioned over a larger area will have proportionately smaller hydrologic inputs. This dilemma was circumvented in the Rock Creek study by the use of a net budget that evaluated the difference between inputs and outputs of organic energy in an ecosystem. For the year, the Rock Creek segment ecosystem experienced a net loss of 127 g/m^2, primarily by particulate transport, since biologic losses and gains were nearly balanced, and the aerial contributions by litter and precipitation were minute (6 g/m^2/yr).

Brock found that spring runoff was important to the annual organic-matter cycle of Rock Creek. The segment lost organic material during spring runoff period as indicated by a negative <u>net ecosystem efficiency</u> (NEF). Accumulation of organic material took place during each nonrunoff month. In winter, when endogenous photosynthesis was curtailed by snow cover, the segment stored particulate organic material imported from upstream. The presence throughout the year of lush aquatic plant beds in the vicinity of Rock Creek's source springs suggested the probable origin of the material accumulated in the segment during the base flow period. The similarities in shape of the net transport and net ecosystem flux curves indicated the relative importance of transported material to the organic energy dynamics of the creek.

To further clarify the pattern of loss and gain of organic matter over the year, Brock examined cumulative NEF, assuming a zero base level at the first of the year. Organic material accumulated from January-March and the cumulative NEF fell below the zero base level during the April-June degradation period due to partial respiration of the pool of stored organic matter. After runoff, the segment again accumulated organic matter until the following April. In a steadystate ecosystem, the cumulative NEF would be expected to return to zero at the conclusion of the annual cycle. Since Rock Creek experienced a net loss during the study year, it appeared to have been degrading stored organic material. The calculated annual loss of 127 g/m^2 was 2.4% of the estimated standing crop and was equivalent to about three day's loss via transport during summer low discharge and less than one-half day at peak runoff flow. These observations suggest that the Rock Creek ecosystem was fairly well balanced during the study period with regard to organic material. Quantification of organic matter fluxes during years representing the full range of runoff flows is necessary before one can generalize with confidence about the organic matter dynamics of a small desert stream (Cummins et al. 1983). The segment ecosystem of Rock Creek analyzed by Brock appeared to rely largely on upstream sources of energy for its sustenance. Thus, biotic processes in the segment are driven by exogenous organic material. The specific origin of this imported organic energy was not determined for Rock Creek, but the low litter inputs to upstream reaches suggested that this material is autochthonously derived. Therefore, the segment appeared to depend on excess production brought from upstream via transport.

Minshall (1978) published the annual energy budget for Deep Creek, Idaho, at a site (station 3) about 30 km downstream from the one examined by Brock (Table 28). Total energy input at station 3 was almost 130 x 10^3 kcal/m^2/yr higher than its Rock Creek headwaters in the years studied (1970-72 versus 1974-75). Most of the difference was due to the higher (+98.3x10^3 kcal) DOM and slightly higher POM (+17.3x10^3 kcal) loads at Deep Creek station 3. Such differences also occurred with respect to export. However, both systems were net exporters of energy (-24.1x10^3 kcal at Deep Creek and -0.6x10^3 kcal at Rock Creek).

Cushing and Wolf (1982) conducted a similar study in Rattlesnake Springs, Washington (Table 28) and compared their results with those for Deep Creek. Energy flow in Rattlesnake Springs is about an order of magnitude less than either the Deep Creek or Rock Creek sites. Also in contrast, Rattlesnake Springs was a net importer of organic matter. Since storage was essentially zero, the system consumed more organic matter than was produced. In terms of the definitions of Fisher and

Table 28. Annual energy budgets for Deep Creek, Idaho, and Rattlesnake Springs, Washington (modified from Cushing and Wolf 1982).

	Deep Creek		Rattlesnake Springs	
Origin	Kcal/m^2/yr	percent	Kcal/m^2/yr	percent
Import				
POM				
Allochthonous POM	12.2	(tr)	1.2×10^3	3.8
Transport POM	130.5×10^3	46.6	1.5×10^3	4.8
DOM	149.1×10^3	48.7	3.7×10^3	11.6
GPP	14.3×10^3	4.7	25.4×10^3	79.8
Total	306.1×10^3	100.0	31.8×10^3	100.0
Export				
POM				
Watercress + Benthos			1.2×10^3	4.5
Transport POM	169.1×10^3	51.2	1.5×10^3	5.5
DOM	149.1×10^3	45.2	3.2×10^3	11.8
Respiration	12.0×10^3	3.6	21.2×10^3	78.2
Total	330.2×10^3	100.0	27.1×10^3	100.0
Storage	0			
Total	330.2×10^3		27.1×10^3	
Balance (In-Out)	-24.1×10^3		4.7×10^3	

Likens (1973), Rattlesnake Springs was an accretive (net importer) system:

import (I) + gross photosynthesis (GPP)
> ecosystem respiration (R)
+ export (E),

and Deep Creek would be a remissive (net exporter) system (Cushing and Wolf 1982):

$$I + GPP < R + E.$$

Thus a situation exists in which Rattlesnake Springs was a net importing system and Deep Creek a net exporting system, and both have P/R ratios exceeding one.

Naiman (1976) compiled an annual energy budget for Tecopa Bore, California. Solar radiation amounted to 757,500 kcal/m^2/yr. Of the total light energy spectrum, only 46.5 percent was available for photosynthesis. Primary producers fixed 11,000 kcal/m^2/yr (1.46% of the incoming light) and allochthonous detritus was negligible. Thus primary production was the only biotic contributor of energy to the system. The relatively small mean annual standing crop of organic matter (720 kcal/m^2/yr), composed of the autotrophic and heterotrophic communities plus detritus, received the newly transformed energy. It was replaced about 15.4 times a year with a mean turnover time of 23 days.

The largest proportion (80.5%) of the annual primary production in Tecop Bore (obtained by summing all other categories and subtracting from 100%) was metabolized by the autotrophic and heterotrophic communities (8,900 kcal/m^2/yr). This was the major energy pathway out of the system. Dissolved organic carbon represented a significant percentage of the annual energy output; drift of particulate organic matter accounted for much less. Output of energy as DOC was 2.2 times the losses through particulate drift. A total of 13.1% (1,450 kcal/m^2/yr) of the primary production was transported downstream and out of the study area by stream flow (DOC plus POM).

Pupfish ingested an estimated 17.0% (1,880 kcal/m^2/yr) of the annual primary production, but only 6.3% of it was used in growth (gross growth efficiency). Naiman (1976) figured that if pupfish in these warm waters respire about five times the amount used for growth (595 kcal/m^2/yr), then an estimated 10.5% would be lost in the feces and eventually degraded by decomposers. The mean annual standing crop of pupfish (23.6 kcal/m^2) produced 119 kcal/m^2 each year. Therefore, the pupfish population had an annual turnover of about five times with a mean generation time of 72 days or about 2.4 months. This pupfish population appeared to be in a steady state, according to annual trends in population numbers and weight. Thus mortality (1.1%) was assumed to equal production.

5.4.2 Lakes

Phytoplankton productivity was, by far, the leading source of Pyramid Lake's organic carbon (Table 29) (Galat et al. 1981). Periphyton and macrophyte productivity were viewed as insignificant to Pyramid's organic budget because the lake's size and form result in a limited area of near-shore shallow water relative to the overall surface area. This disproportionate shallow zone, combined with the lake's salt content, turbulent sub surface environment, and small area of stable substrate, severely restricted growth of attached plants.

Although epilithiphyton production was negligible compared with limnetic production, it was a highly concentrated energy source. On a unit-area basis, mean annual epilithiphyton gross photosynthesis was slightly greater than limnetic phytoplankton gross photosynthesis, but the depth of limnetic water necessary to achieve the phytoplankton production averaged 11 m compared with 5-10 cm for epilithiphyton. Because benthic algae production is a concentrated, easily available food source for invertebrates and forage fishes, its importance to the lake's trophic dynamics can not be dismissed, even though its contribution to the total food base is small.

A 50% input figure from Fox Valley for Pyramid Lake tumbleweeds (see Section 5.3) would amount to 2.5% of the lake's annual organic budget. However, the figure may not represent the importance of this unique energy source to Pyramid Lake because other recently exposed sites with extensive _Salsola_ communities also are present around the lake.

Organic matter imported to Pyramid Lake from the Truckee River was only 0.2% of the lake's 1977 total budget. However, for the

Table 29. Annual contribution to Pyramid Lake's 1977 organic matter budget by various sources (Galat et al. 1981). Carbon equivalent equals 0.312 O_2.

Source	Mean daily (mg C/m^2)	Annual total (mg C)	Percent of total
Autochthonous apparent net photosynthesis			
Limnetic phytoplankton	506	82,095	97
Littoral epilithiphyton	721	287	0.3
Allochthonous import			
Terrestrial vegetation[a]	-----	2,135	2.5
Wind-blown dust	84	14	0.0
Truckee River	1	167	0.2
Total		84,698	100.0

[a] Assumes 50% of terrestrial biomass enters Pyramid Lake.

last 10 months of 1976, Truckee River TOC import amounted to 18.9 mg C/m^2 of lake surface per day, or 3.5% of estimated limnetic apparent net photosynthesis.

The seasonal timing of Truckee River TOC import might be more crucial to the lake's dynamics than the total annual loading. For example, March 1976 TOC input equaled 26% of that month's phytoplankton apparent net photosynthesis. Though the FPOC fraction was not specifically measured during March 1976, a large part probably was in this form due to moderately high discharge and resultant scouring. The Truckee River's FPOC C:N ratio at Nixon during 1978 and 1979 spring discharge averaged about 6:1 while Pyramid Lake's nonzooplankton euphotic zone seston C:N ratio for May 1978 equaled 9.4:1, illustrating that high-quality food is contributed to Pyramid Lake from the Truckee River. Given the conditions observed during a low-water cycle, Galat et al. (1981) are convinced that during years of normal discharge the Truckee River's spring detrital and nutrient inputs have a pronounced impact on the lake's trophic ecology.

CHAPTER 6. STREAM AND RIPARIAN INTERACTIONS

Stream and riparian habitats are integrated by a myriad of interactive processes. Indeed, the apparent relationships have caused some to suggest that riparian ecosystems should include both stream and riparian habitats. The close affinities may have influenced Cowardin et al. (1979) to define riverine and palustrine wetlands as inclusive of lands 2 m below the low-water level; under this definition, the vast majority of western rivers are technically wetlands.

The fundamental mediums common to both stream and riparian habitats are water and sediments. A simplified discussion of the major processes influencing the flux of water and sediments along the gradients of stream corridors was presented in Section 3.1 (Hierarchical Classification of Riparian Habitat). The availability of water, the principal component of streamflow, in excess of that supplied by direct precipitation has been used to differentiate riparian from upland habitats (Johnson et al. 1984). Riparian habitats are both a source of sediments to streams and a temporary sink for sediments transported by streamflow. A history of the flux of water and sediments often is apparent in the morphology of riparian soils. While a function of streams is the transport of sediments from positions of high topographic relief to positions of lower relief, riparian habitat regulates the flux of sediments along the gradients of watersheds. It is through the flux of water and sediments that the dynamics of a watershed are communicated along the elevational and lateral gradients of stream corridors. Thus it is reasonable that riparian and stream habitats are identified according to hydrographic units at the most fundamental level of hierarchy (see Sections 3.2 and 3.3).

Relationships between streamflow and alluvial ground water are of fundamental importance to both stream and riparian habitats. The relationships between streamflow and alluvial ground water are influenced by the geomorphic form of river valleys; discrete geomorphic features impart additional diversity within a given valley-form (see Section 3.3 - Geomorphic Valley-Forms). Along upper segments of watersheds where streams are commonly gaining (discharge increases in a down stream direction), alluvial aquifers associated with riparian habitat may augment streamflow. Alternately, along lower segments of watersheds where streams are generally losing water (discharge decreases in a downstream direction), alluvial ground water may be augmented at the expense of streamflow. Bank storage during periods of high streamflow also may contribute to the dynamics of hydrologic interactions between stream and riparian habitats. The influence of geomorphic valley-form on the relationships between streamflow and alluvial ground water was the grounds for identification of glacial, fluvial, alluvial and lacustrine valley-forms at the second level of hierarchy (see Section 3.1-Hierarchical Classification of Riparian Habitat).

The flux of water and sediments along the gradients of watersheds is principally responsible for the distribution of contrasting riparian communities and the stream habitat. Fundamentally, both stream and riparian habitats may be perceived as responses to the flux of water and sediments along the gradients of watersheds. While streamflow is the most apparent dynamic force, riparian habitats influence the degree to which streamflow is effective in accomplishing its ordained functions. The perfection to which riparian habitats are effective in regulating the flux of water and sediments along the gradients of watersheds would be improbable, if the effective parameters were not viewed as responses to the same processes that they regulate. Indeed, many of the values of riparian habitat (see Section 3.5) are measures of the degree to which riparian habitats are effective in regulating the forces of streamflow.

The influence of vegetation in riparian and stream habitats has several facets. While plants influence water budgets directly through transpiration, shading of the soil and stream surfaces may indirectly affect water budgets by reducing evaporation. Water "weeds," especially Potamogeton and Cladophora, reduce streamflow velocity. In some instances, aquatic vegetation is so productive that herbicides have been applied to restore streamflow. Riparian vegetation is a major nutrient source to stream habitat (see Chapter 5 - PRODUCTION AND CARBON FLUX IN GREAT BASIN AQUATIC ECOSYSTEMS).

Riparian and stream habitats greatly influence the ecological structure of animal life, including the food chain and the mechanism for disease transmission. Birds, such as kingfishers and swallows, consume significant amounts of aquatic invertebrates; ducks consume large amounts of vegetation and invertebrates from both riparian and aquatic habitats. Many amphibians and insects develop in water but invade the land as adults. Aquatic larvae of several dipterans develop into aerial adult forms that irritate and transmit disease to a variety of terrestrial animals. Blackflies (Simulium) and mosquitos (Culicidae) transmit encephalitis; the Tabanidae (e.g. deerflies, horseflies, etc.) have been implicated in the transmission of tularemia and anthrax. Terrestrial animals influence the aquatic habitat through a complex web of biotic processes of which predation and input of organic matter are only the most apparent.

The severest impacts of the land on aquatic systems have resulted from human activities. In the Great Basin, these include flash flooding and erosion due to overgrazing and farming; removal of water through draining, pumping, and irrigation diversion; removal of phreatophytes and the application of herbicides for "weed" control; returns of irrigation waters with high nutrient, salt, pesticide, and sediment loads; and disturbance by cattle and sheep. Over razing, pollution, river impoundment, dredging, ditching, pumping of ground water, and the introduction of exotic species have been extremely important factors in aquatic habitat modification in the Great Basin and in the resultant alteration of faunas. More recently, oil shale, coal, and mineral extraction have further impacted Great Basin streams. Virtually nothing is known of the condition of these ecosystems prior to their alteration or destruction.

Human impacts on Great Basin streams are largely a result of intensive use for irrigated farming and livestock raising, although in some areas, hydroelectric generation, municipal water supply, and waste disposal also are important. The problems associated with these primary impacts include: (1) thermal addition due to impoundment, removal of streamside vegetative cover, irrigation return water, and power generation; (2) streamflow and water-level fluctuations induced as a result of power peaking, irrigation diversion, and pumping of aquifers; (3) nutrient enrichment by runoff from fields, irrigation return flows, livestock wastes, and sewage treatment plants; (4) sediment input from erosion; (5) control of aquatic and riparian vegetation, including the use of herbicides, and (6) alteration of channels by sedimentation, channeling, and dredging. These factors have severely reduced the populations of many of the fishes in the Great Basin. Additionally, dams have blocked spawning runs and eliminated upstream rearing areas, and the indiscriminant stocking of exotic fishes has replaced many native species through competition and introduced disease.

6.1 LIVESTOCK GRAZING

Range animals tend to congregate in or near the limited watering sites. They eat, trample, and otherwise destroy the protective riparian vegetation and contribute to streambank erosion. They eat aquatic plants and reduce primary productivity by stirring up sediments. These sediments also reduce the numbers of invertebrates and fish. Livestock also may add substantial amounts of nutrients to the water. For example, along a 20-km stretch of Deep Creek (Idaho-Utah), more than 3,800 domestic animals overwinter. It is estimated that the cattle alone produced 284 g/m^2 (dry weight) of feces during the 4-month period. Much of this material reaches the stream during periods of runoff and provides nutrients for aquatic plants and food for the bacteria and invertebrates.

Where ranges are heavily stocked with livestock and confined within artificial barriers, changes in vegetation occur (Platts and Nelson 1985). Livestock trample and compact the soil, and the high-quality, fibrillar-rooted plants gradually give way to shallow-rooted annual species or tap rooted forbs or shrubs that can exist on areas with lowered water tables. Generally, these invader species are less palatable than plants with fibrillar roots and provide less nutrition and often only seasonal benefits for livestock. As soil compacts, infiltration of water into deep soils lessens, and surface runoff increases. The accelerated rate of erosion has major effects on terrestrial and aquatic productivity. Rich topsoil is lost by the erosive action of wind and water, and the quality of streams receiving the eroded material is reduced. In addition, fine sediments smother spawning and rearing areas, altering the habitat of fish.

Livestock grazing can affect all four components of the aquatic system: riparian vegetation, stream-channel morphology, shape and quality of the water column, and the structure of the soil portion of the streambank (Platts 1979). It can affect the streamside environment by changing, reducing, or eliminating vegetation bordering the stream, and by the actual elimination of riparian areas by channel widening, channel aggradation, or lowering of the water table. Streamside vegetation is directly affected by grazing because riparian zones usually are grazed more heavily than are upland zones (Holscher and Woolfold 1953; Armour 1977). Duff (1977) found that the riparian vegetation declined 35% in 6 weeks when cattle were introduced into an area that had not been grazed for 4 years. The most apparent effects on fish habitat are the reduction of shade and cover and resultant increases in stream temperature, changes in stream morphology, and the addition of sediment through bank degradation and offsite soil erosion. Lorz (1974) found no difference in fish populations in ungrazed and grazed sections of the Deschutes River, Oregon, when dense willow cover was on one or both banks. Claire and Storch (1977) found the willow canopy in an exclosure provided 75% more shade on the stream than areas outside the exclosure receiving year-round grazing.

Detritus formed from terrestrial plants is a principal source of food for aquatic invertebrates and eventually for fish (Minshall 1967). A change in the quantity and quality of the detritus reaching the stream can severely interfere with natural conditions, resulting in a decline in the organisms fish eat and disruption of the stream's ability to process organic matter (Cummins 1974).

The sloughing and collapse of streambanks caused by improper livestock grazing adversely affects fish populations (Platts 1979). Streambanks erode because livestock congregate along streams for shade, more succulent vegetation, and drinking water. Livestock grazing off the vegetative cover and caving in overhanging streambanks are principal factors contributing to the decline of native trout in the West (Behnke and Zarn 1976). Winget and Reichert (1976) found that livestock grazing on selected Utah streams reduced bank stability 59%. In other Utah studies where livestock exclosures were used, streambank stability increased 100%-740% (Berry and Goebel 1978; Duff 1977). Duff (1977) found that introduction of livestock into an area ungrazed for four years resulted in a 14% decline in streambank stability within 6 weeks.

Livestock grazing can change channel morphology by sediment accrual, altered channel substrate composition, disrupted pool-riffle relationships, channel widening, and increased runoff. Duff (1977) found stream-channel widths were 173% greater in grazed stream reaches of Big Creek, Utah, than in ungrazed.

Livestock grazing can alter conditions in the water column by increasing water temperature, nutrients, suspended sediment, and bacterial counts and by altering the timing and volume of water flow. Stream temperatures increase in small headwater streams when riparian vegetation is removed and changes occur in the composition of fish communities in downstream receiving streams. Clair and Storch (1977) noted that the average stream temperature dropped 12 °C alongside an exclosure on the Deschutes River, Oregon, that was ungrazed for 10 years. Busby and Gifford (1978) also found that grazing may damage water quality by affecting the hydrologic conditions within a given watershed. High coliform bacteria counts in streams were attributed to livestock grazing (Kunkle 1970; Darling and Coltharp 1973; Skinner et al. 1974). Photosynthesis is decreased by stream turbidity, and primary productivity is reduced, thus decreasing the productivity of the entire ecosystem. Increased runoff resulting from livestock grazing not only scours the bottom materials and widens the stream bed, destroying pools and cover, but it also provides the mechanism by which rich organic materials essential for an abundant bottom fauna are swept away (Tarzwell 1938).

Between 1978 and 1984, broad areas of the Great Basin experienced some of the lowest and highest streamflows on record. Platts et al. (1985) found that in three widely separated streams, floods resulted in marginal to dramatic changes in riparian stream habitat. They also found, however, that when the riparian ecosystems were in good condition, the effects of floods were minimal. Dramatic changes were evident in heavily grazed areas. In these reaches, floods caused changes in stream width, depth, meander pattern, and longitudinal profile that caused riparian-stream habitats to suffer. Streams, from which large aspen stands had been removed by livestock grazing and beaver activity, suffered severe streambank and channel erosion (Platts et al. 1985). The aspen limbs and logs that held the valley alluvial materials in place decreased drastically over time. As they decreased in size and abundance, they no longer had the capacity to hold the acquired alluvium in place. Consequently, large floods were capable of scouring valley alluvial materials and accelerating erosion of streambanks and channels.

In Big Creek, Utah, a rehabilitated riparian-stream section within an ungrazed exclosure experienced large storm events that exceeded all streamflows on record. This rehabilitated reach sustained little damage, and better stream-riparian conditions probably resulted from the high discharge. The adjacent grazed sections of Big Creek were heavily scoured. Based on this experience, it may be concluded that if Great Basin streams had been in good habitat condition, many of them could have easily withstood the large floods that occurred over the area in 1983 and 1984. In degraded condition, these streams had little chance to hold themselves together, and many years will be required for their recovery.

Livestock grazing can cause annual microchanges in the environment that accumulate over many decades (Platts 1979). These subtle changes are difficult to detect and document, because nature causes similar alterations and effects. Aquatic ecologists and fishery biologists are confronted with the problem of determining how different types of grazing systems affect the various aquatic components and how changes in these components affect fish health and survival. Whether a stream has suffered a catastrophic degrading event, such as flooding or a long period of annual small events, the end point for fish can be the same: the stream and its fisheries are damaged and, once stress is relieved, recovery may take years.

The eastern half of the Great Basin (Bonneville Basin) was the first to develop a livestock industry. The period of expansion of livestock production on the open sagebrush-grass ranges provides a chronicle of degradation for Great Basin ecosystems.

The horse was the first domestic herbivore introduced into the Great Basin (West 1983), brought in by Indians mainly from the Great Plains in the 1500's. Cattle and sheep were not introduced into the Great Basin in significant numbers until the late 1700's (Young 1978). By the 1800's, the ability of Great Basin ranges to support large numbers of livestock became evident, and the immense "seas of grasses" were soon being grazed. With the advent of domestic livestock, a valuable new industry became part of the Great Basin's economy. In the beginning, there was little doubt that the Basin could continue forever to support all the livestock that could be brought in, but as time would soon show, even the immense Great Basin had its limits.

6.1.1 Early History of the Livestock Industry (1840-1920)

The Civil War triggered the development of the livestock industry in the west. Just before the war, the Great Basin received a preview of what was to come when Mormon settlers colonized the Bonneville Basin in 1847. The Mormons used a type of grazing used in northern Europe, where herds grazed surrounding ranges in the daytime, but returned to settlements each night. Therefore, the first range and stream/riparian deterioration occurred close to settlements.

Growth of the livestock industry in Utah began with cattle which numbered about a quarter-million head by 1885 (Peterson 1985); by 1895, the number was approaching 360,000. From this period on, because of increasing sheep numbers, hard winters, and unfavorable market conditions, cattle numbers barely held their own until 1905 (Peterson 1985). Between 1865 and 1900, the sheep industry expanded rapidly, and by 1900, livestock numbers had peaked and exploitation of upland and riparian rangelands was reaching a maximum. During this era the Lahontan Basin was being settled by livestock ranchers, who used the Spanish system of allowing cattle to range freely without fences. Broad expanses of range were quickly invaded by livestock. This sudden introduction into ranges that had not been heavily grazed for thousands of years (close of Pleistocene) had spectacular results on environmental conditions (Young et al. 1976). The introduction of livestock into the Bonneville and the Lahontan Basins had a greater deleterious effect on the environment than any other event in the previous 1,000 years (Davis et al. 1977). Between 1880 and 1910 in the Great Basin, there was a great reduction in rangeland resources due to overgrazing and conversion of rangeland to farmland. Little thought was given to the deterioration of range resources; rather the guiding principle was who could use the grass first and establish rights to it by the constant presence of stock.

Sheep appeared about 1860, and their numbers grew rapidly. By 1870, large herds of sheep in Oregon and California were being driven eastward through the Great Basin to midwestern railheads. Sheep herds expanded greatly after the devastating winter of 1889-90, which weakened the cattle industry. By 1900, the cattle industry was in major retreat, and sheep outnumbered cattle in most western states. Many cattlemen, who once abhorred the sheep industry, turned to sheep to make a living. By 1885, the state of Utah supported 1 million sheep, and by 1890 about 1.5 million; but by the turn of the century, numbers had skyrocketed to about 4 million (Young and Evans 1985). Herds of free-roaming horses added to the associated and growing devastation of western ranges.

The increase in sagebrush and the decline in the more favorable grasses began with the settlement of the Mormon colonists and continued as ranges were more and more heavily used (Stewart 1941). In Cache Valley (Utah and Idaho), explorers and early settlers found abundant grass and little sagebrush, but excessive livestock grazing drastically reduced the abundance of grasses and led to increases in sagebrush. Although sagebrush now dominates the heavily grazed areas, some tracts that have not been grazed, plowed, irrigated, or frequently burned continue to support much the same vegetation described by early travelers (Ferguson and Ferguson 1983).

Within a brief span of about 25 years (1875-1900), the great empty rangelands of the Great Basin, once thought to be inexhaustible, were overstocked with domestic livestock. The productivity of the range for supporting livestock was greatly diminished. Upland ranges were changed from grassland to shrubland while, conversely, riparian-wetlands had been changed from a brushy-tree type to mainly grasses and forbs. In both cases, with continual grazing pressure, the stage was now set for the invasion of the noxious weeds the livestock operators brought with them into the Basin (Young 1978).

Because the price of cattle was high during World War I, a period of severe overgrazing took place between 1915 and 1920. National Forest ranges began to improve again after World War I because controlled grazing was implemented; however, other rangelands in the west continued to deteriorate. Cattle numbers would not make great gains again until the 1940's. During the 1916 grazing season, stockmen suffered in the west because of a small hay crop and a cold, extended winter. To meet the war emergency, every acre of grazing lands was opened to the greatest possible use. With most ranges already overstocked, the addition of extra stock under "temporary permit" came as a staggering blow to conservation efforts on the ranges. In years to follow, federal grazing officials often pointed to the wartime measures as a significant setback in range resource protection (Rowley 1985). Others, however, felt it was only an acceleration of a process already underway.

6.1.2 Government Intervention

In 1897, President McKinley initiated the Forest Reserves in an attempt to regulate detrimental impacts on public lands. Grazing on the Forest Reserves was allotted mainly to cattle. In 1901, sheep were allowed to graze on Forest Reserves if it could be shown that they would cause no injury to the land. When the Federal Government created the Forest Reserves from portions of the public domain, administrators found themselves in the midst of the ongoing controversies over forest range use. The young science of forestry was generally concerned with timber production and watershed protection, not range use. By 1900, issues of grazing had joined the list of urgent problems (Rowley 1985).

Forest Reserve designation did not help the Great Basin very much, because the Basin was designated to be mainly public-domain lands to be managed by the Grazing Service and eventually the Bureau of Land Management. The Forest Reserves immediately initiated controlled management, but it was to be many years before those lands, managed by the Grazing Service and Bureau of Land Management, would come under any kind of control because these agencies were influenced primarily by Western senators who had little understanding of the problem and were strong supporters of the livestock industry. Even the Forest Service admitted that one decade after the Forest Reserves were formed, livestock numbers had increased by 50% (Rowley 1985).

Government intervention in the Great Basin really began in the 1890's with the classification of certain lands according to potential use. Between 1910 and 1920, grazing laws were put into effect on what would become National Forest lands. Starting in the devastating drought years of the 1930's, and fostered later by the red-meat demands of World War II, there developed a recognition of the responsibility of the Federal Government to restore the productivity of the grazing resource entrusted to its care (Young and Evans 1985). However, not until 1934, when Congress passed the Taylor Grazing Act, was a real attempt made to stop injury to the public-domain grazing lands. This act also reserved the Public Domain for the wealthier livestock operators and spelled the demise of the "tramp" operator. The act ended an era of open, indiscriminant grazing started 87 years earlier with the first settlement of the Great Basin. However, because of slow government reaction and strong western congressional political pressures, uncontrolled grazing did not really end in the Great Basin until the late 1950's. The traditions of free and open range died hard.

In the 1930's, a book titled The Western Range, published by the U. S. Department of Agriculture, for the first time informed citizens of overgrazing on western ranges including the Great Basin. The book reported that 58% of public rangeland was in poor condition, while only 26% could be rated fair (Holechek 1981). Also during this period, as the Depression came to a close, range professionals and conservationists were critical of range management policies. The range had deteriorated tremendously since the 1920's as concessions were continually made to the livestock operator. The onset of World War II again created pressure for more livestock production on Great Basin lands. Western Senators again tried to stifle the policies of professional range managers in order to support their small but powerful group of rangeland forage users (Rowley 1985).

6.1.3 Improving Ranges

After the 1930's when private range owners and land management agencies initiated improved grazing management practices, upland rangelands slowly began to improve. Because livestock, particularly cattle, are attracted to stream-riparian areas, that portion of the range did not respond as well to the improved management as the overall rangelands did. The real problems occurring because of overstocked rangelands were not being recognized. In 1946, the U.S. Forest Service pushed for reductions in numbers of livestock. The 1950's were years of great improvement in upland range management on public lands. More range research was conducted in the 1950's than in all the preceding years (Holechek 1981). Water developments, brush control, reseeding, stocking rate adjustments, and grazing period adjustments were initiated. During the 1960's, the multiple-use concept of range management on Federal lands was developed. For the first time, wildlife, fisheries, water, and recreation received some recognition.

During the 1960's, both positive and negative effects resulted from widespread use of crested wheat plantings and elimination of brushy species with herbicides. Net forage production increased for the first time since 1860 (Young 1978), and concern for the environmental management of natural resources continued to accelerate. In 1960, the Multiple-Use Sustained Yield Act emphasized the Nation's commitment to better range management. The National Environmental Policy Act of 1969 soon followed, leading to the requirement for Environmental Impact Statements on management of Federal lands, allowing U.S. citizens for the first time to analyze how the Federal Government was managing their lands.

In the 1970's, there was a shift in emphasis from range management solely for the production of red meat to multiple-use management. Numbers of livestock grazing on public ranges was reduced 48% between 1966 and 1972, and there have been further reductions since 1972 (Holechek 1981). At this same time, however, concern over world population growth and food shortages generated a new interest in using public rangelands for livestock production. These concerns led to the Forest and Rangeland Renewable Resource Planning Act of 1974 and the Federal Land Policy and Management Act of 1976.

6.1.4 Today's Situation

Today, the cattle population in the West stands at an all-time high. Cattle alone exert more grazing pressure on western rangelands than did all the native ungulates before the arrival of Europeans.

Although the sheep industry enjoyed a moderate resurgence between about 1925 and 1945, the number has since dropped nearly 75%. Today, sheep are about as numerous in the West as they were in 1870, but cattle are now more than eight times as abundant (Ferguson and Ferguson 1983). Although the largest numbers of livestock were grazing western rangelands while the sheep industry flourished, the large increase in number of cattle during the past 20 years has brought the total number of livestock to a level exceeding that of all the years prior to about 1910 (Ferguson and Ferguson 1983).

Thus the need is great to intensify rangeland management in the Great Basin, because most Great Basin streams no longer have their once-productive streamside vegetative cover. Streambank and channel conditions have been drastically altered by a century of heavy impacts. These streams cannot begin to produce the numbers of fish and other aquatic organisms they have the potential to produce until grazing is better controlled in stream-riparian areas.

Although the 1950's, 1960's, and 1970's were periods of great upland rangeland improvement in the Great Basin, present aquatic habitat conditions show that Great Basin streams deteriorated during this period (Platts et al. 1985). The most threatened and abused rangeland type within the Great Basin is the riparian-stream type. These green, usually narrow, strips of vegetation attract domestic livestock, especially cattle, because water, shade, gentle topography, and more succulent vegetation can be found there. Major fish populations, including endangered species, are directly dependent on proper rangeland management of these critical riparian areas.

Climatic variability during the past two decades demonstrated ever-changing climatic conditions in the Great Basin. Since 1961, the Great Salt Lake has risen 4.3 m, inundating thousands of square kilometers of land. Carson Sink, Nevada, almost dry in 1963, now covers 259 km^2. In recent years, particularly during the winters of 1983 and 1984, the Great Basin has had above normal precipitation and snowpacks which led to some of the highest streamflows on record. These conditions had great impacts on Great Basin fisheries (Platts et al. 1985). Future storms and droughts will put Great Basin streams under additional stress. Only well-managed riparian-stream habitats will be able to withstand these ever-changing climatic events without impact on aquatic resources.

6.2 WATER USES

Because of the limited availability of water in this large and potentially productive land mass, virtually all streams having reliable flows have been intercepted and impacted by humans through impoundment, diversion, and irrigation withdrawal and recharge. Irrigation along the valleys of larger streams modified much of the total drainage pattern, ground water, dissolved solids content, and surrounding vegetation.

Early settlements generally coincided with stream courses where water for crops, animals, and human consumption was readily available. As human populations grew and the needs for water increased, dams and diversions were built to maintain or augment irrigation supplies. Urban developments began filling in the farmland along rivers and streams, often encroaching upon the floodplain and setting the stage for future channel modifications in the name of flood control. Ground water was pumped to meet the needs of the growing urban and municipal communities. Agriculture was gradually displaced by urban development into areas distant from surface water sources, creating demand for more extensive diversions and increased losses in conveyance. Extensive depletion of ground waters for irrigation purposes followed.

Over the last century, humans have taken an ever-increasing role in orchestrating the hydrology of surface and ground waters in the Great Basin. Dams have been built to reduce the seasonal oscillations of stream discharge and irrigate summer crops or to transform the elevational potential of flowing water into electric power. Diversions to agriculture, municipal, and industrial centers have altered the quality and quantity of stream discharge through depleted return flows. Extensive pumping of aquifers has caused a drawdown of stream levels and alteration of water quality through degraded return flows. Pumping of consolidated aquifers has interrupted sensitive relationships regulating spring discharge along structural gradients, some to the demise of unique aquatic systems and endemic species. Channel modifications in the name of flood control and water conservation have disrupted the balance between streamflow and sediment transport, generally securing a short-term benefit at the expense of continued maintenance.

The average annual undepleted water for the Great Basin, which is the natural flow in streams before human modification, is about 1×10^{10} m^3 (U. S. Bureau of Reclamation 1975). About 6.5×10^8 m^3, or 6% of the undepleted yield, is exported from the region, mostly from Owens and Mono Lake Basins through the Los Angeles Aqueduct. Several diversions import water from the Colorado River Basin to population centers along the western flank of the region. In 1975, there were 48 reservoirs with storage capacities greater than 6.1×10^6 m^3 in the Great Basin (U.S. Bureau of Reclamation 1975). The total maximum storage of these reservoirs is about 5.3×10^9 m^3, or about half of the undepleted water yield. A summary of withdrawals and depletions from surface- and ground-water sources is presented in Table 30. Water withdrawals are approximately equally divided between surface- and ground-water sources. Assuming that depletions are approximately equal for surface- and ground-water withdrawals, stream depletions for human uses account for about 43% of the total undepleted surface-water yield of the Great Basin.

Table 30. Surface- and ground-water withdrawals and depletions estimated for 1975 (data compiled from U.S. Bureau of Reclamation 1975).[a]

Water use	Withdrawal (10^9 m^3)	Depletion (10^9 m^3)
Irrigation	9.08	4.72
Municipal and Industrial	.65	.25
Minerals	.09	.02
Thermal/electric	.08	.01
Recreation	.76	.57
Other	1.05	.98
Reservoir evaporation	---	1.99
Conveyance losses	---	.25
Total	11.71	8.79

[a] Data does not include most of the Northwest Basin Hydrologic Subregion.

CHAPTER 7. AQUATIC AND RIPARIAN HABITAT MANAGEMENT

The aquatic/riparian zone is the most important wildlife (including fish) habitat type in managed rangelands. It is also the area of maximum potential conflict over the use of timber, grazing lands, recreation, water, and wildlife resources (Thomas et al. 1979). Riparian areas are the productive part of western grazing lands, usually containing the most productive timber and forage sites. Cattle forage on such areas more frequently than on adjacent, drier areas. Road builders often use riparian areas because of the gentle topography, and recreationists are drawn to such places for the scenic values associated with water. Riparian zones are usually quite sensitive to management activities and should be cautiously managed (Beschta 1978). As each riparian zone is somewhat different, the land manager should consult both a fishery and a wildlife biologist during the planning process if fish and wildlife welfare are objectives of management.

Because of their distinct vegetative community and structure, aquatic/riparian zones must be considered fragile and vulnerable to alteration (Thomas et al. 1979). The more mature the vegetative complex of the riparian zone, the more apt it is to assume distinct edges and strata that intensify edge-effect and increase diversity. This mature condition is sensitive to management activities that occur within the riparian zone itself or on the surrounding rangeland.

The sensitivity of the vegetatively mature riparian zone, including both the terrestrial portions and the associated aquatic zone (Boussu 1954; Gunderson 1968), can also be attributed to its distinct microclimate. Changes in the canopy cover can alter this climate markedly (Cordone and Kelley 1961; Collings and Myrick 1966; Brown and Krygier 1967; Brown et al. 1971). For example, an increase of a few degrees in water temperature may eliminate a stream as a trout habitat.

7.1 LIVESTOCK MANAGEMENT

Proper management of livestock grazing can improve both the quality and quantity of fish populations. In Otter Creek, Nebraska, Van Velson (1979) found that within 3 years after an area was fenced to exclude livestock, stream width decreased, streambanks quickly stabilized, and summer water temperatures were reduced 2-5 °C. The stream improved from a nonproducer to a major producer of trout. Clair and Storch (1977) found that over a 10-year period of no grazing, the fish population shifted from predominantly dace (Rhinichthys) to rainbow trout (Salmo gairdneri).

In Rock Creek, Montana, Marcuson (1977) found brown trout (Salmo trutta) biomass per unit area in a stream within a non-grazed section was 440% higher than in an adjacent stream section that was heavily grazed. In the same stream, Gunderson (1968) found trout were 127%-500% more abundant in ungrazed sections than in grazed. Kennedy (1977) reported that trout were 240% more abundant in ungrazed sections of an Oregon stream than in grazed sections. Duff (1977) found trout populations 360% greater in ungrazed stream reaches of Big Creek, Utah, than in grazed stream reaches.

Proper grazing management should include particular attention to insuring the welfare of riparian zones. If livestock grazing is to be permitted in a riparian zone, the environmental impact on the zone should be carefully evaluated (Thomas et al. 1979). The heavier the grazing and the more prolonged the grazing period, the more severe will be the impacts. These impacts may be magnified because of the sensitivity of the microclimate and water temperature to increases in solar radiation reaching the ground or water surface.

Range-management activities outside the riparian zone may impact the riparian zone by changing the quantity and quality of water entering and influencing them (Buckhouse and Gifford 1976). Of the main factors that influence the amount of surface erosion and subsequent water quality, some can be controlled through management action, the most important of which is the maintenance of appropriate vegetative cover and soil conditions (Satterlund 1975). Infiltration may be enhanced by the maintenance of plant cover, both alive and dead. Under excessive grazing, livestock not only remove protective ground cover but also compact the soil, both which accelerate erosion (Dambach 1944; Satterlund 1975).

The noteworthy recovery in overall range condition after the 1930's resulted from a variety of management practices, from reduced livestock stocking rates (numbers per unit area) to special grazing strategies (Platts and Nelson 1985). One of these strategies, rest-rotation grazing, was developed early in this century but was not accepted until Forest Service personnel applied it to perennial bunchgrass ranges (Hormay and Evanko 1958; Hormay and Talbot 1961). It is now the primary strategy used on many ranges. Under rest-rotation grazing, the grazing area or allotment is partitioned into several pastures, and each pasture is grazed in turn and usually is rested at least one year during a grazing cycle.

Rest-rotation may be sound theoretically but is difficult to implement without aggressive management. Platts and Nelson (1985) showed that under certain types of rest-rotation grazing, streamside forage can be overused, resulting in damage to the riparian stream habitat, while adjacent range and overall pasture forage is being used at a level acceptable under the allotment management plan. In Utah, Starostka (1979) also found no streamside improvement under rest-rotation grazing, and speculated that the lush riparian growth produced by rest periods caused heavier than normal use of the riparian zone. Platts and Nelson (1985) measured as much as 47% use of bank forage in a pasture that was supposed to be rested. They also measured six consecutive years of streamside forage utilization in excess of 30% (moderate or greater), with an average of 59% in their Lower Bear Valley study area. This occurred while a three-pasture system of rest-rotation was supposed to provide at least two seasons of rest.

Heavy and prolonged use of streamside vegetation not only will alter a bank but also retard the rehabilitation of previously altered banks. After one cycle of rest-rotation grazing (3 years) in grazed treatment pastures (previously ungrazed meadows) where forage use would be better balanced than on conventional allotments, streambank alteration relative to the adjacent ungrazed control sites was detectable (Platts and Nelson 1985). The alteration was not enough to affect fisheries resources; however, cumulative effects may eventually result in some fishery impacts.

Land managers have often failed to recognize that streamside environments are different from other terrestrial systems and thus need specialized management (Thomas et al. 1979). The stream, the riparian environment, and the adjacent upland environments require different land-management strategies. For example, even among riparian systems a broad riparian zone in a wet meadow has a different influence on a stream than a narrow riparian zone in a sagebrush ecosystem. Because riparian environments are lumped into broad terrestrial environmental classifications, they become unidentifiable for land-management purposes. Often what is good for timber or range management is not good for riparian or stream management.

Any grazing management scheme for preserving, enhancing, or re-establishing woody vegetation along streamsides or other riparian zones must consider the physiology of the plants and their response to grazing (Thomas et al. 1979). Standard grazing systems, such as continuous rest-rotation or deferred rotation in various forms, have generally been developed considering only the production and maintenance of forage plants--primarily grasses and forbs. It is likely that the application of such systems to maintain woody streamside vegetation and streambank integrity will not be satisfactory because the physiology of shrubs and trees is different from that of forage plants.

Information on how grazing systems may be used to accomplish such goals as maintenance of woody streambank vegetation and the prevention of bank crumbling and soil compaction is only now being studied. It is likely that special systems may have to be developed to include six or more pastures in the rotation-grazing systems (compared to the present two to five pastures) or to provide complete protection for some period coupled with restricted grazing after satisfactory conditions are achieved (Thomas et al. 1979).

Platts and Nelson (1985) recommend that land managers use the special riparian pastures when standard grazing strategies are not working well. Such pastures may encourage a more equitable use of all available forage and would allow the intensity of use to be carefully controlled, especially where close control of livestock without fences is difficult to attain. Fencing such pastures would be expensive, with costs approaching $3,730/km of stream. (Platts and Wagstaff 1984), but increases in revenues derived from increased recreational fishing and the other riparian stream resources may make it cost-effective in certain situations. Existing grazing strategies must continually be refined for more compatibility with other uses and new strategies developed if existing ones do not work.

7.2 STREAM REHABILITATION

To stabilize and protect altered stream channels, natural energy dissipators (such as bends, vegetation, logs, and boulders) are created or simulated by placing structures in the stream channel (Starnes 1985). In addition to providing natural physical changes, these structures provide habitat necessary for fish and other aquatic life. The absence of energy dissipators increases the velocity of flow and intensifies erosion and sedimentation at areas further downstream. Perhaps the most common rehabilitation practice involves creation of structures within the stream to alter flow (Saunders and Smith 1962; Starnes 1985; Wesche 1985). Structures are utilized to increase, decrease, or divert flows which will create riffle-pool areas (Gee 1952).

Stream improvements have been shown to increase fish and fish food production in streams of the Southwest (Tarzwell 1938). Brusven et al. (1974) evaluated the sediment removal capabilities of different structures. In-stream structures, gabion deflectors, and channel diversion (which tend to increase turbulence and current velocity), and log jam removal all resulted in increased sediment transport. Where control of sedimentation is the focal point of reclamation efforts, structure success and lifespan will depend on the extent the structure can accommodate sedimentation (Starnes 1985). If the structure design facilitates self-cleansing of recently deposited silt, it will help the stream return to a more stable, as well as more natural, configuration without dredging, channelization, or complete loss of aquatic life. Barton and Winger (1973) found structures in altered channels of the Weber River provided for aquatic invertebrate recovery which enhanced rapid fish recovery.

Smith (1982, 1983a) and Apple et al. (1984) described the use of beaver for aquatic/riparian restoration of cold-desert stream systems. Beaver dams trapped sediment, reduced stream velocity, locally elevated the water table, and reduced seasonal fluctuations of the water table. Reduced velocities resulted from lateral dissipation of streamflow energies, which in turn reduced downcutting and caused sediment deposition. These modifications, in conjunction with livestock grazing management, allowed for re-establishment of willow and other riparian plants which stabilized streambanks and improved aquatic habitat and fisheries. In addition, the gully-cutting process was not only stopped, but was reversed. In one case the willow-based beaver complexes reduced the sediment load 90% from 1400 mg/L to 160 mg/L (3,628 kg/d) in just 8 km of stream length (Smith 1983b).

CHAPTER 8. RECOMMENDATIONS

Historically, water has been a principal factor limiting political, social, industrial, and agricultural developments in the Great Basin (Worster 1986). It is suprising that the intrinsic values of stream and riparian habitats have garnered interest only in recent years. The Utah Division of Wildlife Resources is developing a hierarchical classification for identification and inventory of riparian and stream habitats (Utah Division of Water Resources, Salt Lake City, unpubl.). Similarly, an approach to classification of riparian and stream habitats in Nevada is being considered (Dr. Sherman Swanson, Department of Range Science, University of Nevada, Reno; pers. comm.). The Bureau of Land Management (BLM) also is developing a uniform approach for collection and analysis of riparian data for the purpose of classification and evaluation (Karl Gebhardt, Bureau of Land Management, Boise, ID; pers. comm.). The approach being developed by the Bureau of Land Management and the classifications being considered for Nevada both consider a broad scope of environmental criteria, in addition to vegetation parameters. While it is encouraging that efforts to identify riparian habitats are ongoing, it is hoped that final classifications will be consistent for the Great Basin hydrographic region as a whole.

Descriptions of stream and riparian habitats in several hydrographic units of the Great Basin are lacking. While minimal descriptions are available for watersheds along the eastern and western flanks of the Great Basin where major population centers are located, relatively little information is available for the vast interior areas of the region. An intensive study of representative drainages in the Central Basins hydrographic subregion may provide valuable information for extending and revising concepts.

Investigations concerning the processes responsible for the structure, dynamics, and values of riparian and stream habitats in the Great Basin are sparse. An understanding of what is happening is fundamental to effective management of riparian and stream habitats. To be applicable to an array of land and water uses, the scope of investigations should include a broad range of expertise (e.g., climate, geology, hydrology, geomorphology, soil, plants, and animals).

Intensive land and water uses over the past century have relegated the vast majority of stream and riparian habitats to a disturbed or altered condition. Scientists and land managers have few (if any) pristine sites to judge condition and potential. The identification and protection of pristine stream and riparian habitats is of critical concern.

It is generally accepted that many stream and riparian habitats in the Great Basin are in poor condition. Several studies administered by Dr. William Platts (U.S Forest and Range Research Station), are yielding valuable information concerning the recovery of damaged stream and riparian habitats under several grazing alternatives. Continuation of these studies is essential to devise methods for rejuvenating stream and riparian habitats for optimal multiple-use values.

Great Basin streams offer a challenging and scientifically rewarding area of research. Clearly, much remains to be done in terms of both descriptive and experimental investigations. Many areas and stream types remain virtually unstudied. For example, there have been only one or two studies of algae and vascular plants, one study of organic matter processing comparable to the leaf-pack studies of deciduous forest streams, and only three of the major Great Basin rivers have been investigated in any detail (and even in these much is left undone). The invertebrates, which have been comparatively better studied than the other groups, need considerably more investigation. Many existing studies (1) have had too narrow an orientation (e.g., insects only) and have ignored or considered only a few environmental factors; (2) have been short-term and limited to isolated parts of the annual cycle; or (3) have not dealt with the species level. A detailed examination of invertebrate life history strategies along the lines of a study of a Sonoran desert stream (Gray 1981) would be especially profitable.

Yet, time is rapidly running out. Long-term disturbances by humans and their livestock have virtually eliminated the archetypical Great Basin stream (essential for placing present conditions in perspective and for interbiome stream comparisons), and the opportunities to reconstruct the presettlement stream type have been made more difficult by intensified land use. Sporadic information coupled with the diversity of stream types and sizes represented and the lack of a historic presettlement perspective hampers understanding of Great Basin stream ecosystems. Nevertheless, it appears that they are potentially rich in species and high in production as compared with streams in other climatic regions and that they will continue to provide new insights and challenge conventional wisdoms in the development of stream ecology.

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7. Author(s)

G. Wayne Minshall[a], Sherman E. Jensen[b], William S. Platts[c]

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

[a]Idaho State University
Department of Biological Sciences
Pocatello, ID 83209

[b]White Horse Associates
P.O. Box 123
Smithfield, UT 84335

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16. Abstract (Limit: 200 words)

Surface waters of the Great Basin include perennial, intermittent, and ephemeral streams; freshwater and saline lakes; playa lakes; freshwater and saline wetlands and thermal springs associated with faulting and volcanic activity. All of these aquatic habitats generally have associated riparian habitats. However, riparian habitats of the Great Basin may be more mesic than the riparian habitats of the eastern United States.

The Great Basin comprises the northern half of the Basin and Range Physiographic Province and covers most of Nevada and western Utah and portions of California, Oregon, and Idaho. The entire basin actually consists of numerous subbasins and mountain ranges which present an extremely diverse physical setting. Typical mountains range from about 2,100-3,000 m in elevation while subbasin floors are typically 1,500-1,800 m in elevation. The entire Great Basin lies in the rain shadow of the Sierra Nevada Mountains and the region is semi-arid to arid.

Riparian and stream habitats within the Great Basin have received less attention from ecologists than similar habitats elsewhere in the United States. As a consequence, little is known about biotic communities or about certain aspects of structure and functioning of these ecosystems.

17. Document Analysis a. Descriptors

Streams (perennial, intermittent, ephemeral)
Lakes (freshwater, saline, and playa)
Wetlands (freshwater and saline)
Aquatic plants

Riparian
Mammals
Fishes

Springs
Birds
Invertebrates

b. Identifiers/Open-Ended Terms

Great basin
Water quality

Water resource development
Nutrient cycling

Grazing
Productivity

c. COSATI Field/Group

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(Formerly NTIS-35)
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Development in the U.S. and Puerto Rico, for dam locations.

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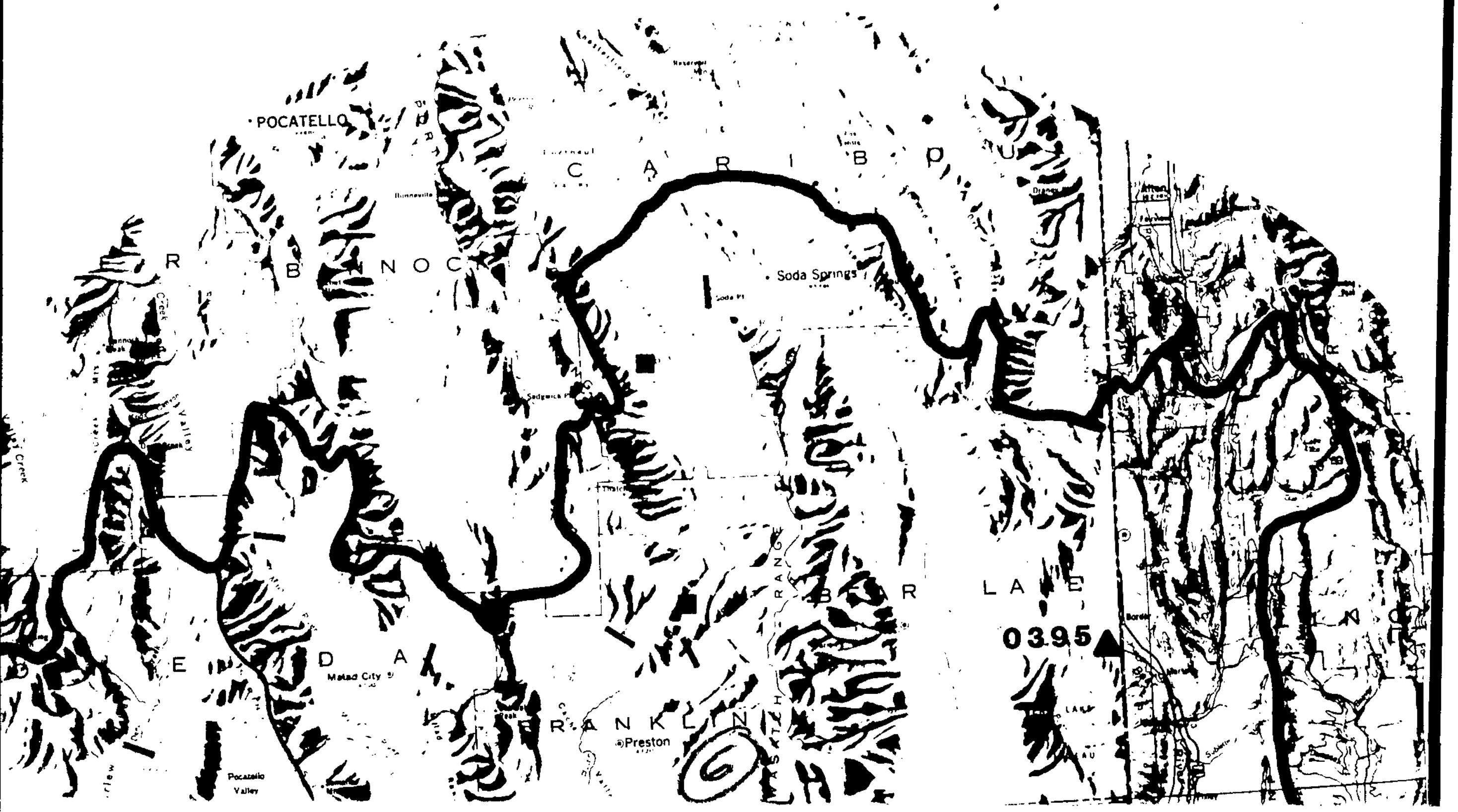
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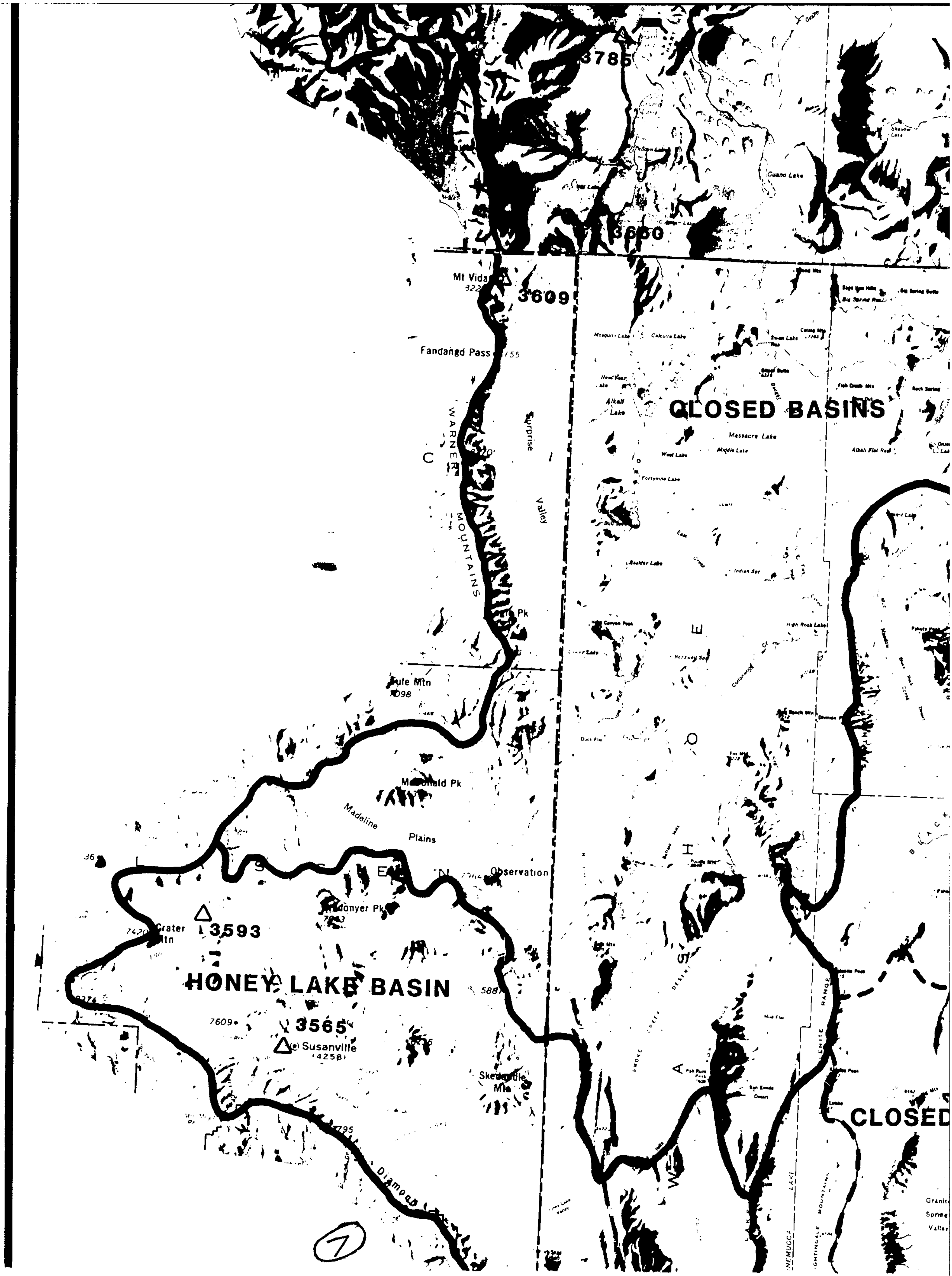
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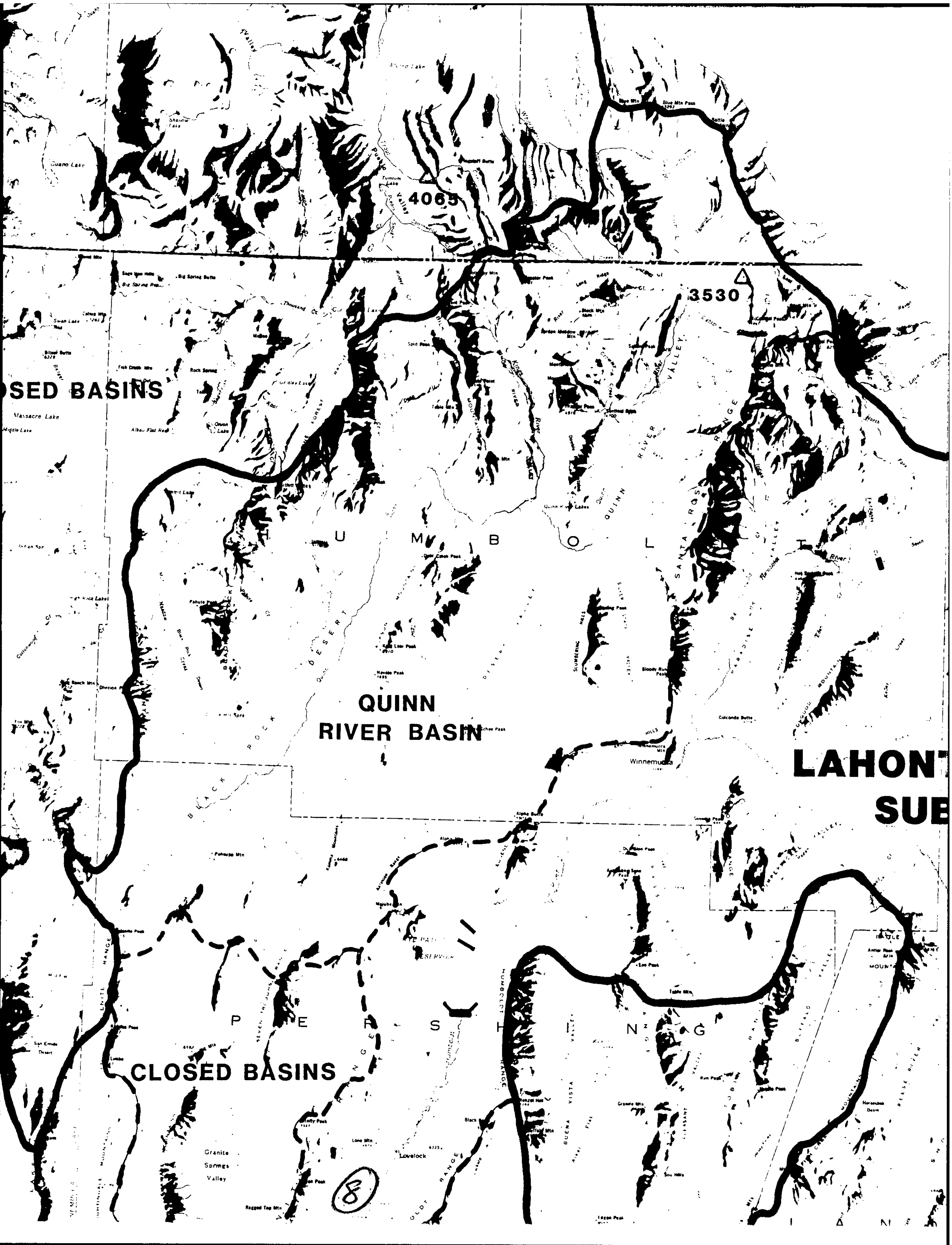
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Golconda Butte
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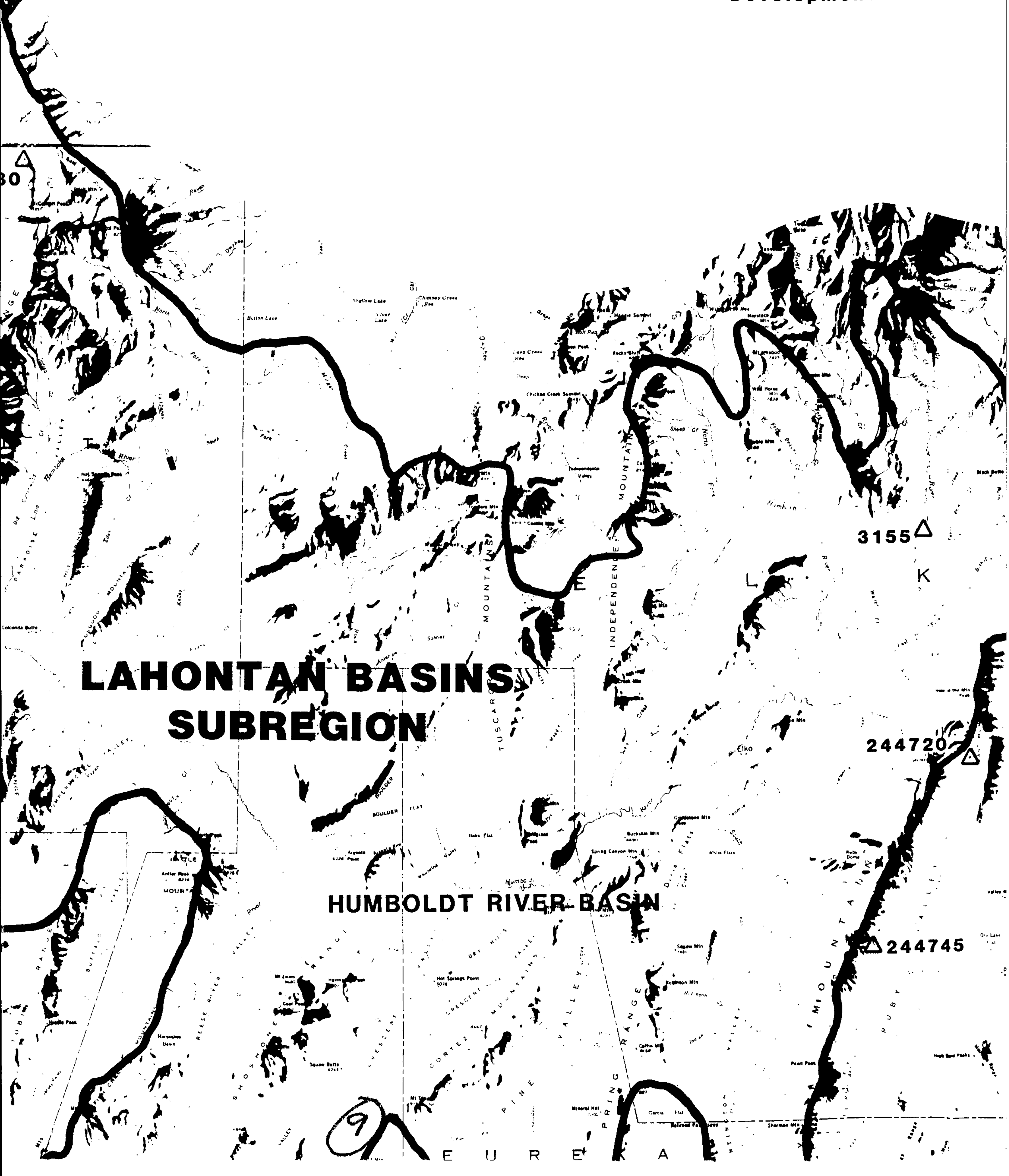

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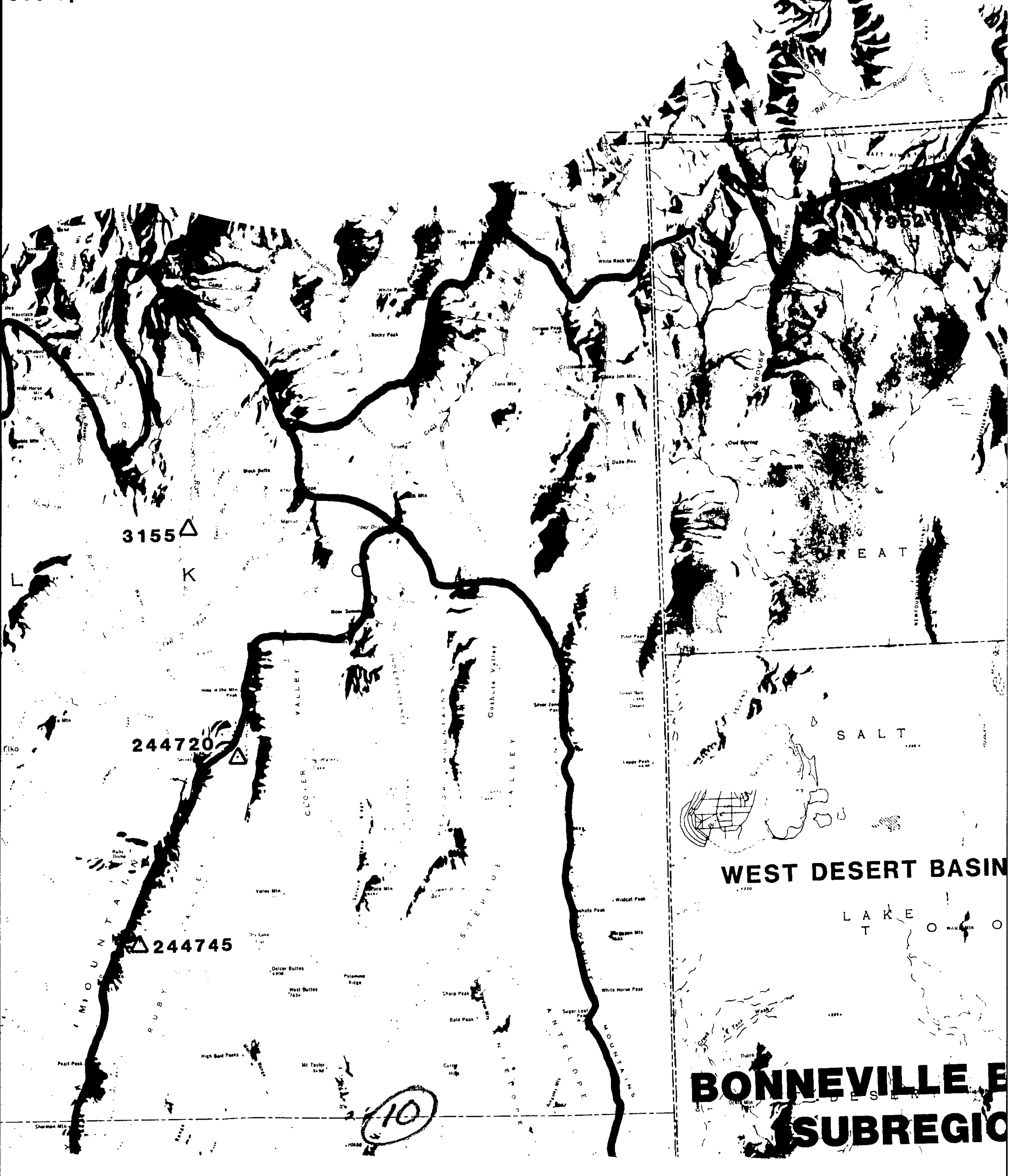


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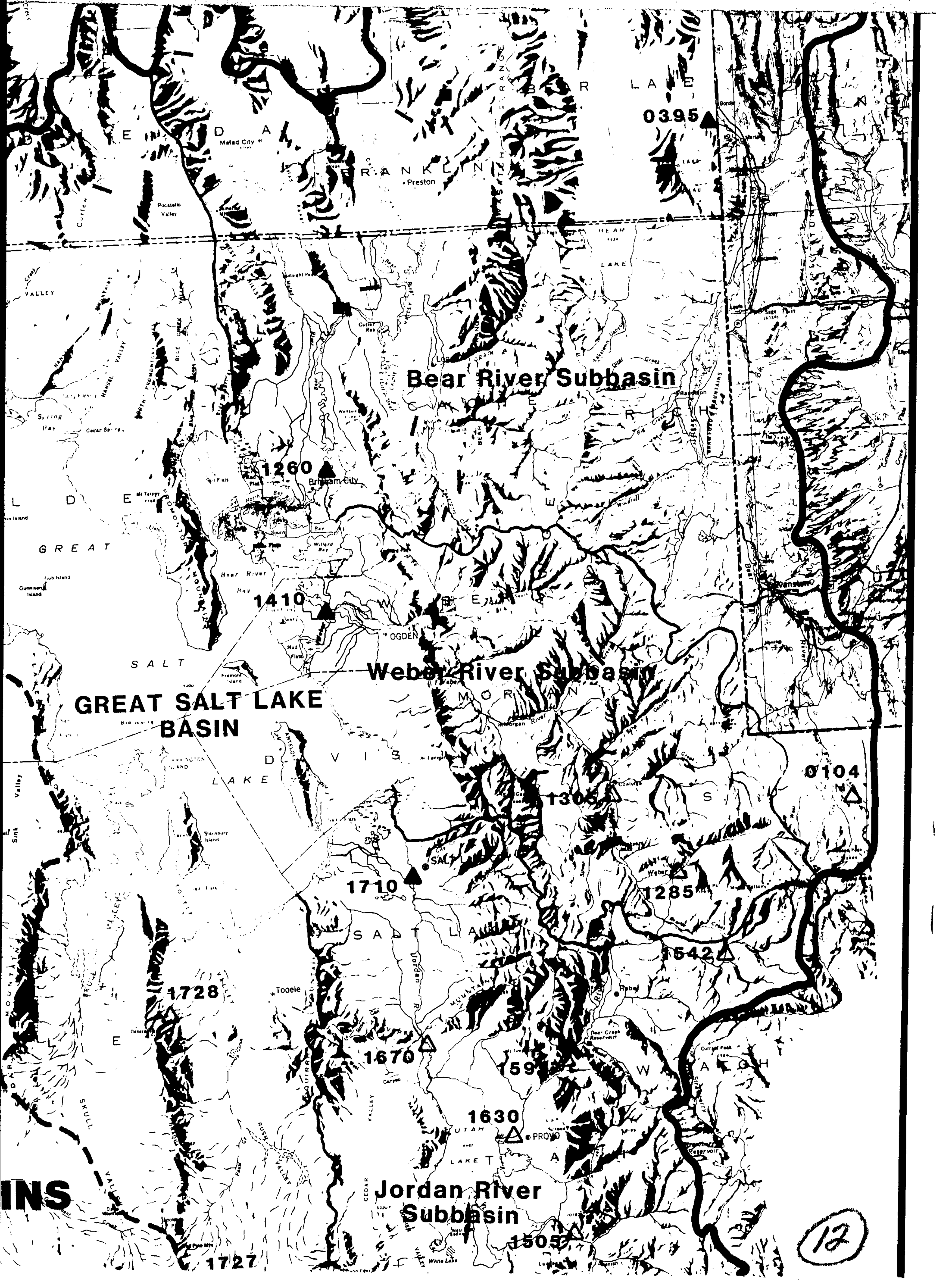
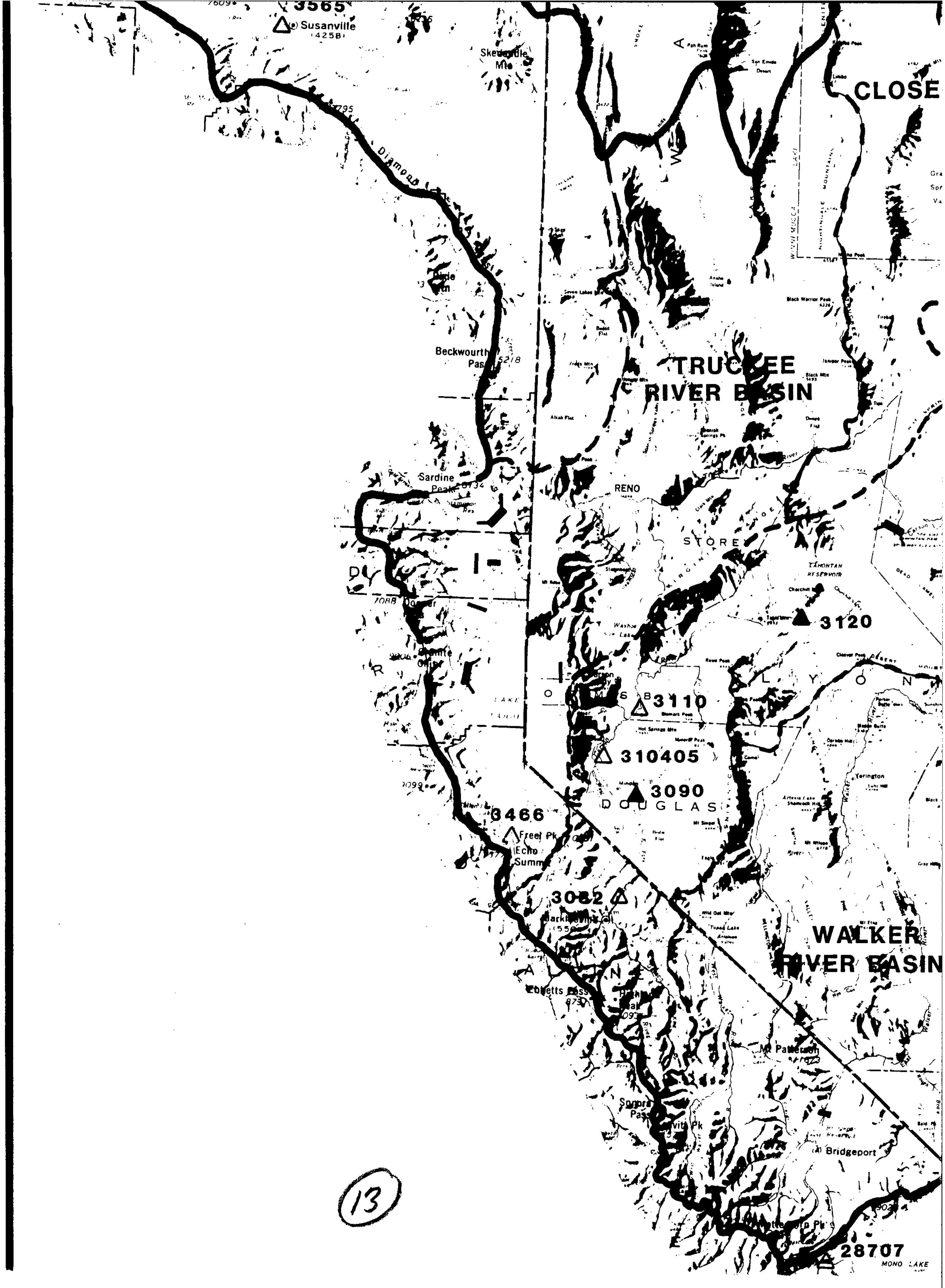
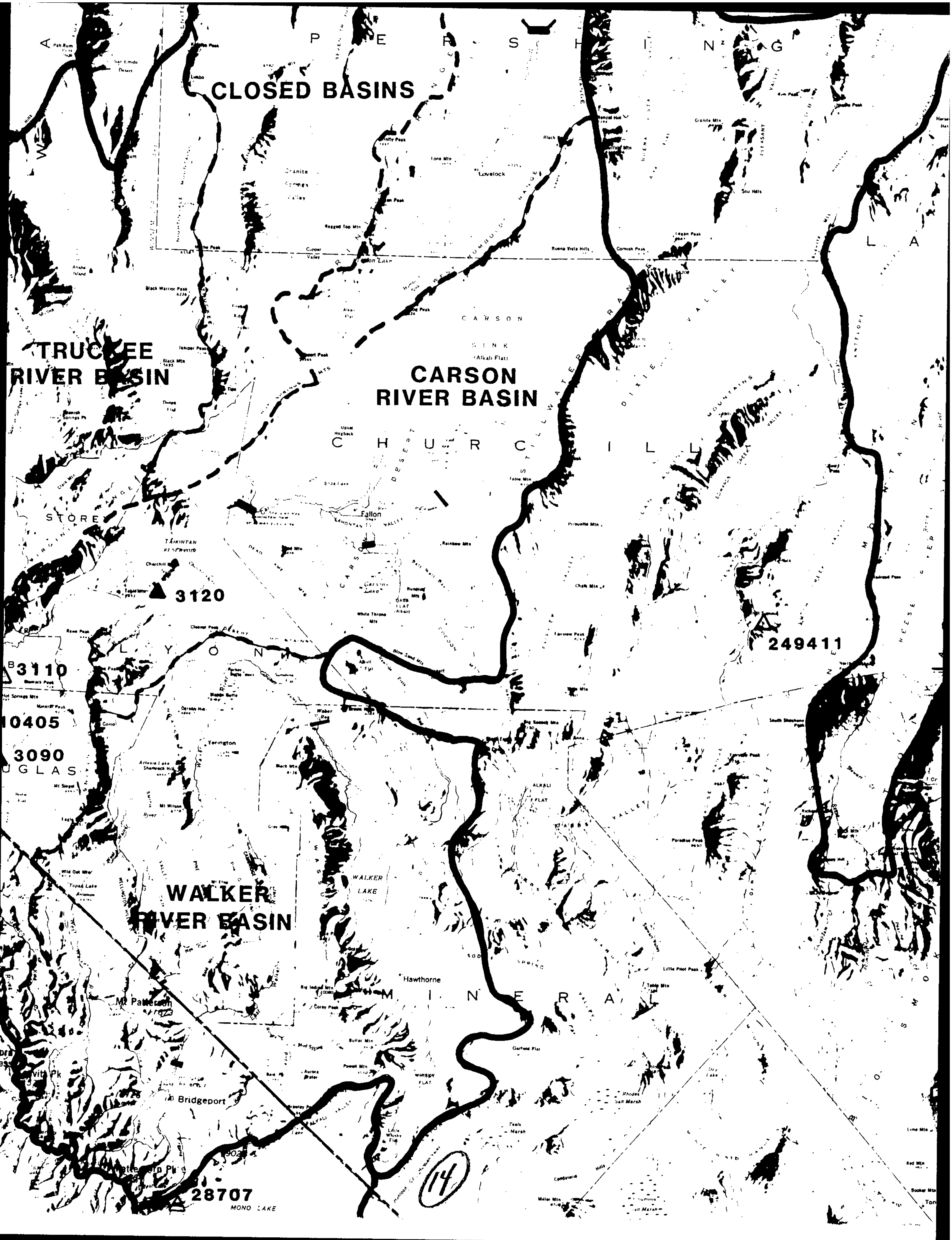
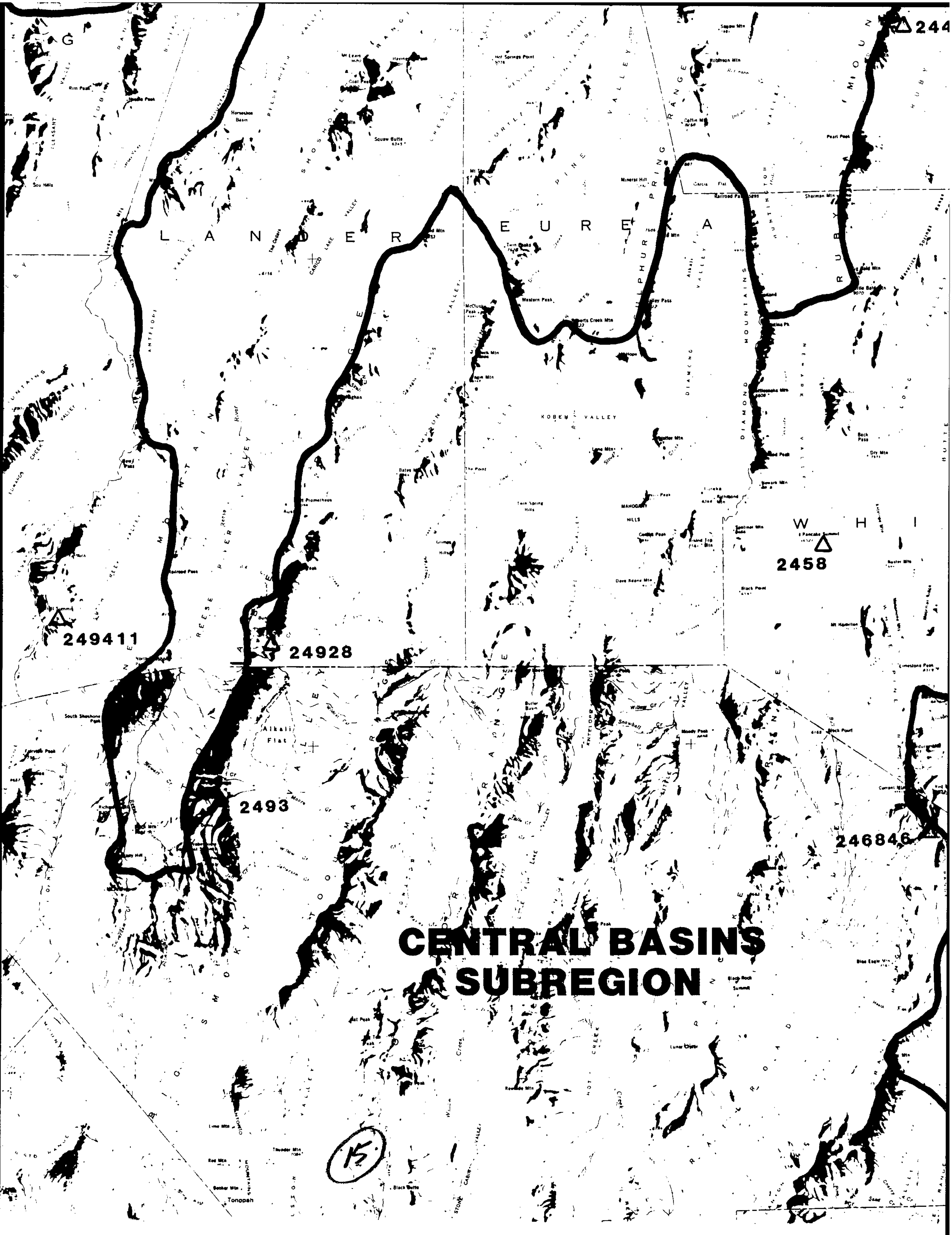
1710
1728
1670
1630
1505
1727
1305
159
03
Preston
Brigham City
OGDEN
Tooele
PROVO
Curlew Valley
Locomotive Springs
Dolphin Island
Gunnison Island
Willard Bay
Bear River Bay
Mud Flats
Fremont Island
Jordan River
Utah Lake
Skull Valley
Rush Valley
Cedar Valley
Malad City
Pocatello Valley
G R E A T
S A L T
L A K E
D A V I S
S A L T L A K E
T O O E L E
W E B E R
M O R G A N
B O X E L D E R
O N E I D A
F R A N K L I N
U T A H
C A C H E
R I C H
G R E A T S A L T L A K E D E S E R T


0395
Bear River Subbasin
1260
Brigham City
1410
OGDEN
Weber River Subbasin
GREAT SALT LAKE
BASIN
0104
1305
1285
Weber
1710
SALT
1542
1728
Tooele
1670
1597
1630
PROVO
Jordan River
Subbasin
1505
1727
INS
Preston
Malad City
Pocatello Valley
Evanston
Rebel
Deer Creek Reservoir
Strawberry Reservoir
Currant Peak
Utah Lake
Morgan River
Bear River Bay
Willard Bay
Fremont Island
Antelope Island
Stansbury Island
Gunnison Island
Cub Island
Bird Island
Jordan R
Mud Flats
GREAT
SALT
LAKE
FRANKLIN
BEAR LAKE
MORGAN
DAVIS
SALT LAKE
UTAH
WASATCH
CACHE
RICH
WEBER
TOOELE
BOX ELDER
Spring Bay
Cedar Springs
Curlew Valley
Hansel Valley
Promontory
Bear River
Skull Valley
Rush Valley
Cedar Valley
Sink Valley
White Lake
Oquirrh Mountains
Pilot Peak
Monte Cristo
Stansbury Mountains


3565
Susanville
4258
7609
Skedaddle Mts
CLOSE
Diamond
TRUCKEE
RIVER BASIN
Beckwourth Pass
5218
Sardine Peak
8134
RENO
STOREY
LAHONTAN RESERVOIR
3120
LYON
Washoe Lake
3110
310405
3090
DOUGLAS
3466
Freel Pk
Echo Summit
3082
Markleeville
7088
WALKER
RIVER BASIN
Yerington
Ebbetts Pass
Mt Patterson
Sonora Pass
Leavitt Pk
Bridgeport
28707
MONO LAKE
Black Warrior Peak
Pah Rum Peak
San Emidio Desert
Juniper Peak
Black Mtn
Churchill Butte
Clover Peak
Mt Siegel
Topaz Lake
Wild Oat Mtn

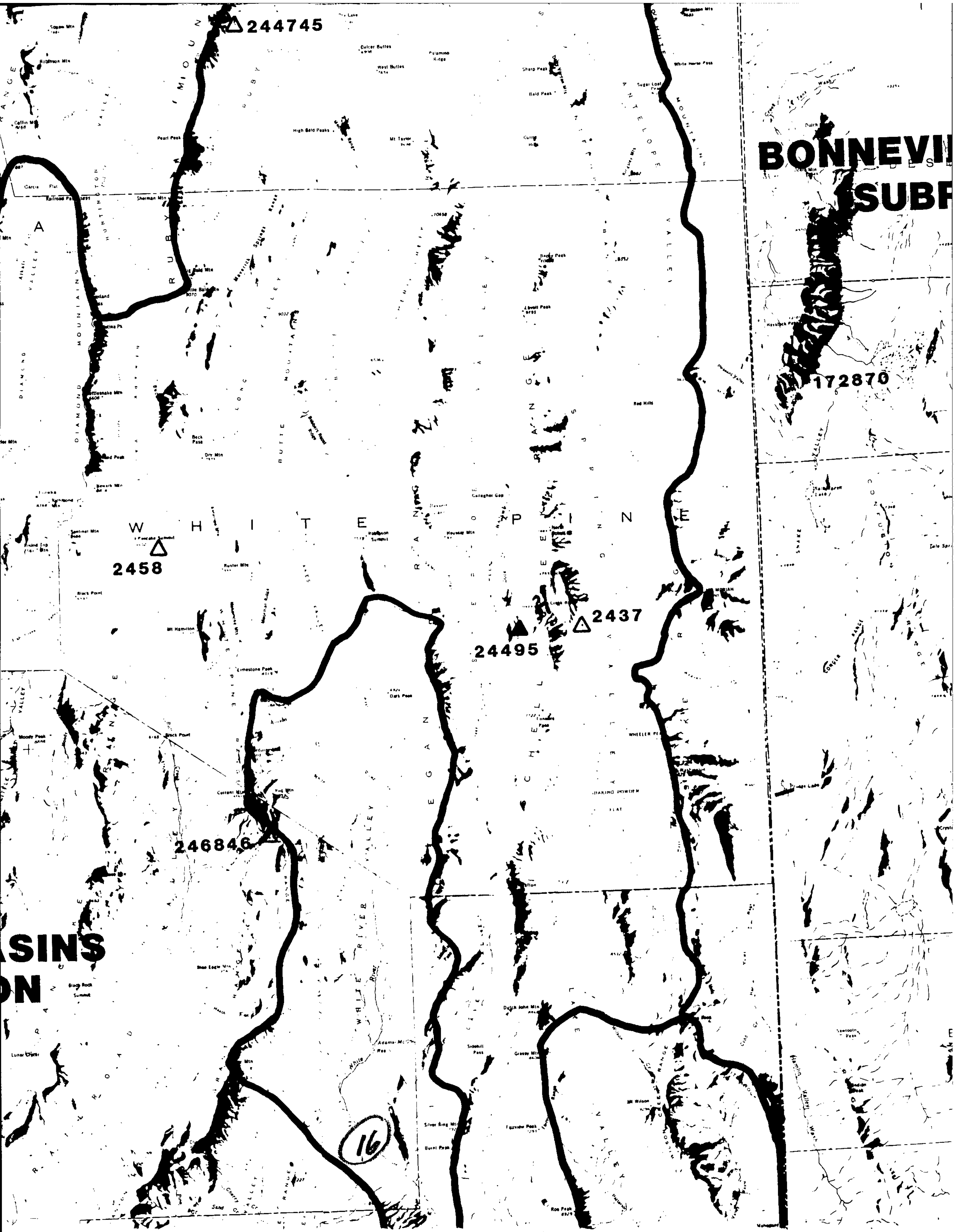
13


CLOSED BASINS
P E R S H I N G
TRUCKEE
RIVER BASIN
CARSON
RIVER BASIN
C H U R C H I L L
CARSON SINK
(Alkali Flat)
STILLWATER RANGE
DIXIE VALLEY
Lovelock
Fallon
3120
L Y O N
3110
10405
3090
UGLAS
249411
L A
WALKER
RIVER BASIN
WALKER LAKE
Hawthorne
M I N E R A L
Yerington
Mt Patterson
Bridgeport
28707
MONO LAKE
ALKALI FLAT
Garfield Flat
Rhodes Salt Marsh
Teels Marsh
Candelaria
14

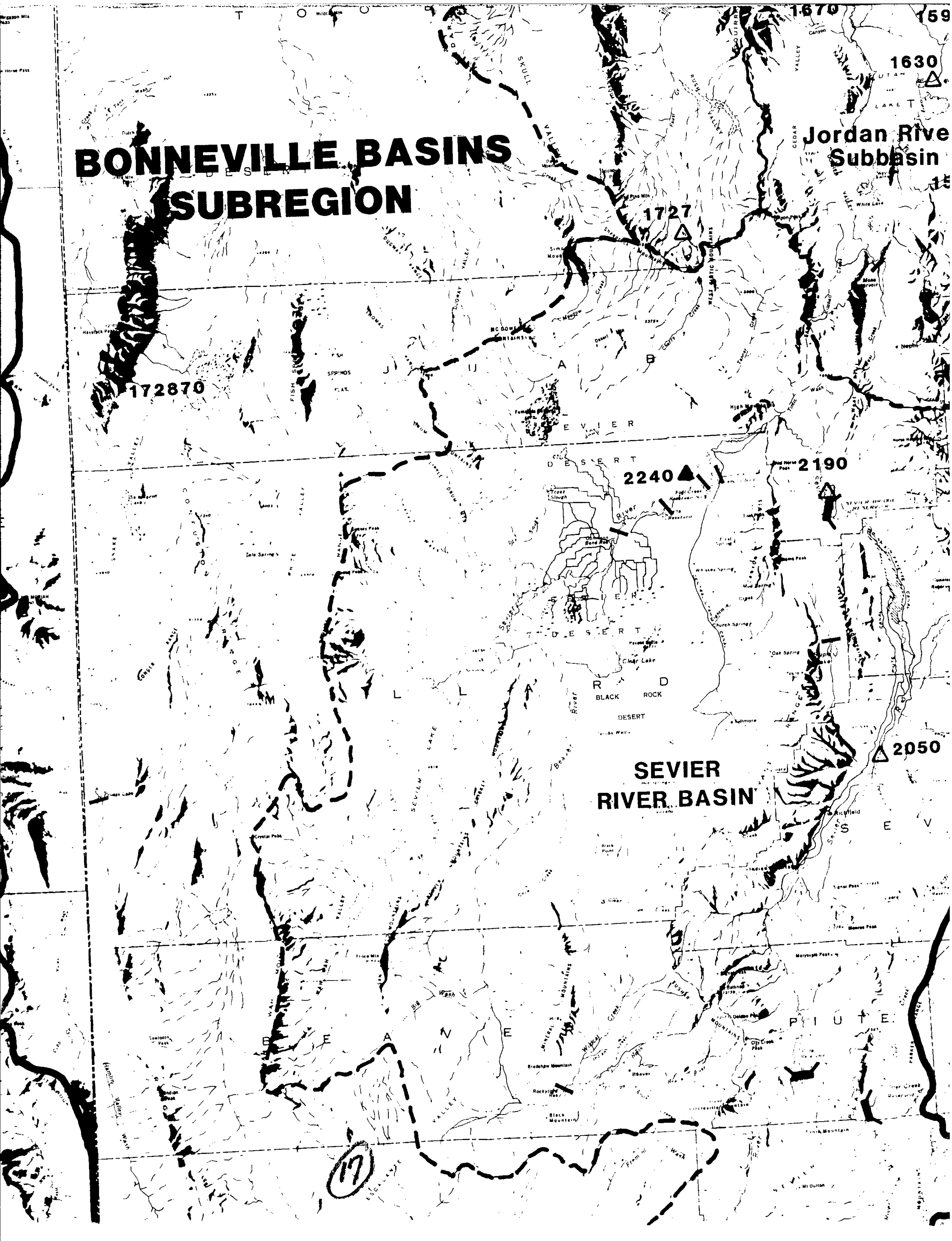


CENTRAL BASINS SUBREGION

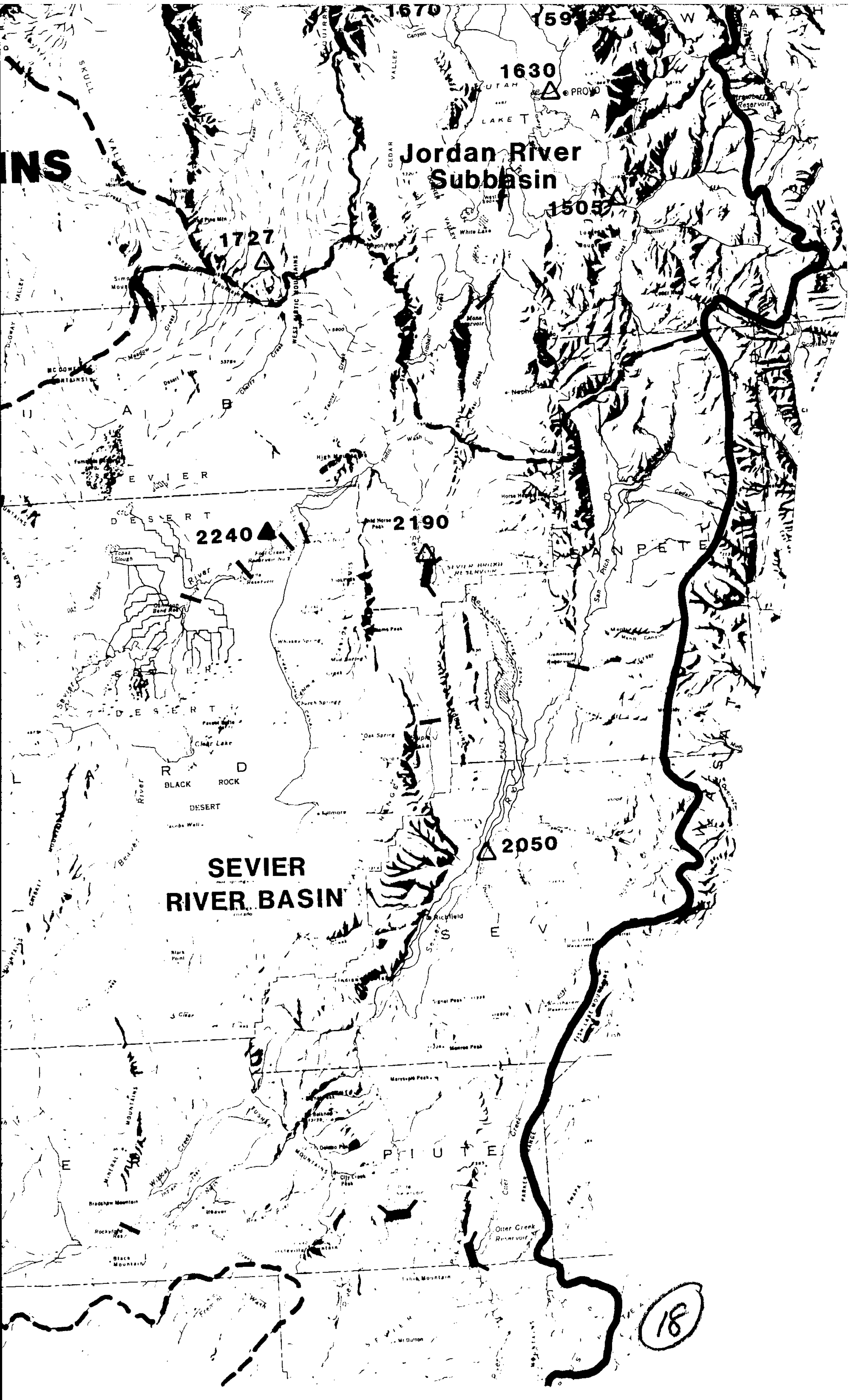
15



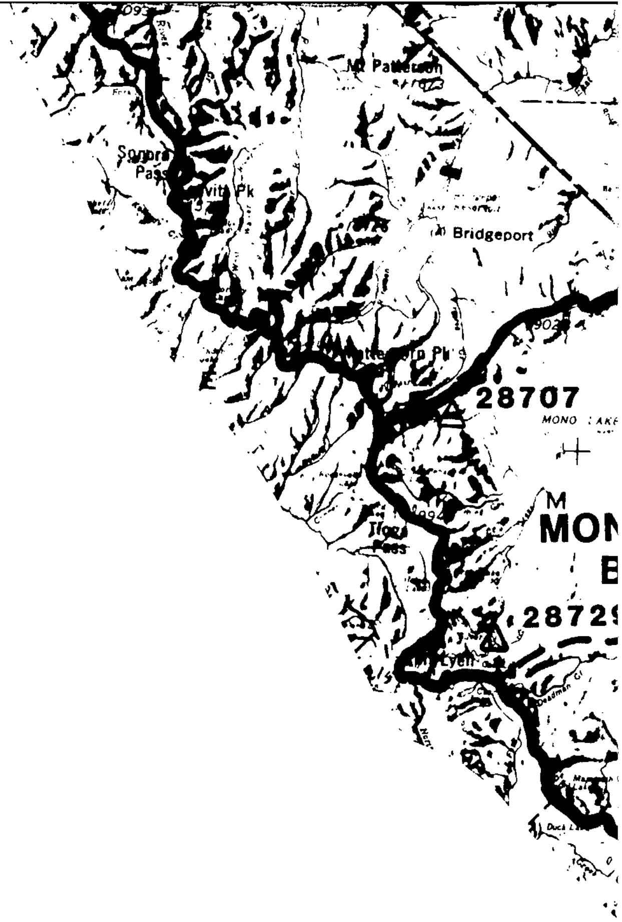
244745
2458
2437
24495
246846
172870
BONNEVI
SUBR
ASINS
ON
W H I T E P I N E
16
RUBY MOUNTAINS
DIAMOND MOUNTAINS
BUTTE VALLEY
STEPTOE VALLEY
ANTELOPE VALLEY
SPRING VALLEY
SCHELL CREEK RANGE
EGAN RANGE
SNAKE RANGE
WHITE RIVER VALLEY
White River
RAILROAD VALLEY
LAKE VALLEY
Robinson Mtn
Coffin Mtn
Pearl Peak
Railroad Pass
Sherman Mtn
High Bald Peaks
Mt Taylor
Sharp Peak
Bald Peak
White Horse Pass
Sugar Loaf Peak
Currie Hills
Becky Peak
Lovell Peak
Red Hills
Gallagher Gap
Sentinel Mtn
Pancake Summit
Robinson Summit
Black Point
Mt Hamilton
Limestone Peak
Dark Peak
Moody Peak
Current Mtn
Red Mtn
Blue Eagle Mtn
Black Rock Summit
Lunar Crater
Dutch John Mtn
Sidehill Pass
Grassy Mtn
Silver King Mtn
Burnt Peak
Fairview Peak
Mt Wilson
Roe Peak
WHEELER PEAK
BAKING POWDER FLAT
MORIAH
Haystack Peak
Sawtooth Peak
Adams-McGill Res
Beck Pass
Dry Mtn
Newark Mtn
Eureka
Richmond


BONNEVILLE BASINS SUBREGION
Jordan Rive
Subbasin
SEVIER RIVER BASIN
1670
159
1630
15
1727
172870
2240
2190
2050
T O O
J U A B
S E V I E R
D E S E R T
M I L L A R D
BLACK ROCK DESERT
B E A V E R
P I U T E
S E V
Sevier Lake
Skull Valley
Rush Valley
Cedar Valley
Utah Lake
Fish Springs
Sevier River
Beaver River
Richfield
Fillmore
Clear Lake
Wah Wah Mountains
Mineral Mountains

(17)


INS
Jordan River
Subbasin
SEVIER
RIVER BASIN
1670
1630
1505
1727
2240
2190
2050
PROVO
UTAH
LAKE
SANPETE
SEVIER
DESERT
BLACK
ROCK
DESERT
SEVI
PIUTE
Nephi
Richfield
Otter Creek
Reservoir
SEVIER BRIDGE
RESERVOIR
SKULL
VALLEY
CEDAR
VALLEY
Scofield
Strawberry
Reservoir
Topaz
Slough
Clear Lake
Fillmore
Mona
Reservoir
White Lake
Fool Creek
Reservoir No. 1
Gunnison
Reservoir
Black
Point
Bradshaw Mountain
Black
Mountain
Mt Dutton
Marysvale Peak
Delano Peak
City Creek
Peak
Signal Peak
Monroe Peak
Oak Spring
Church Springs
Whiskey Spring
Mud Spring
Pavant Butte
High Mountain

(18)



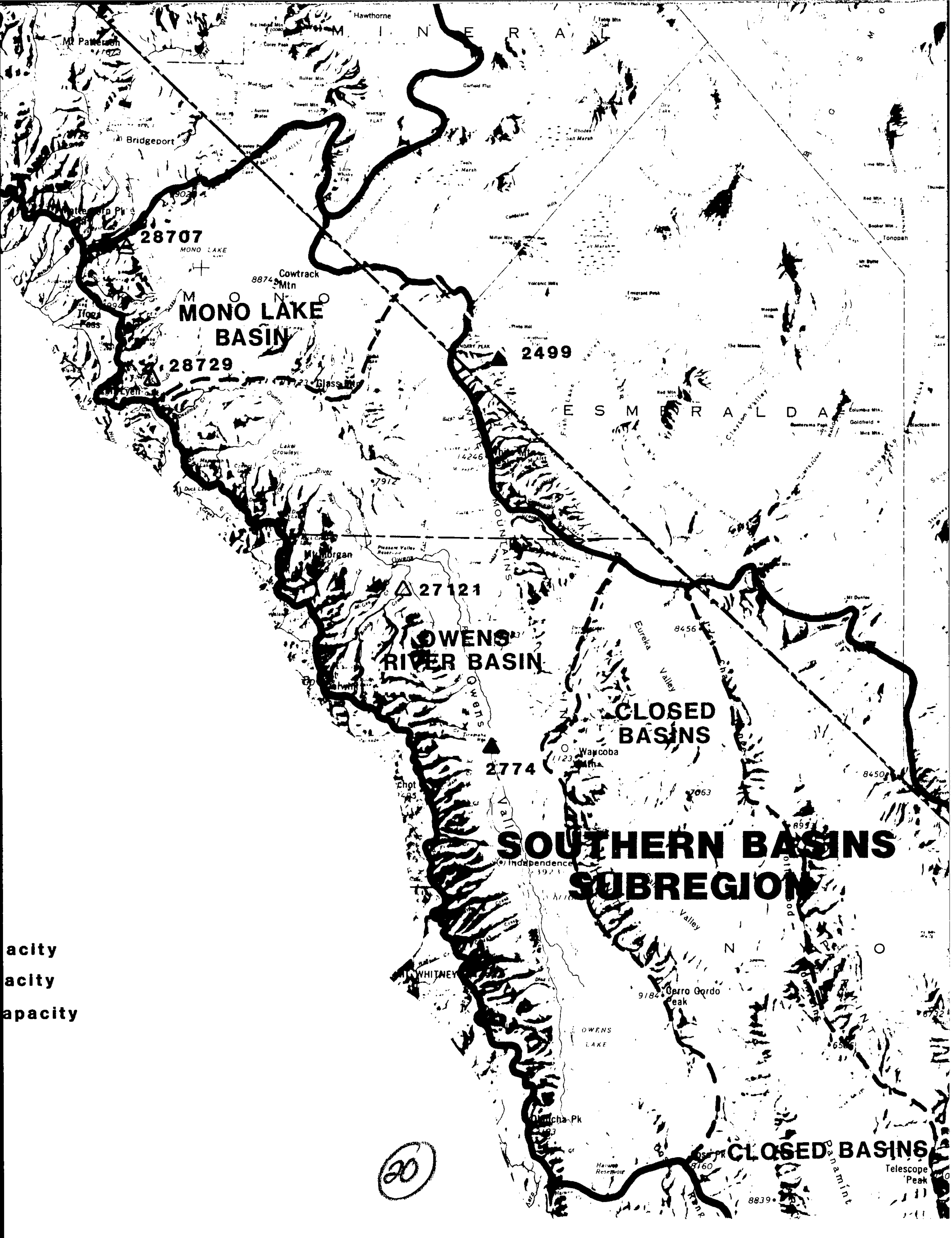
KEY

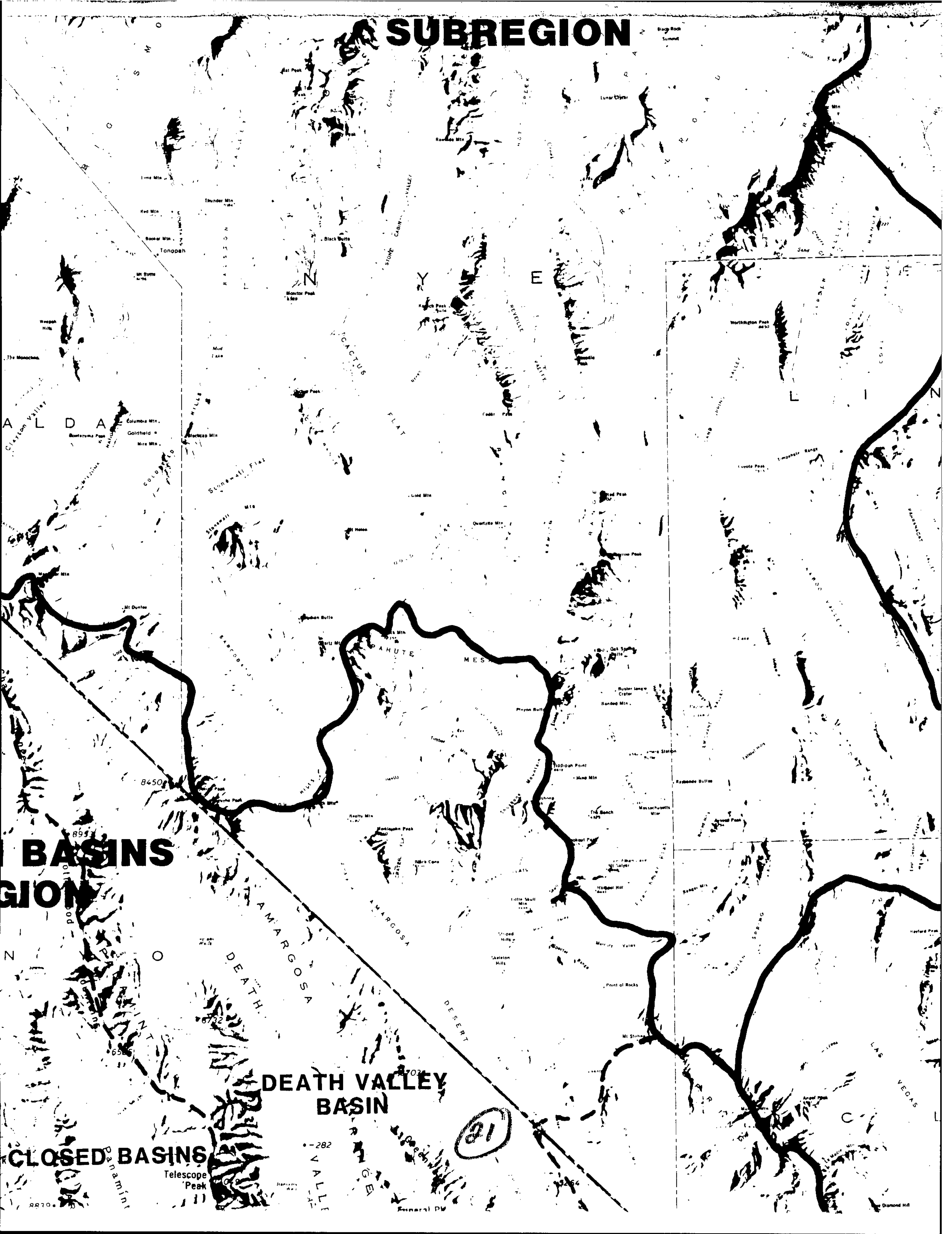
DAMS and DIVERSIONS

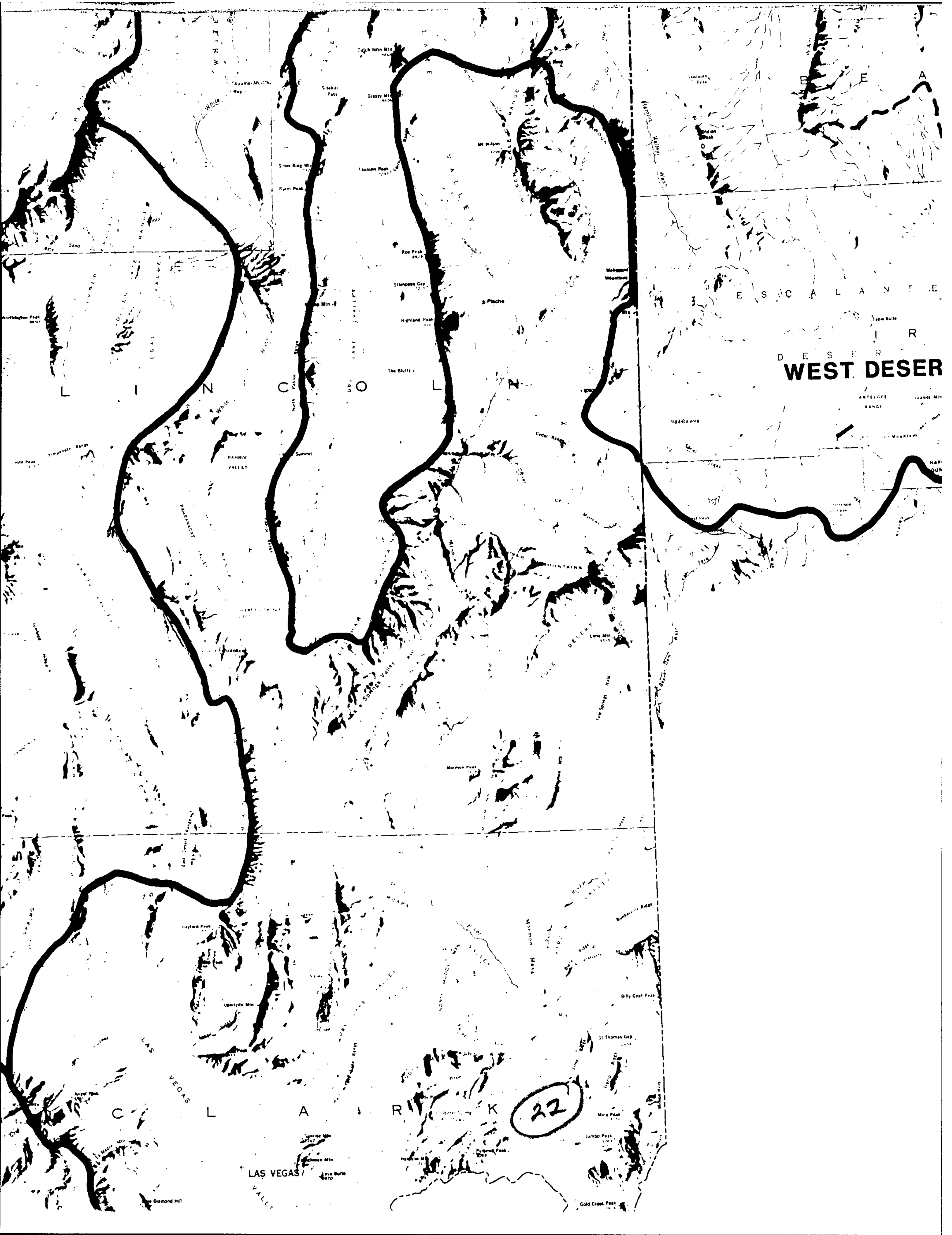
— 5,000 - 25,000 AC/FT Storage Capacity
▬ 25,000 - 50,000 AC/FT Storage Capacity
More than 50,000 AC/FT Storage Capacity

USGS Stream Gaging Stations

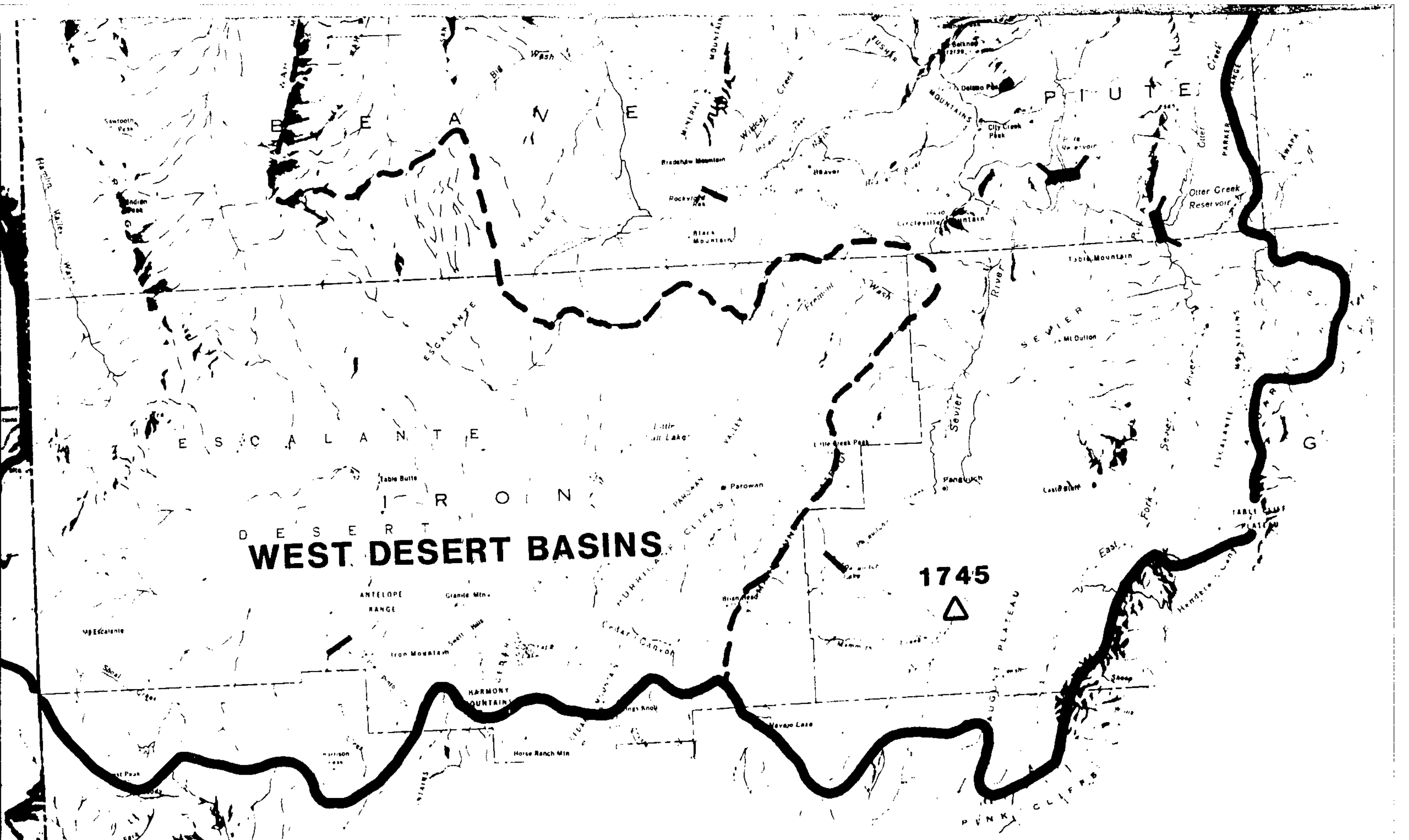
△ Flow Data
▲ Flow Data and Water Quality


Hawthorne
M I N E R A L
Mt Patterson
Bridgeport
28707
MONO LAKE
Cowtrack Mtn
8874
M O N O
MONO LAKE BASIN
28729
Glass Mtn
Lyell
2499
E S M E R A L D A
Tonopah
Goldfield
Lake Crowley
Owens River
7912
14246
WHITE MOUNTAINS
Mt Morgan
27121
OWENS RIVER BASIN
Eureka Valley
8456
CLOSED BASINS
Waucoba Mtn
2774
7063
8450
SOUTHERN BASINS SUBREGION
Independence
I N Y O
MT WHITNEY
Cerro Gordo Peak
9184
OWENS LAKE
Olancha Pk
Haiwee Reservoir
8160
CLOSED BASINS
Panamint
Telescope Peak
8839
acity
acity
apacity


SUBREGION
Black Rock Summit
Lunar Crater
Eel Peak
Rawhide Mtn
Lime Mtn
Thunder Mtn
Red Mtn
Booker Mtn
Tonopah
Black Butte
Mt Butte
Monitor Peak
STONE CABIN VALLEY
RALSTON
N Y E
Kawich Peak
REVEILLE
Worthington Peak
L I N
Weepah Hills
The Monocline
Mud Lake
CACTUS FLAT
Cedar Peak
Clayton Valley
A L D A
Columbia Mtn
Goldfield
Montezuma Peak
Mira Mtn
Blackcap Mtn
Stonewall Flat
Stonewall Mtn
Gold Mtn
Mt Helen
Quartzite Mtn
Timpahute Range
Mt Dunfee
Sugarloaf Butte
Quartz Mtn
PAHUTE MESA
Oak Spring Butte
Buckboard Mesa Crater
Banded Mtn
Pinyon Butte
Timber Mtn
Rainier Mesa
Tippipah Point
Shoshone Mtn
The Bench
Massachusetts Mtn
Yucca Mtn
Skull Mtn
Ranger Mts
Specter Range
Striped Hills
Skeleton Hills
Mercury Valley
Point of Rocks
Mt Stirling
Hayford Peak
LAS VEGAS
Angel Peak
Charleston Peak
Diamond Hill
8450
8993
BASINS
GION
DEATH VALLEY BASIN
CLOSED BASINS
Telescope Peak
Panamint
AMARGOSA
AMARGOSA DESERT
DEATH
6732
6585
7032
-282
11,049
8839
Funeral Pk

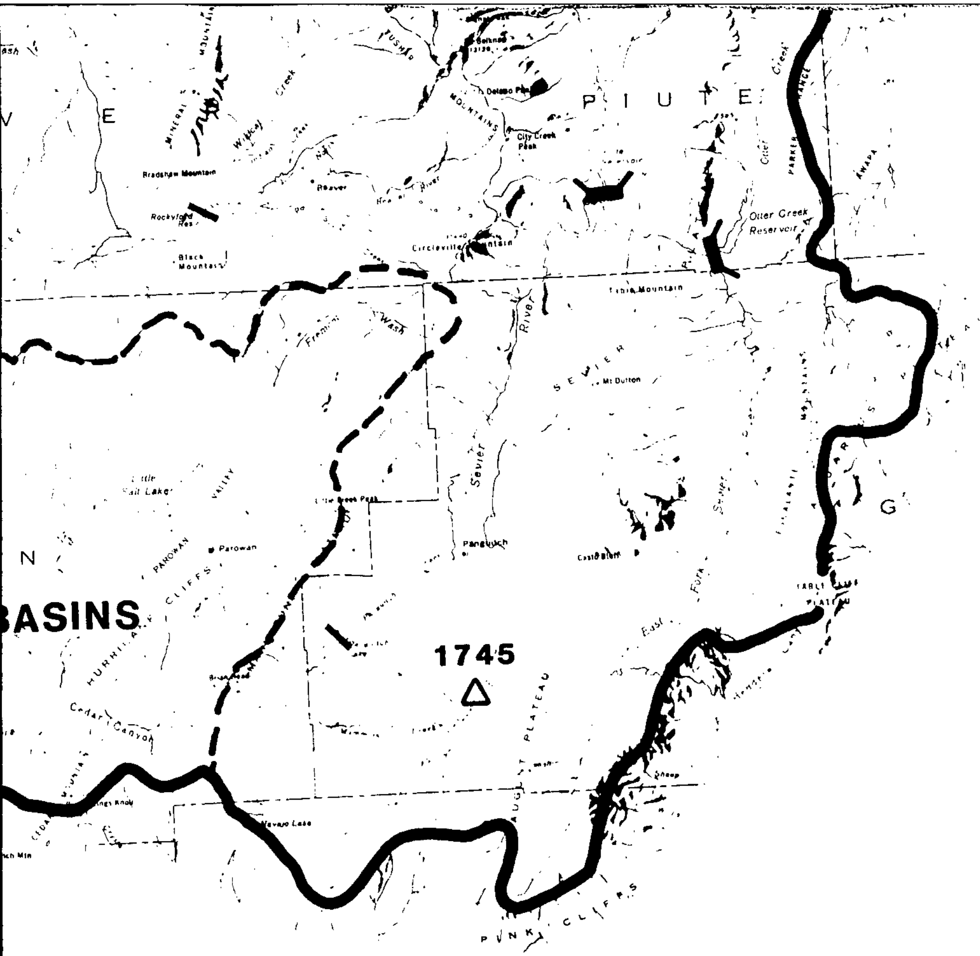

LINCOLN
CLARK
WEST DESER
ESCALANTE
DESERT
LAS VEGAS
PAHROC VALLEY
Mt Wilson
Pioche
Highland Peak
The Bluffs
Stampede Gap
Roe Peak
Summit
Cedar Range
Mormon Peak
Hayford Peak
Sunrise Mtn
Frenchman Mtn
Lava Butte
Jumbo Peak
Mica Peak
Gold Cross Peak
Billy Goat Peak
St Thomas Gap
Lime Mtn
Dutch John Mtn
Grassy Mtn
Sidehill Pass
Silver King Mtn
Fairview Peak
Burnt Peak
Mahogany Mountains
Table Butte
Antelope Range
Worthington Peak
Pyramid Peak
Hamblin Mtn
Bunkerville Ridge
Mormon Mesa
Muddy Mountains
Black Mtn
Spring Valley
Lone Mountain
Lyon Peak
Uppertrile Mtn
Beaver Dam

22



THE ECOLOGY
AND RIPARIAN
OF THE GRE
REGION: A C
PROFI

23



THE ECOLOGY OF STREAM AND RIPARIAN HABITATS OF THE GREAT BASIN REGION: A COMMUNITY PROFILE

24

BIOLOGICAL REPORT 85(7.24)

KEY

DAMS and DIVERSIONS

—	5,000 - 25,000 AC/FT Storage Capacity
▬	25,000 - 50,000 AC/FT Storage Capacity
⊔	More than 50,000 AC/FT Storage Capacity

USGS Stream Gaging Stations

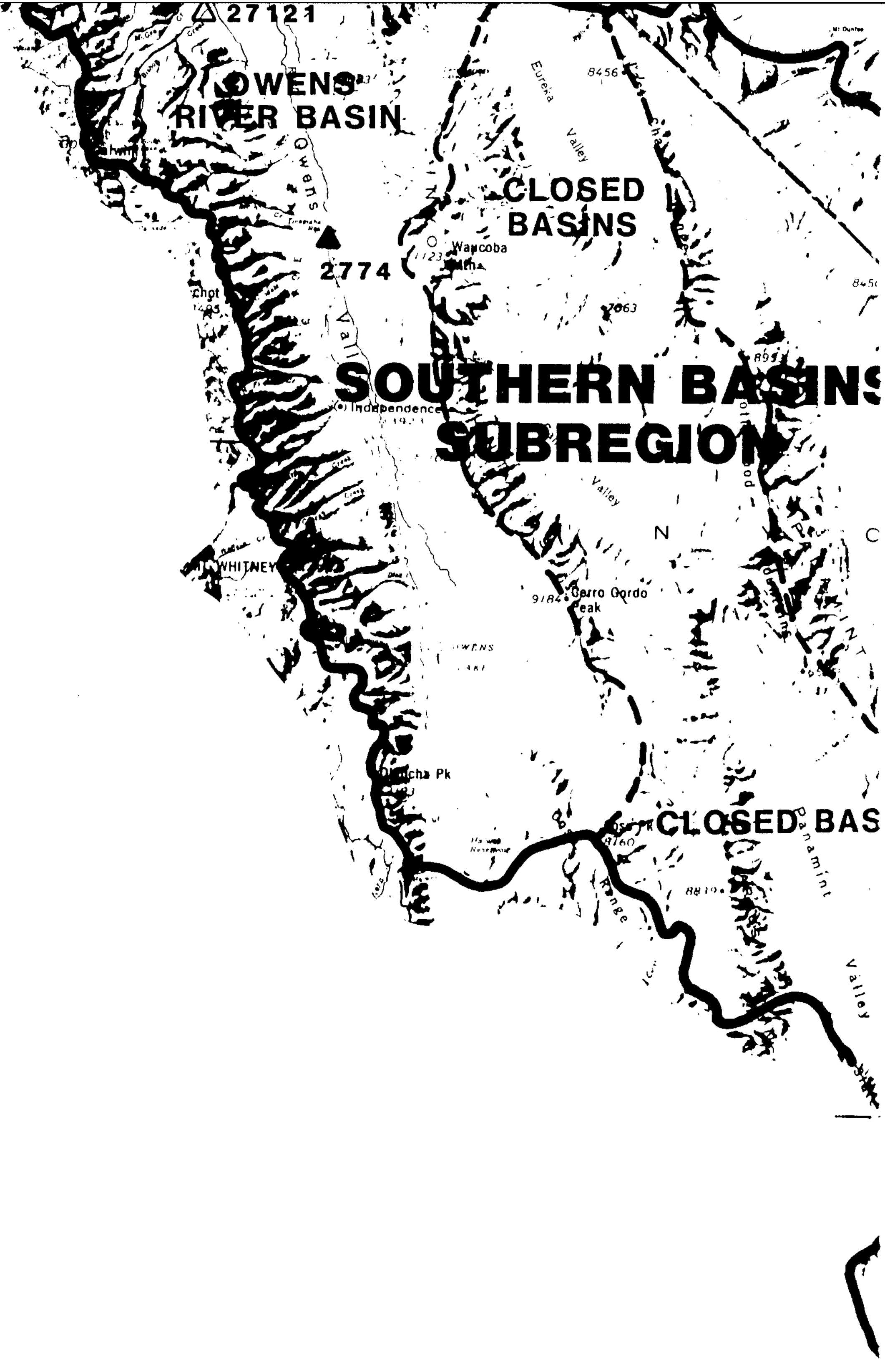
△	Flow Data
▲	Flow Data and Water Quality

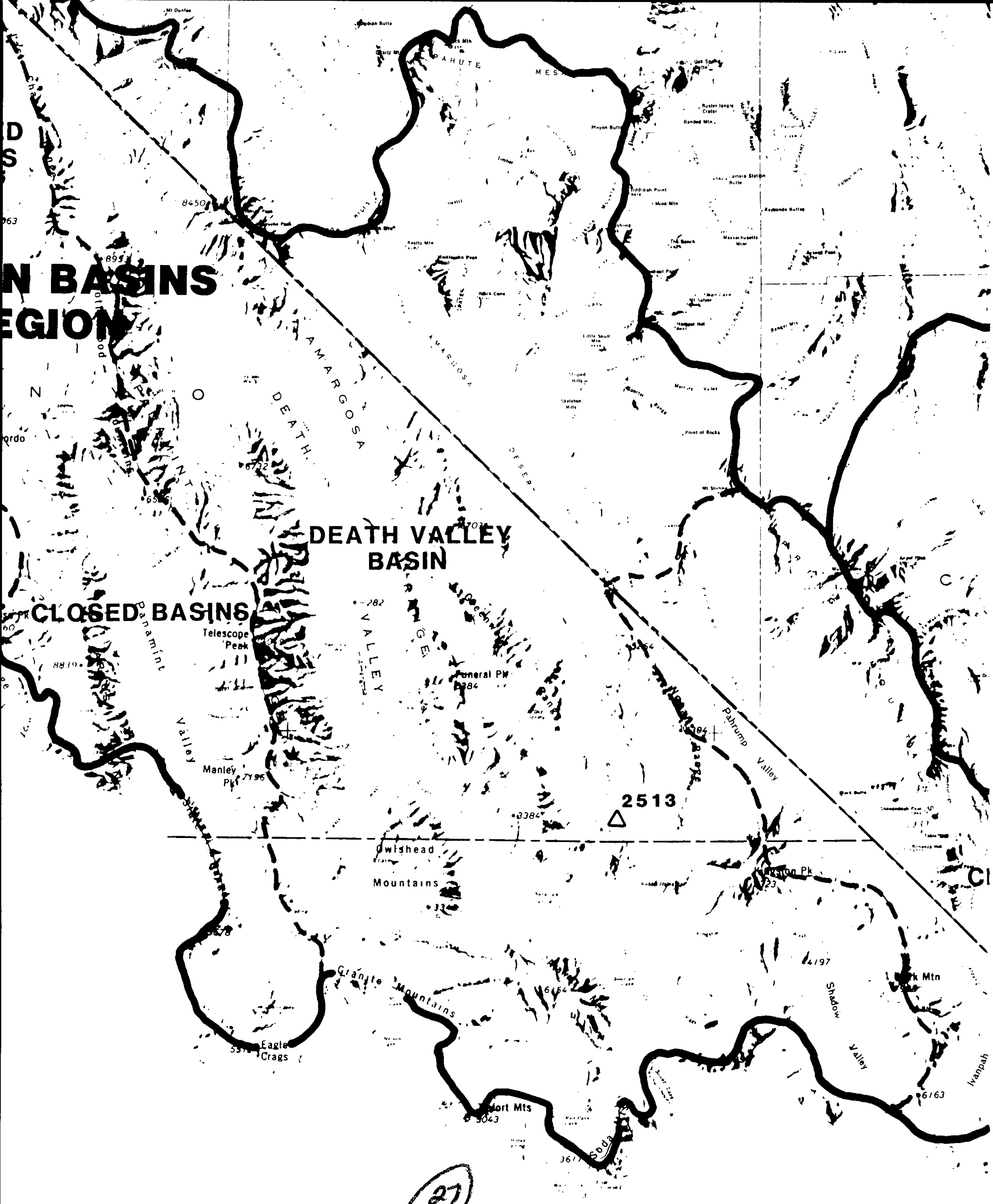
Capacity

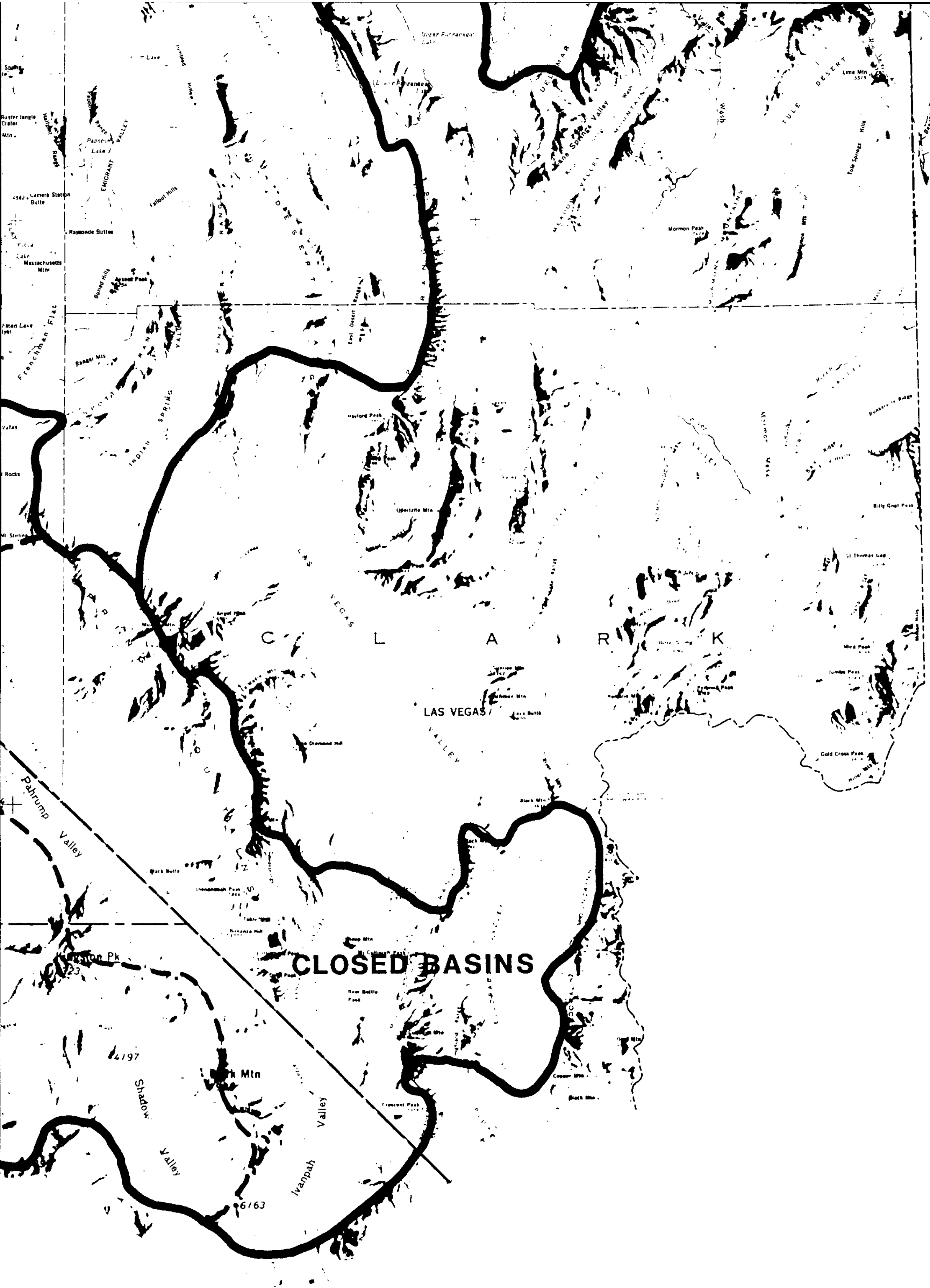
apacity

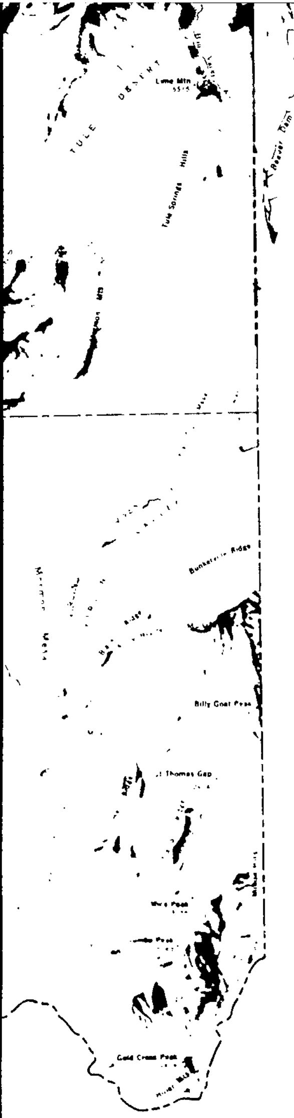
e Capacity

s




N BASINS
EGION
DEATH VALLEY
BASIN
CLOSED BASINS
AMARGOSA
DEATH
AMARGOSA DESERT
Panamint
Valley
Telescope
Peak
Manley
Pk 7196
Funeral Pk
8384
VALLEY
2513
Owlshead
Mountains
Pahrump
Valley
Granite Mountains
Eagle
Crags
Avawatz Mts
Soda
Shadow
Valley
Ivanpah
Kingston Pk
PAHUTE
MESA
Mt Dunfee
8450
6732
8839
3384
4197
6163
5043
3677
6454
Clark Mtn
Mt Stirling
Point of Rocks
Skeleton Hills
Mercury Valley
Pinyon Butte
Rainier Mesa
Yucca Flat
Frenchman Flat


CLOSED BASINS
C L A R K
LAS VEGAS VALLEY
Pahrump Valley
Shadow Valley
Ivanpah Valley
TULE DESERT
Kane Springs Valley
Lime Mtn
Mormon Peak
Hayford Peak
Gass Peak
Frenchman Flat
INDIAN SPRING
EMIGRANT VALLEY
Papoose Lake
Fallout Hills
Camera Station Butte
Rainbow Mtn
Bunkerville Ridge
Billy Goat Peak
St Thomas Gap
Mica Peak
Jumbo Peak
Gold Crown Peak
Frenchman Mtn
Sunrise Mtn
Black Mtn
Diamond Hill
Black Butte
Potosi Mtn
Table Mtn
Bonanza Hill
Mt Stirling
Mt Sterling
Kingston Pk
Clark Mtn
Crescent Peak
Sheep Mtn
McCullough Peak
Copper Mtn
Bear Bottle Peak
4197
6163



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BIOLO

GREAT B

29

THE ECOLOGY OF STREAM AND RIPARIAN HABITATS OF THE GREAT BASIN REGION: A COMMUNITY PROFILE

BIOLOGICAL REPORT 85(7.24)

September 1989

APPENDIX

GREAT BASIN HYDROGRAPHIC REGION

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